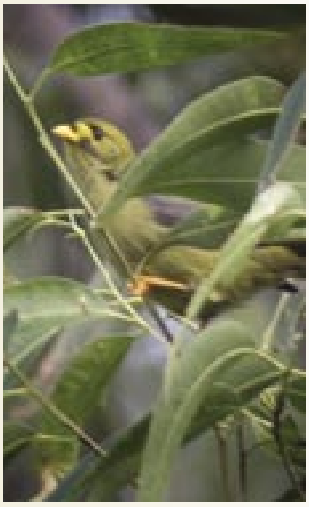
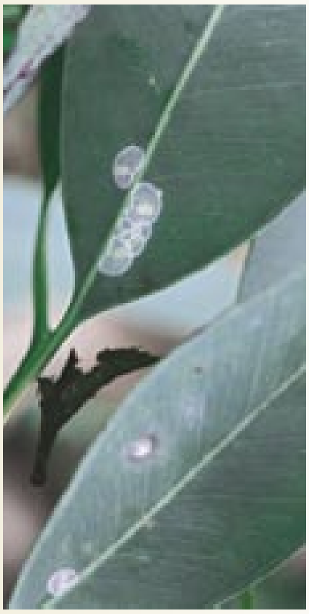
Natural Heritage Trust

Bell Miner Associated Dieback (BMAD) Independent Scientific Literature Review





Grant Wardell-Johnson, Christine Stone,
Harry Recher & A. Jasmyn J. Lynch

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Project: BMAD 01/04: Science Report

A review of eucalypt dieback associated with Bell miner habitat in north-eastern New South Wales, Australia

For further information and additional copies of this plan contact:

The Chairperson
BMAD Working Group
c/- Project Officer
Operational Services and Support Unit
Parks and Wildlife Division
Department of Environment and Conservation
PO Box 1236
Coffs Harbour NSW 2450
Tel: 02 6650 7100
www.bmad.com.au

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Bell Miner Associated Dieback (BMAD) Independent Scientific Literature Review

A review of eucalypt dieback associated with Bell miner habitat in north-eastern New South Wales, Australia

by Grant Wardell-Johnson, Christine Stone,
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Summary

Introduction

Bell Miner Associated Dieback (BMAD) is a significant threat to the sustainability of the moist eucalypt forests of north-eastern NSW and south-eastern Qld, and to biodiversity conservation at a national scale. The aim of this report is to assess the extent and relevancy of existing scientific knowledge, and to identify gaps in the knowledge concerning BMAD. We review BMAD as a form of forest dieback, Bell miner and psyllid interrelations, proximal and ultimate causal factors associated with insects, and finally, proximal and ultimate factors associated with environmental disturbance. We have explicitly included personal communications with many researchers, managers and members of conservation groups and the timber industry in this report.

Eucalypt dieback and BMAD

BMAD refers specifically to eucalypt forest dieback which is associated with the coincidence of outbreaks of predominately psyllid species (other insect species such as the leaf-mining micro lepidopteran, *Acrocerops* spp. observed in affected *E. saligna* canopies, can also build up to damaging levels) and colonies of the Bell miner or Bellbird (*Manorina melanophyrys*), a honeyeater (family Meliphagidae) distributed across the coastal and sub-coastal region of south-eastern Australia. There is a wealth of general information on the phenomenon.

In BMAD areas, there is a significant correlation between Bell miner density and the condition of affected eucalypt crowns. In these areas, the sustained presence of Bell miners creates negative feed-back mechanisms that maintain elevated and damaging populations of psyllids in the eucalypt canopy. The departure of Bell miners results in a general decrease in herbivorous insect populations. However, factors associated with the commencement or facilitation of Bell miner colonies or psyllid outbreaks have not been investigated.

Considerable research effort is currently directed at mapping canopy dieback. However, we have not noted literature directly linking particular crown condition with the history and development of the associated BMAD problem. Similarly, we have not unearthed literature on the development of insect outbreaks, particularly associated with BMAD, and have found no quantified information on the history, distribution, spread and extent of the BMAD problem.

Bell miner and psyllid inter-relations

Bell miners are relatively restricted in comparison with psyllid outbreaks and there are many instances of psyllid outbreaks in forests and woodlands where Bell miner colonies do not occur. There are many species of psyllids, and the groups of species associated with particular forms of forest dieback have not always been made explicit in the literature.

Bell miner colonies require tree crowns that can maintain high densities of insects and a forest structure that provides suitable nesting sites, and that is defendable. There is some evidence that Bell miners nest in dense understorey - habitat that can be rendered more favourable by the opening of the overstorey canopy. There is some indication in the literature that an open midstorey also favours Bell miners. Although it is generally known that the Bell miner is increasing in abundance and range in the region affected by BMAD, there has been no quantification of this phenomenon.

Tree decline associated with psyllids is caused by multiple factors rather than by Bell miners. Research on psyllids and Bell miners has been limited to a few sites where psyllids and Bell miners co-occur. There are situations where Bell miners are a major factor in facilitating and sustaining psyllid outbreaks. The limited direct evidence suggests that management practices which create habitats with a structure and floristic composition favouring the establishment of Bell miner colonies are more likely to favour the establishment of psyllid outbreaks (and vice versa). In such situations, colonisation by Bell miners will lead to the exclusion of other avian insectivores, resulting in an increase in the numbers of psyllids, and dieback of the eucalypt overstorey. However, quantification of these associated floristic and structural factors has not been achieved.

The literature has demonstrated that management can provide and maintain a diverse forest structure which also increases bird numbers and diversity. A rich avifauna will not prevent insect outbreaks, but may dampen arthropod abundances, and limit damage from herbivory. Research on the interactions of bird assemblages and insect outbreaks has been limited in the areas affected by BMAD.

Proximal and ultimate factors associated with insects

The ultimate causes of BMAD are difficult to untangle, and have not yet been effectively investigated. Outbreaks of some psyllid species have been associated with host tree stress. However, most herbivorous insects on eucalypts lay their eggs on young expanding foliage. Therefore environmental factors that promote young foliage provide the opportunity for herbivorous insects capable of exploiting this resource to rapidly increase their populations. Once initiated, outbreaks are likely to be associated with numerous interacting factors and feedback loops. The lack of literature on the spread of BMAD limits capacity to understand causal mechanisms, and hence allow management resolution.

There is a vast literature on nutrients and plant growth, and also considerable literature exploring forms of nitrogen in soils and vegetation. For example, there have been many studies that have demonstrated differences in nitrogen compounds associated with forest management activities.

Glycaspis psyllids (the taxa most usually associated with BMAD) are phloem feeders and obtain their essential nitrogen (N) from free amino acids and other soluble nitrogen compounds. Total nitrogen is not a good indicator of foliar quality for sap feeders. Both young expanding eucalypt foliage, and epicormic (replacement) foliage have been shown to have higher free amino acid concentrations than mature adult foliage. Also, concentrations of certain free amino acids have been shown to increase in foliage under high levels of soil nitrogen, although this has not yet been demonstrated for eucalypts. On the other hand, stress induced disruption of the carbon and water balances in eucalypts can result in accumulation of osmolyte amino acids (e.g. proline) in mature leaves.

Studies have demonstrated that environmental stresses such as drought, salinity and water logging reduce crown evaporation rates and foliar photosynthetic efficiency in affected eucalypt crowns. This results in slower rates of leaf initiation and expansion, therefore providing less suitable foliage for most herbivorous insects. The impact of insect defoliation tends to be greater on slower growing trees. While there have been suggestions of links between disturbance, nitrogen compounds, forest management and Bell miners, there has been a lack of field-based or experimental research to resolve these links.

The literature does demonstrate that the maintenance and expansion of psyllid outbreaks is influenced by changes in light intensity and leaf phenology in a forest stand. Eucalypt tree crowns responding to increased penetration of sunlight into the canopy possess more expanding foliage favourable to psyllids. Because most psyllids have several generations in a year they can respond quickly to an increase in leaf production brought about by increased sunlight and accelerated plant growth. However, research to explicitly address these factors in relation to BMAD has yet to be carried out.

Proximate and ultimate factors associated with environmental disturbance

A range of multi-tropic attributes (e.g. local climate/host tree condition and structure/natural enemies) have been identified as contributing to elevated psyllid populations. Fragmentation, changed disturbance regimes (particularly fire and logging), and pathogens are implicated. Changes in nutrients and other soil constituents, climatic regimes and hydrological factors have also been implicated. There has been no attempt to unravel the various competing disturbance factors; with some literature relying on anecdotal evidence, and taking an advocatory approach to the problem.

Forest fragmentation, including internal fragmentation (e.g. roads and powerlines) is recognised as a major biodiversity threat. The north-eastern region of NSW is no exception, and there is some suggestion that interacting factors associated with forest fragmentation tend to favour Bell miners, and hence BMAD. However, there has been no quantification or testing of hypotheses associated with suggestions concerning fragmentation.

Logging and associated disturbances can have direct and indirect effects on overstorey, midstorey and understorey structure and floristics. However, studies directly associating logging, forest structure, floristics and BMAD have not been carried out. While the proliferation of dominant understorey weeds, such as Lantana (*Lantana camara*), in the north-eastern region of NSW has largely been attributed to the disturbance caused by logging and associated activities, no direct link between BMAD and Lantana has been established.

While Lantana may not be a primary causal factor initiating BMAD, the literature suggests that its presence reflects increased canopy opening, which in itself may be a primary cause for increases in psyllids. These outbreaks in turn may attract the presence of Bell miners, which have the benefit of increased food resources and suitable structure for nesting. There has been some advocacy for management strategies which reduce weed encroachment and plant community degradation to identify and maintain ecological barriers to Lantana invasion. Because large areas in the region affected by BMAD are dominated by Lantana, there has also been advocacy towards the use of fire as a means of Lantana control.

The relationship between nutrients, fire and understorey structure has received some attention in the literature. There has been general agreement that the establishment of a dense shrubby understorey contributes to lowering the carbon/nitrogen (C/N) ratio, and to nitrogen turnover: soil conditions favourable for nitrification. There has been some suggestion that the relatively higher concentration of free amino acids in eucalypt foliage that may result from nitrification could enhance the desirability of this foliage to psyllids and other herbivores. Most commercial eucalypt plantations are now established on ex-pastural sites in which nitrogen mineralisation is often dominated by nitrification.

There is also general agreement with a converse position that frequent low-intensity fires are associated with a grassy understorey of fire-tolerant species producing litter of higher C/N ratios and reduced soil moisture. These soil conditions provide a competitive advantage to eucalypt species that assimilate nitrogen as ammonium. However, the optimal range of inorganic nitrogen concentrations in the soil, and whether affected stands deviate beyond this range has not been quantified for the species of eucalypts affected by BMAD. There is a suggestion that increasing the frequency of fire will also reduce the dominance of Lantana in such sites, although this may also lead to the dominance of herbaceous weeds, particularly grasses, in some sites.

There have been suggestions that limiting the tendency towards nitrification may provide a mechanism for facilitating the dominance by eucalypts in frequently burnt sites that are otherwise favourable to nitrophilic species (including mesic understorey species and rainforest trees). In establishing eucalypt plantations it has been shown that the presence of any other dominant plant species, including grasses, act competitively with the eucalypts, but even in the absence of any understorey eucalypts can still become 'unhealthy' due to a wide range of reasons independent of the processes associated with BMAD.

For the environments in which BMAD occurs, arguments have been presented suggesting a need both for more frequent fire, and for less frequent fire in particular ecosystems. However, the position concerning fire history is complex, and it is likely that fire regimes have in the past differed between vegetation types, locations and regions. Recent literature, which provides anecdotal, rather than site-based survey data or experimental evidence, has not contributed to the development of appropriate fire regimes under current and likely future circumstances.

Experienced field botanists in north-eastern NSW argue that there is a greater diversity of forest types in the areas affected by BMAD than warrants categorisation of forests simply into 'grassy' or 'shrubby' understorey types. While high quality quadrat-based data exists for the area, limited analysis or publication has precluded effective assessment of the various tree species and vegetation types affected by BMAD. The possibility of different factors being associated with the spread of an outbreak than with its

initiation may preclude clear assessment about species and vegetation types.

Changed hydrological balances and climatic regimes, and an increased presence of pathogenic disease have all been implicated in BMAD. However, the research associated with these forms of disturbance remains very scant in relation to BMAD. Recent research has demonstrated an increasingly wide geographic distribution and impact of *Phytophthora* spp., and identified pathogens as potentially interacting forms of disturbance relevant to BMAD.

A variety of approaches to remove Bell miners have been trialled on private property in the region in an effort to limit the spread of psyllids and crown dieback. Examples include the clearing of understorey, removal of dead trees, conversion to grass, grazing by cattle and spraying to hold regrowth in check on the one hand; and the encouragement of a dense rainforest understorey and dam removal on the other. Although one needs to be wary of the findings described from isolated instances, field experience in the management of BMAD may suggest some relevant research directions.

Synthesis

BMAD is a nationally significant conservation problem that has the potential to reduce the chances of achieving sustainable forest management in north-eastern NSW. There is a strong likelihood for significant biodiversity loss in the medium future in the general region, including south-eastern Qld, as well as reduced available timber volumes. Blaming Bell miners for the problem will not lead to its resolution.

There are serious deficiencies in the information base for most issues concerning BMAD. While the literature has demonstrated a clear interaction between Bell miners and psyllids, there are many other, less well quantified interactions that may be of greater significance to the development of the problem. It is suggested that management and research efforts towards solutions should urgently target disturbances that lead to changes in forest canopy structure.

There is likely to be no single or simple management solution. In managing forests, it is necessary to recognise that there is a complexity of connections and interactions, many of which have yet to be deciphered. Because BMAD is associated with interacting disturbances, concentration on particular management regimes in isolation is unlikely to resolve the BMAD problem. Rather, an integrated management program will be necessary.

1. Introduction

During the early 1990's, the remnant eucalypt forests of north-eastern New South Wales (NSW) were increasingly recognized as suffering from canopy dieback. It was apparent that this dieback was coincidental with an increase in the populations of Bell miners (*Manorina melanophrys*) in the region. This form of dieback rapidly became known as Bell Miner Associated Dieback (BMAD), with the acronym being used to focus research and management attention towards dealing with the problem. This form of dieback was soon recognized for its rapid expansion and for its severe effect on the overstorey canopy, such that whole stands of trees were killed. This has led to concerns of a fundamental change in species composition, and more general effects on the biota and landscape of the region (Billyard 2004).

The severity of the BMAD problem is such that tens of thousands of hectares in north-eastern NSW is currently affected with over 2.5 million hectares considered potentially vulnerable (Ron Billyard pers comm., Nov. 2004). A substantial (although uncertain) area of south-eastern Queensland is similarly affected, although less attention has been directed there. BMAD occurs on both public and private land and the area affected is expanding rapidly. The severe impact of this form of forest canopy dieback has profound implications for the conservation of the internationally significant biodiversity of the region.

The lowland and hilly subtropics of north-eastern NSW and south-eastern Qld are nationally and regionally significant for flora and fauna conservation, ecological sustainability, water catchment, tourism, and economic products including timber and honey. The region includes five World Heritage listed areas that are part of the Central Eastern Rainforest Reserves of Australia (CERRA); and the general area is located within one of the most bio-diverse regions in Australia. The region supports the second highest number of threatened flora taxa in Australia, and is also second to the wet tropics in avian diversity (NPWS 1995).

This region was, and remains of considerable importance to the Aboriginal people of the area, and the fertile soils and abundant rainfall of the region was attractive to early European settlement. As a result, lowland areas have been extensively cleared for agriculture, with rainforests in particular being targeted and extensively cleared between 1860 and the early part of the 20th century (Webb 1956). Lott and Duggin (1993) document the clearing of 99.3% of the 75 000 hectares Big Scrub subtropical rainforest on the north coast of NSW. Much of the lowland forest of north-eastern NSW was logged from the 1920's with steeper country becoming available to logging with the availability of bulldozers after World War II. The 1980's saw a cessation of the logging of rainforest in the region, and most areas of rainforest are now in conservation reserves. Logging continues under agreements in some areas of eucalypt forest in the region, while there has also been an increase in the establishment of plantations, chiefly on private land during the 1990's. Substantial areas cleared for the dairy industry now support regrowth as a result of the decline in the industry in the 1970's.

1. Introduction

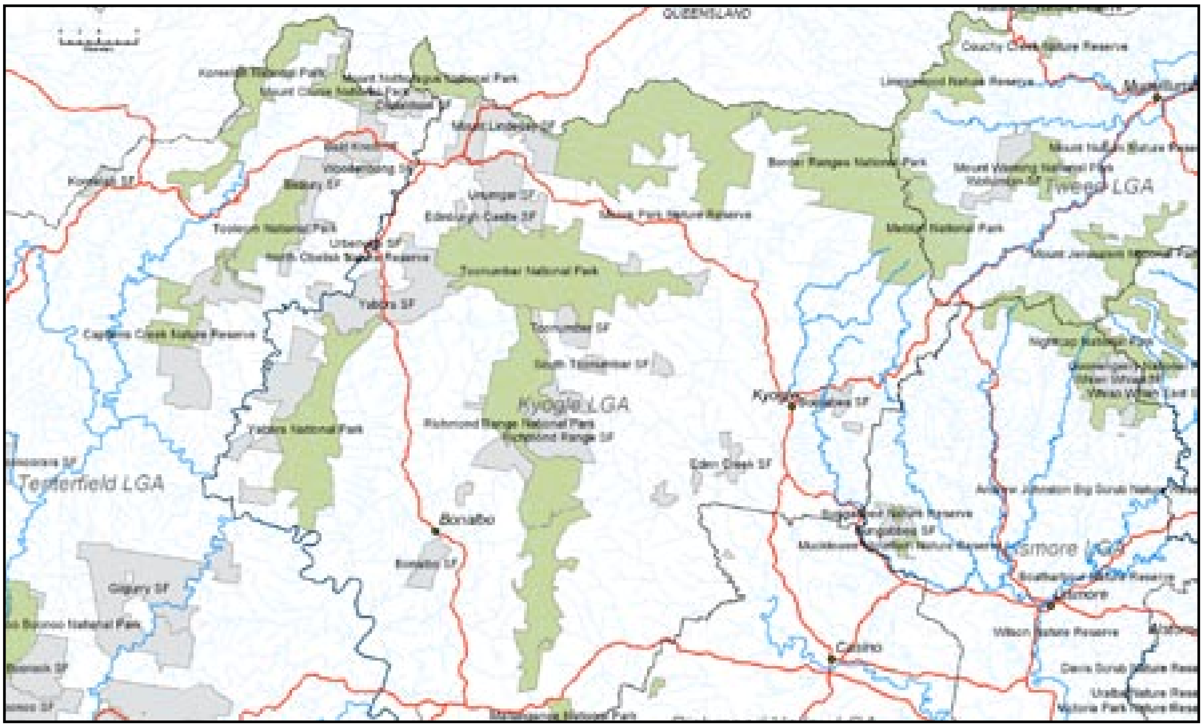

Figure 1 The general area associated with the severe impact of Bell Miner Associated Dieback (BMAD) in north-eastern New South Wales. State Forest is shaded light gray, National Parks, green and private property, white. This area includes the major towns of Kyogle, Lismore and Casino to the east, and the settlements of Wiangaree, Woodenbong, Urbenville, Bonalbo and Mallanganee. Photo courtesy of Department of Environment and Conservation, NSW.

Considerable attention has been directed at the BMAD problem by State management agencies and the conservation community, particularly in recent years when the magnitude of the problem and its rate of spread were recognised. During the 1950's, Forest NSW (FNSW) investigated dieback of Sydney Blue Gum (*Eucalyptus saligna*) in forests of the central coast associated with defoliation by psyllids (e.g. Moore 1961). Further investigations followed increasing concerns during the 1990's that dieback associated with psyllids and Bell miners was increasing (e.g. Stone 1996). The NSW conservation movement has had a defined involvement in BMAD since the early 1990's (Jim Morrison pers comm., Jan. 2005). In 1992, the North East Forest Alliance (NEFA) included BMAD in its submission as one of the issues that should be addressed in the proposed State Forest Urbenville Management Area Environmental Impact Statement (EIS), and subsequently other State Forest EISs (Jim Morrison pers comm., Jan. 2005). In 1997 NEFA sought the mapping of the extent of BMAD in State Forests to ensure that harvesting plans identified both affected and vulnerable areas, where logging should be excluded, and to develop

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an appropriate rehabilitation strategy for affected areas.

NEFA also attempted to have the problem taken into account in the Ecologically Sustainable Forest Management (ESFM) component of the Regional Forest Agreements (RFA). In March 2001 both NEFA and the North Coast Environment Council made representation on BMAD to what is now the NSW Department of Environment and Conservation (DEC) (formerly NSW National Parks and Wildlife Service (NPWS)) stakeholder workshop on the management of the parks and reserves of the northern Richmond Range. This prompted the NPWS to investigate the nature of the problem and its severity. While some NPWS staff had been aware of the problem in the Murray Scrub area, inspection of the Toonumbar / Richmond Range from a FNSW helicopter showed that the problem was severe (John Hunter pers comm., Jan. 2005). An email survey of ranger and field staff across the NPWS Northern Directorate also indicated that the problem was widespread, but probably not as severe elsewhere.

In March 2001 following successive transfers of land from FNSW to DEC, DEC held a meeting to gain stakeholder input to the management of the new areas of National Park in the area. Stemming from this meeting, a Working Group was formed specifically to consider BMAD, and met in April 2001. FNSW joined and continue to contribute to the process. A workshop convened by NPWS in Coffs Harbour in November 2001 led to the formation of the BMAD Working Group to provide a co-operative approach to the problem. Membership and draft terms of reference for the Working Group were agreed at the workshop, and NPWS accepted an invitation to become a partner in co-operative research being undertaken by Christine Stone of Forests NSW and CSIRO Forestry and Forest Products.

The BMAD Working Group has been operational since early 2002. Some of the activities undertaken include; the convening of scientific workshops to discuss possible management approaches to BMAD control; a survey of landholders to determine the extent of BMAD in the Toonumbar / Richmond Range area; the securing of Envirofund funding to undertake Lantana (*Lantana camara*) control trials on private land; working with NPWS on Lantana control trials adjacent to Murray Scrub; undertaking a 'first cut' assessment of possible forest area at risk in the Urbenville State Forest Management Area; securing of Catchment Management funds to undertake remote sensing work; participation in a Dieback Colloqium; formulation of a BMAD Strategy and securing of funding to undertake a literature review; and finally to convene a National Forum on BMAD and associated projects (John Hunter pers comm., Jan. 2005).

The aim of this report is to assess the extent and relevancy of existing scientific knowledge, and to identify gaps in the knowledge concerning BMAD. This report therefore reviews the scientific knowledge relating to BMAD predisposing factors, causes and prevention and control methods. We ask whether these forests are predisposed to the establishment of Bell miner colonies or psyllid outbreaks (and if so why and how), and seek to determine the relationship between Bell miner colonies and outbreaks of psyllids. The habitat of Bell miners and the types of forest in which the dieback occurs are

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assessed. BMAD predisposing factors and causes may also include disturbance factors, such as fragmentation, logging and associated disturbances, and fire regimes. Other relevant factors include moisture and soil factors. It is important to determine the extent to which complex interacting factors are involved. The scientific knowledge of relevant natural and anthropogenic disturbance regimes is examined. Because of the limited literature directly related to BMAD, we have explicitly included personal communications with many researchers, managers and members of conservation groups and the timber industry in this report.

2. Eucalypt dieback and BMAD

Eucalypt dieback refers to a progressive decline in forest or woodland health expressed through the dying back from the tips of twigs, branches or tops of individual trees or affected stands of eucalypts (Stone et al., 1995) – the most diverse and dominant group of Australian forest trees (Wardell-Johnson et al., 1997). It may include cycles of defoliation and regrowth (Stone et al., 1995). However, over time, a tree's reserves become depleted and the regrowth phase is likely to become less vigorous (Bamber & Humphreys 1965; Stone et al., 1995). If the causal factors continue to operate, tree death may eventuate, although this may occur some years after the first round of defoliation. Wylie et al. (1993) noted that dieback often affects primary and secondary growth, is caused by a variety of agents that affect the trees physiological processes, acting either singly or in combination, and when persistent may lead to the death of the tree. Dieback has affected many tree species and therefore hundreds of dependent animal and plant species across Australia (Heatwole & Lowman 1986).

Eucalypt dieback has been noted since at least the mid 19th century when hundreds of hectares of eucalypt dieback near Walcha in NSW were noted by Norton (Wylie et al., 1993). Many forms of eucalypt dieback have been recognized, and a range of dieback agents recorded. Most attention from the 1940's has been directed at rural (as opposed to forest) dieback, particularly in NSW. More recently, extensive research and reviews into the many types of dieback occurring throughout Australia have been undertaken (e.g. Shearer & Tippett 1989; Wylie et al., 1993; Landsberg & Cork 1997). Most reviews have focused on the diverse range of causal agents according to regional, State or continental scale categories.

Dieback associated with the soil-borne pathogen *Phytophthora* spp. (particularly *P. cinnammomi*) has received considerable attention, particularly in the high rainfall zone of south-western Australia and Tasmania (Shearer & Tippett 1989), but also, more recently in other States. Insect associated dieback has involved investigations into host tree susceptibility, insect control, nutrient and water status of dieback affected trees and the types of land management that favour insect outbreaks, particularly in southern Australia (e.g. Wylie et al., 1993; Stone et al., 1995; Landsberg & Cork 1997).

Some perceptions of eucalypt dieback are dependent on forest management objectives. For example, stands of Alpine Ash (*E. delegatensis*) in Tasmania diagnosed as suffering high altitude dieback (Ellis et al., 1980) were actually in a successional stage in which eucalypt species decline as a forest progresses to temperate rainforest. It was acknowledged that the forest had probably been rainforest with eucalypt emergents prior to being burnt and that the eucalypts (which colonized the burnt site) declined with time as the rainforest vegetation re-established. However, the management objective was to maintain stands of Alpine Ash in these locations. Hence, this situation was seen as a 'problem' and not as a typical successional process.

Eucalypt dieback, however, is a real phenomenon which is increasing in extent, and is associated with a decline in forest ecosystem health. It thus becomes important to differentiate the forms and factors associated with eucalypt dieback.

2. Eucalypt dieback and BMAD

This requirement becomes imperative where intensive disturbance is advocated as one solution to the problem (e.g. Jurskis & Turner 2002), or where mapping and model prediction is employed as a means to define management and research direction (e.g. Stone & Coops 2004). One deficiency in the literature is the frequent lack of clarity on the type of eucalypt dieback that is being referred to. Nevertheless, several reviews have demonstrated the extent to which eucalypt dieback is associated with multiple interacting factors (e.g. Landsberg & Wylie 1991; Wylie et al., 1993; Stone et al., 1995).

Landsberg and Cork (1997) presented a concise review of eucalypt herbivory, including the following topics: 'The main groups of herbivores'; 'Whether eucalypt herbivores are different from other groups'; 'Eucalypts as hosts for herbivores'; 'Eucalypt systems as models for comparing theories of plant-herbivore interactions' and; 'Impacts of herbivory'. Eucalypt dieback associated with psyllids figured prominently in this review. While both vertebrates and invertebrates include eucalypt herbivores, insects which eat a wide variety of plant tissues include the greatest diversity of feeding guilds. Landsberg and Cork (1997) divided invertebrate herbivores into five main groups: 'Leaf-chewers', 'Leafminers', 'Sap-suckers', 'Wood-borers' and 'Seed-eaters'. A sixth group ('Mutualisms') was noted but not discussed in detail because no true mutualisms have been observed in eucalypts. Sap-suckers, specifically psyllids, are most often implicated with BMAD.
It should be noted that different guilds of insects cause different types of damage and their population dynamics are likely to be affected in different ways by environmental factors. We concentrate primarily on sap-suckers in this review, as these include psyllids, the primary insects that have been associated with BMAD.

Rural tree decline has been thoroughly investigated through survey and well-designed experiments by Landsberg and colleagues. However, eucalypt dieback has also been reported in environments that are not associated with broad-scale land clearing, and that remain largely forested. Dieback associated with the cleared and semi-cleared rural landscape is usually caused by a different suite of insect species to that within extensively forested landscapes (an exception being psyllid outbreaks on *E. camaldulensis* which can occur in both rural and forested landscapes). However, change in forested landscapes has also been profound in the 200 or so years since European settlement, (e.g. Lunney 2004). Therefore, in reviewing the literature associated with BMAD, we have also considered the literature relevant to insect-related dieback in rural landscapes. Because eruptive psyllid species are known to occur on eucalypts beyond the distribution of Bell miners, we have considered psyllid associated dieback generally in Australia – albeit with an emphasis on south-eastern Australia.

2.1. BMAD as a form of dieback

There is a considerable body of literature of relevance to BMAD. However, we have not been able to locate literature which clearly differentiates BMAD from other tree decline. Thus, the only point of reference to BMAD is the presence of a particular species of colonial bird, the Bell miner. Nevertheless, a considerable body of research has been directed at the biology and behaviour of the Bell miner. Current understanding of the association between Bell miners and psyllid outbreaks is the focus of this section of the review.

2.2 Definition of BMAD

Bell Miner Associated Dieback (BMAD) refers to the association of dieback of various species of eucalyptus trees with the presence of populations of the Bell miner and severe infestations of phytophagous insects, especially psyllids. The association of the bird and psyllids became prominent following a demonstration by Loyn et al. (1983) that Bell miners excluded a wide range of smaller insectivorous birds from the areas of forest occupied by Bell miner colonies. A more diverse bird community collectively had a much greater impact on psyllid infestations than did the communities dominated by Bell miners. Numerous studies (e.g. Clarke & Schedvin 1999; Ewen et al., 2003) have now shown that there is a tight feed-back relationship between Bell miner density and psyllid density. Similarly, the closely related Noisy Miner (*M. melanocephala*) has been linked to rural tree decline (and more open forest and woodland habitats) through exclusion of smaller insectivorous birds (e.g. Grey et al., 1997, 1998). However, despite their close taxonomic relationship, the close link identified between Bell miners and insect outbreaks has not been observed for Noisy Miners (Catterall et al. 2002, Piper & Catterall 2003, Catterall 2004). Hence, BMAD appears to be a unique phenomenon and involves complex bird, insect, and environment interactions.

2.3 Extent of BMAD and forest types affected

Since the early 1900's, there have been reports in NSW of isolated patches of crown dieback and tree death in moist regrowth eucalypt forests that also tended to be occupied by Bell miners (Moore 1961). The dieback was most prevalent in stands of Sydney Blue Gum on moist sites and with a dense, mesophyllic understorey (Stone et al., 1995). Recent reports indicate that affected areas are increasing in size and that new areas are displaying symptoms (Stone et al., 1995). During the mid to late 1980's, extensive areas of Murray Scrub (now Toonumbar National Park) were identified as being affected by dieback. These areas included previously selectively logged forest that was dominated by a substantial understorey of Lantana (John Hunter pers comm., Jan. 2005).

BMAD is now considered to be spreading rapidly through the moist eucalypt forests in NSW, including the northern region and parts of the south coast (Billyard 2004; Florence 2004). As of April 2004, almost 20 000 hectares of the approximately 100 000 hectares of apparently susceptible forest types in an area of north-eastern NSW bounded by the Border Ranges, Richmond Ranges and Captains Creek (see Figure 1) had been aerially sketched-mapped by the FNSW Forest Health Surveillance Unit as being affected by dieback attributed to BMAD (Ron Billyard, pers comm., Nov. 2004). Bell miners also occur in drier forest types such as Spotted Gum, but they are not as successful and therefore crown damage is less severe (Stone 2005). The area affected is increasing rapidly, with an estimated 2.5 million hectares being considered to be at risk across eastern NSW (Ron Billyard, pers comm., Nov. 2004).

Field ecologists and managers (e.g. Ron Billyard, Steve Rayson, John Hunter and Peter St Clair: all pers comm., Jan. 2005) have noted the rapid expansion of eucalypt dieback in north-eastern NSW since the general decline in mean annual rainfall, commencing in the late 1990's. However, it should be noted that any link to rainfall decline has not been demonstrated (see Section 5.7).

In Victoria, Bell miner and psyllid interactions have been linked to extensive decline of isolated patches of native forest around the outer areas of Melbourne. BMAD has been claimed to affect many species from all locally occurring eucalypt subgenera in the south coast region of NSW (Florence 2004) and the central and northern regions (Stone et al., 1995). The study by Stone et al. (1995) identified numerous species of eucalypts that suffered psyllid infestation and occurred in areas occupied by colonies of Bell miners. Many of the damaging psyllid species were restricted to a single eucalypt host species or to a group of closely related species and hence a large number of psyllid species contributes to the tree crown symptoms of BMAD.

Interpretation of the helicopter-based mapping, in association with the list of trees linked to psyllid infestation and Bell miner colonies leads to the conclusion that about 8600 (43%) of the 20 000 hectares of forest suffering dieback in northern NSW can be directly linked to Bell miners and psyllids. While not precise concerning geographic coverage and forest type affected, it does indicate the seriousness of the problem and the areas affected (Ron Billyard pers comm., Jan 2005). A more reliable digital mapping program is under development (Stone & Coops 2004, Coops et al., 2003, 2004, Stone et al., 2003). This program recognises the need to identify the severity of crown dieback being mapped, as well as the species affected. While this form of remotely sensed mapping can accurately map the extent and severity of canopy decline, it does not identify directly the different causal or secondary agents contributing to the dieback. This requires expert local knowledge in order to correctly interpret the classified maps.

The current mapping has not until very recently enabled a clear association between dieback affected forest and either Bell miner colonies or psyllid outbreaks to be made. Stone (unpublished data) has recently noted a very close spatial association between the spatial distribution of Bell miner colonies in compartment 270, Mt Lindesay mapped from the ground and eucalypt crown dieback as detected and mapped using Digital Multi-spectral Imagery. Currently though the status of forest types affected remains poorly understood. Similarly, we are not aware of attempts to understand the history or mechanisms of the spread of BMAD, at local, plot or regional scales. While there has been considerable focus on Bell miners and psyllids, there has yet to be research on whether there are other likely causal or associated agents with dieback in the north-eastern forests (see Clarke & Schedvin 1999 for an example of potentially interacting factors).

3. Bell miner and psyllid inter-relations

3.1 The Bell miner

The Bell miner is a predominantly insectivorous honeyeater (family Meliphagidae) that is endemic to south-eastern Australia (Clarke & Schedvin 1999; Barrett et al., 2004). It is common in the coastal region from Melbourne in Victoria, north to around Gympie in Queensland, but also occurs occasionally in the Australian Capital Territory (ACT) and central Victoria (Barrett et al., 2004). The Bell miner is a medium sized bird of 19 centimetres (cm) length (bill-tip to tail-tip) and about 30 grams (g) in weight, with olive-green plumage, slight dark facial marks, a red triangle behind the eye and deep yellow bill and legs (Poiani et al., 1990; Pizzey & Knight 2003). It is smaller than its relatives, including the Noisy Miner (length 24-27 cm), with which its range (but not its habitat) overlaps.

Bell miners live in colonies of 20 to 200 individuals composed of cooperatively breeding territorial units of up to 9 birds (Clarke & Fitz-Gerald 1994; Poiani et al., 1990). The Bell miner occurs in gullies near rivers and creeks in temperate rainforest, eucalypt-*Angophora* woodland with a dense shrubby understorey, and Swamp Gum (*E. robusta*) woodland (Clarke & Fitz-Gerald 1994). Several studies have demonstrated that they may occur at high local densities (over 30 birds per hectare), and be the most common species at a site (Bower 1998; C. Stone 2005; J. Shields, unpublished data).

There is surprisingly little available literature on the habitat preferences of the Bell miner in north-eastern NSW, although Bower (1998) correlated colonies of Bell miners with various habitat variables. Bower's (1998) study included eight replicates of sites where there were Bell miners, and eight where they were not present. Each of his treatments included a range of forest types and a range of growth stages and disturbance levels. While we consider that restricting analysis to the use of regression, limited the synthesis of results in this study, Bower (1998) did make several observations that are useful as qualitative indicators of the habitat requirements of Bell miners.

Bower (1998) found that the numbers of dead trees, levels of crown cover, and average crown width differed between treatments. However, none of the remaining vegetation variables showed any significant differences when comparing sites where Bell miners were present or absent. Levels of Lantana cover were not significantly different between the two treatments, despite the wide general acceptance of Lantana as a factor in the occurrence of Bell miners in the region (see Section 5.4). Bower (1998) cited anecdotal evidence that Bell miners favour structural simplicity in the midstorey, rather than in the overstorey. There has been little investigation of structural variation in the mid-storey or the extent to which this influences the presence or absence of Bell miners. Bower (1998) attributed much of the difference between sites with and without Bell miners to the impact of the Bell miners themselves. Therefore, Bower's (1998) study does not enable determination of the habitat features that characterise the colonisation of a site by Bell miners.

There is no doubt that Bell miner colonies are expanding in north-eastern NSW. For example, Bob O'Neil (pers comm., Jan. 2005) who has lived all his life (66 years) in the Toonumbar area recalls the distribution of Bell miners in the area as a boy in the 1940's. He recalls three colonies, one on

'Valleys End' – the farm in forest near a cattle dip that was called 'Bellbird dip'. A second occurred at Toonumbar in State Forest, while a third was at the Glen near Woodenbong. These were the only colonies he knew of in an area of some 10's of thousands of hectares. He now recognizes 1000's of hectares of these forests in this area as being dominated by Bell miners. Bower's (1998) study in the same region found that sixty five percent (476) of the bird detections at a total of eight sites occupied by Bell miners were of that species. Other recent personal observations include the suggestion that Bell miners occurred at low densities generally in the region, but have become abundant in recent years (Michelle - Woo Wei Richards pers comm., Jan 2005). However, apart from a local study by Kavanagh and Stanton (2003) in south-eastern NSW, we are not aware of any published accounts of the medium-term changes in distribution and abundance patterns of Bell miners.

3.2 Bell miner effects on psyllids

There is general consensus that Bell miners are largely insectivorous and that a large proportion of their diet comprises psyllids and their protective lerps (Campbell & Moore 1957; Poiani 1993). Lerps are a waxy or sugary coating secreted by the nymphs of many psyllids, and form an important food resource for a range of insectivorous birds and marsupials (Paton 1980). Poiani (1993) demonstrated that the diet of Bell miners in outbreak areas is dominated by psyllids (~ 70%). However, they also feed on other arthropods such as flies, beetles, moths and spiders and some plant material (Poiani 1993) and probably the wasp parasitoids that help regulate psyllid numbers (Stone 1996).

Despite several studies having demonstrated a significant positive correlation between Bell miner density and psyllid numbers or associated foliar damage, the extent of occurrence of populations of Bell miners outside psyllid infestations has not been reported. Apart from Clarke and Fitz-Gerald (1994), there are no maps showing the distribution and abundance of Bell miner colonies at a landscape scale. Similarly, the success (as measured for example by size of population, number of offspring or longevity of population) of Bell miner populations in such situations has not been reported. The mobility of Bell miner colonies has also not been investigated, although it may be relevant to the conservation of remnant vegetation.

In Victoria, both Michael Clarke (pers comm., Jan. 2005) and Ewen et al. (2003) have observed newly founded Bell miner colonies, and found that the psyllids were not greatly abundant at the time of the arrival of the Bell miners. Clarke has not been able to identify the host tree factors that may promote the observed increase in psyllid numbers after colonisation by Bell miners but regards any form of site disturbance as predisposing an area to insect attack (although is uncertain of the mechanisms involved), and considers there to be a link between colonies and fragmentation. We are not aware of any published evidence for this, but note the considerable difficulties of carrying out an effective study of the association between Bell miners and fragmentation (see Section 5.1).

Bell miners show a remarkable capacity to change the sex ratios of offspring depending on the densities of psyllids (Ewen et al., 2003). Bell miners aggressively defend their territory from all interspecific competitors and by so doing allow food resources to dramatically increase (Loyn et al., 1983, Clarke & Schedvin 1999, Ewen et al., 2003). The increase in psyllids leads to a decrease in tree health, often culminating in the death of the tree (Ewen et al., 2003). Bell miners then move as groups to new areas with low psyllid abundance, and the cycle repeats (Ewen et al., 2003). Hence, the population dynamics of Bell miners are closely linked with psyllid populations and the capacity of the host trees to maintain an adequate supply of insects.

Loyn et al. (1983) working in Victoria, removed a colony of Bell miners from a psyllid-affected site dominated by Messmate Stringybark (*E. obliqua*) and Mountain Grey Gum (*E. cypellocarpa*), and observed a rapid influx of other lerp-eating birds, a decline in the abundance of lerps per leaf on trees at the site and a 15% increase in epicormic foliage during the 6 months following the removal of Bell miners. Loyn et al. (1983) likened the behaviour of Bell miners to that of a farmer who tends and harvests a crop sustainably. However, the validity of this metaphor was later questioned by Poiani (1993). The evidence is weak for Bell miners 'harvesting' the lerps while leaving the psyllid. Regardless, evidence to date supports the contention that Bell miners feed on psyllids (e.g. *Glycaspis* spp.), and other invertebrates present on the leaves, aggressively defend their territories against other insectivorous birds, and are not as effective in reducing an 'outbreak' of psyllids as the community of birds which they displace.

Clarke and Schedvin (1999) sought to determine if the findings of Loyn et al. (1983) could be replicated in another forest type, and specifically whether the removal of Bell miners would result in an increase in the abundance and diversity of birds at the site, a sustained decrease in the abundance of psyllids on leaves of the canopy trees and a sustained improvement in the health on the site. They also sought to determine whether the interspecific territorial behaviour of Bell miners changes as the density of individuals within the colony is reduced. They found that the removal of Bell miners resulted in an immediate influx of other bird species, although this was reduced after a few weeks as the psyllid population was reduced. Although there was a higher total population of birds in the psyllid affected areas, these areas had a lower diversity in comparison with the same sites following the removal of Bell miners. Once Bell miners recolonised the site, the psyllid (*Glycaspis* sp.) population returned close to its former levels. Clarke and Schedvin (1999) found that the reduction in Bell miners did not lead to an improvement in tree health as reported by Loyn et al. (1983) and argued that Loyn et al. (1983) prematurely equated epicormic shoot production with forest health, whereas it may also be a symptom of tree decline. The study by Clarke and Schedvin (1999) was carried out over a longer period than that by Loyn et al. (1983).

Both Loyn et al. (1983) and Clarke and Schedvin (1999) adopted careful experimental approaches. However, both studies were limited in replication, were in different site types from one another, and were affected in various ways by other disturbances. Thus their work does require some qualification. Clarke and Schedvin (1999) inadvertently chose sites that were affected by *Phytophthora*, and concluded that they could not rule out this pathogen as the primary cause of the trees' ill-health and lack of recovery. Furthermore, only one site was used for the removal treatment. Thus, only three sites were used (a treatment site, a control with neither psyllids nor Bell miners, and a control with both psyllids and Bell miners). A more complete design would have included replication (although the difficulty of the exercise is acknowledged), and included sites that had psyllids but not Bell miners (although the extent of such sites is unclear from the literature). We acknowledge that finding neighbouring sites that have elevated psyllid populations but no Bell miners would have to be very opportunistic, and that it would be very unlikely that they would be the same psyllid species (e.g. *Cardiaspina* spp. versus *Glycaspsis* spp. in the Bell miner stands).

We have not noted any research on the association between Bell miners, habitat characteristics and psyllid outbreaks. Although the literature has demonstrated that Bell miners are associated with psyllid outbreaks, there has not been a clear demonstration that Bell miners are the primary cause of the dieback problem. Before we examine other potentially proximate or ultimate factors, we examine the biology and characteristics of the psyllid outbreaks with which Bell miners are associated.

3.3 The distribution of psyllids and psyllid outbreaks

Psyllids (order Hemiptera, family Psylloidea) are a world-wide distributed family of sap-sucking insects. Eucalypt associated psyllids dominate the Australian psyllid fauna with at least 67% of the 379 currently recognised species using eucalypts as host plants (Majer et al., 1997). Not only are there many species of psyllids in Australia, they are also abundant. A diverse array of sap-sucking insects, especially psyllids, appears to be particularly prominent on eucalypts in the monsoon tropics of Australia where they constitute up to 80% of all leaf-feeding insects collected in these woodlands (Fensham 1994).

The sedentary nymphs of many species of sap-suckers cover themselves with a starchy (e.g. *Cardiaspina* spp.) or sugary (e.g. *Glycaspis* spp.) shell or lerp and feed by inserting their stylets into the leaf phloem. Many other species do not produce lerps and are free-living. There are at least ten genera of lerp-building psyllids on eucalypts with the most common species belonging to the genera *Cardiaspina* and *Glycaspis* (Morgan 1984; Morgan & Taylor 1988). Different genera exhibit different behaviour. For example *Glycaspis* spp. prefer to feed on young foliage while others, such as *Cardiaspina* spp. feed on mature foliage. Some psyllid species occur on a range of eucalypt species (*C. fiscella*) while other species are host specific (e.g. many of the *Glycaspis* spp.).

No one species of psyllid has been linked with Bell Miner Associated Dieback (although they most commonly belong to the genus *Glycaspis*), with Stone (1996) reporting 16 species of psyllid collected from *E. saligna* crowns colonised by Bell miners in Olney State Forest. A listing of psyllid species sampled from a range of eucalypt species known to occur in forest types affected by BMAD is presented in Stone et al. (1995).

Psyllid-associated crown damage can occur extensively on many eucalypt species not known to be colonised by Bell miners. For example, periodic outbreaks of *C. densitexta* (Pink Lace Gum Lerp) have severely damaged rural and woodland stands of *E. fasiculosa* (Pink Gum) in the south-east of South Australia (Collett 2001). *Cardiaspina*

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albitextura commonly occurs on Blakely's Red Gum (*E. blakelyi*) and River Red Gum (*E. camaldulensis*) and occasionally causes severe defoliation and sometimes death of its host plants in south-eastern Australia (Landsberg & Cork 1997). Outbreak populations of *C. fiscella* in Rose Gum regrowth forests and *C. bilobata* in Mountain Ash regrowth native forests have also been recorded.

There have been many reviews and models developed to progress theory concerning the patterns of species distributions. For example, Hengvelt and Haeck (1982) demonstrated that in general, species tend to be most abundant in areas of most favourable habitat, while Carter and Prince (1989) presented an epidemic model to explain the local abundance of species beyond areas of their most favourable habitat. While it is possible that the spread of BMAD conforms to such a model, we are not aware of the development or testing of any such model. Similarly, the models and experimental work of species interactions by Austin and colleagues (e.g. Margules et al., 1987; Groves et al., 2003) indicated that competition across the overlapping ranges and environmental tolerances tends to result in species only partially occupying their potential niche. White (1993) discussed the changes in abundance of outbreak forest insects in space and time. He argued that subtle differences and interactions in site quality, climatic conditions and tree stress can have pronounced effects on the patterns of insect outbreaks.

If the susceptibility of different tree species varies (Williams & Nadolny 1981; Lowman & Heatwole 1992), then dieback has the potential to change the mix of tree species surviving chronic psyllid infestation. Based on their research on rural tree decline, where there is limited opportunity for recolonisation by host trees, Williams and Nadolny (1981) argued that if insect populations remain high for prolonged periods, most eucalypt species at a site become susceptible. However, this will depend on whether the damaging insect pests are generalist feeders or specialists restricted to one or a few hosts only. Such a situation is unlikely to occur generally in forested environments where colonisation by relatively resistant tree species follows the decline of susceptible species. Exceptions may occur where shading by a Lantana-dominated understorey prevents the germination of eucalypt seedlings.

Unlike the situation of Bell Miner Associated Dieback, high psyllid populations in the absence of Bell miners tend to be cyclical in nature (Collett 2001). Collett (2001) suggests causes of these psyllid populations reaching outbreak levels include: the abundant presence of appropriately-aged foliage, the lack of floristic diversity, elevated foliar nutrition, deviation from average seasonal ambient temperatures, sufficient soil moisture to maintain full turgor of the host foliage; low population levels of psyllid-specific predators and/or parasiotoids, and correspondingly high levels of hyperparasites. Many of the causes are correlated, and the population dynamics of psyllids are influenced by several of these generic multi-trophic, interacting environmental factors (see Sections 4 and 5). Although fundamental in understanding BMAD, we are unaware of any investigation into the origin of any BMAD related increase in psyllids, or of its pattern of spread at plant, plot, habitat or regional scales.

3.4 Psyllid effects on trees and forests

In order to test whether Bell miners or psyllids (or some other factor) are the primary agent responsible for the BMAD form of dieback, it is first necessary to separate the impacts of one from the impacts of the other. However, this may not be possible because the two are inter-related. Thus high densities of Bell miners require high densities of insects as a food source. Conversely, under low densities of Bell miners most crowns can tolerate the resultant lower levels of psyllid feeding damage. We have included literature from beyond the range of the Bell miner, including two examples from south-western Australia.

When densities of psyllids are low, they cause little apparent damage to the host tree apart from discolouration and leaf necrosis at the feeding site. When psyllid densities are high however, whole leaves and canopies become necrotic and are shed prematurely, resulting in severe dieback (Farr 1992; Landsberg & Cork 1997). There is at least one recent instance of a previously undetected species (and hence a species new to science – *Cardiaspina jerramungae*) suddenly reaching outbreak levels over a large proportion of the range of its host –Flat-topped Yate (Janet Farr pers comm., Nov. 2004).

While most eucalypts have considerable resprouting ability, repeated defoliation can exhaust the tree's carbohydrate reserves and may eventually lead to the death of the tree, and possibly the stand. Stand death has been reported in relation to BMAD by several authors (e.g. Stone et al., 1995; Bower 1998) and the now well recognised seriousness of the problem has led to the establishment of the Bell Miner Associated Dieback (BMAD) Working Group, and the suggestion of a listing of the phenomenon as a threatening process under NSW environmental legislation (Jim Morrison pers comm., Dec. 2004). In BMAD areas, there is a significant correlation between Bell miner density and the condition of affected eucalypt crowns (e.g. Clarke & Schedvin 1999; Ewen et al. 2003; Stone 2005). In these areas, the sustained presence of Bell miners creates negative feed-back mechanisms that maintain elevated and damaging populations of psyllids in the eucalypt canopy (Stone 1999).

Clay and Majer (2001) examined the pattern, extent and correlations with various habitat components of psyllid (*Creiis periculosa*) outbreaks in Flooded Gum (*E. rudis*) communities along the Swan River in Western Australia. They worked in a transformed environment (metropolitan Perth), but found that the intensity of effect was reduced in more intact communities in the upper reaches of the river near Guildford (outer metropolitan with much lower housing densities etc). Clay and Majer (2001) concluded that the dieback they observed along the Swan River was a recent phenomenon, which was in its first cycle of defoliation. They also found this dieback to be widespread but of variable occurrence, and failed to discern any pattern in the distribution of the tree decline.

Outbreaks of psyllids have also occurred in eucalypt plantations within north-eastern NSW. The main eucalypt species planted in the more than 4 000 hectares of plantation in north-eastern NSW are Dunn's White Gum and Spotted Gum (*Corymbia maculata* and related species), with only the former being affected by psyllids in this area. Jim

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Morrison (pers comm., Jan. 2005) observed the commencement of an outbreak of psyllids (*Creiis literatus*) in the winter of 2001 in the Deep Creek subcatchment at Mallanganee, when the plantation was about five years old. The patch of brown expanded rapidly, with sites lowest in the profile being most badly affected during wetter periods and sites on ridges being most badly affected during dry periods. Some eucalypt plantations have been sprayed for psyllids, and a patch of upwards of 200 hectares was entirely lost to psyllid outbreaks.

Outbreaks of psyllids in this plantation environment were initiated in planted sites which were apparently unsuitable to Dunn's White Gum (Steve Rayson pers comm., Jan. 2005). Bell miners were not associated with these outbreaks, which were less than three years old and had not yet reached canopy closure. The Forest Health Surveillance Unit in Forests NSW has been closely assessing, monitoring and databasing this problem since 2000 across the entire estate (Carnegie & Angel 2005). In these young plantations, *E. dunnii* saplings were stressed by local site conditions (waterlogging or drought stress) and produce foliage that is more suitable for *Creiis* development than vigorously growing crowns. At high densities the ovipositing *Creiis* females 'drift' away from damaged crowns to neighbouring undamaged crowns. Because this *Creiis* species completes up to five generations in a year, a 'hot spot' can spread rapidly throughout a plantation.

There is some information on insect pest impacts in a eucalypt plantation environment, also within the north-eastern NSW forests (e.g. Stone et al. 1997, Stone et al. 1998, P. Angel pers. comm., unpublished PhD Thesis). Most studies on the impacts of psyllid outbreaks are actually outside the distribution of Bell miners. We conclude this section by considering links between Bell miners, psyllids and other bird species. We are not aware of any studies that have traced forest changes with the development of an outbreak associated with BMAD.

3.6 Bell miners, other bird species & psyllid populations

There are many species of lerp specialist birds in the eucalypt forests of Australia (Woinarski et al., 1997). In studies of canopy eucalypt arthropods, Recher and associates (e.g. Recher et al., 1991a b, 1994; Majer et al., 1989, 1992) found significant differences between tree species in the abundances of psyllid insects. This was reflected in the selection of tree species by birds as foraging sites, with psyllid dependent species foraging preferentially on trees with high psyllid numbers. No difference was found in tree species use by non-dependent avian insectivores.

In a study of psyllid outbreaks in south-western Australia, where aggressive, colonial insectivorous birds are not present, Farr (unpublished data) recorded the dramatic reduction of a population of one psyllid species (*Cardiaspina jerramungae*) caused by the arrival of a large flock of Striated Pardalotes (*Pardalotus striatus*) to her Flat-topped Yate study sites. Following the arrival (and subsequent departure) of the pardalote flock, the outbreak took three generations (one year) to return to its previous (outbreak) levels (Janet Farr pers. comm., Dec. 2004). Conversely Clark (1964) reported that at low psyllid densities, the principal conditioning agencies in psyllid outbreaks were probably the whole complex of species predacious on psyllid nymphs and eggs, and weather. Clark (1964) argued that at high psyllid densities, the conditioning agencies were the density of host trees, and wind. He listed the major natural enemy groups as: birds; encyrtid parasitoids, ants and a malachiid beetle.

Recher and Majer (in press) examined the effects of bird predation on canopy arthropods in Wandoo (*E. wandoo*) woodland in south-western Australia. They used bird mesh to exclude insectivorous birds from the foliage of Wandoo saplings, and found that exclosure resulted in an increase in the number of herbivorous and predatory arthropods, and that total arthropods, spiders, adult Coleoptera and larval Lepidoptera were significantly more abundant on meshed than unmeshed saplings. All size classes of spiders increased in abundance on saplings from which birds were excluded. Seasonal patterns of abundance and differences between sample periods appeared to be determined by rainfall and low temperatures. Recher and Majer (in press) concluded that relative to physical conditions, eucalypt forest birds have limited effects on temporal variation in canopy arthropod abundances, but depress abundances, and affect size and trophic composition of the fauna. They argued that in most circumstances, predation by eucalypt forest birds has limited effects on the magnitude of temporal variation in canopy arthropod abundances. A possible exception might be in circumstances where the birds affect the 'efficiency' of natural enemy species.

There are several aggressive colonial bird species in south-eastern Australia that exclude other small passerines from their colony. For example, Loyn et al. (1983) reported that experimental removal of Bell miners resulted in birds of 11 other species of insectivorous birds moving in to feed on psyllids, with a consequent reduction in the psyllid infestation. It should be noted that Loyn et al. (1983) did not measure the abundances of other insects, which may also have been higher in the Bell miner sites.

A study in 24 remnants in Queensland demonstrated that remnants occupied by high numbers of two species of 'aggressive' honeyeaters (Noisy Miner and Blue-faced Honeyeater *Entomyzon cyanotis*) had significantly fewer bird species than remnants where theses two species were absent, the effect being greater in smaller patches (Chan 2004). In these situations high densities of psyllids may be able to develop – a situation Recher and Majer (in press) regards as being unusual in Australia. However recent changes to the vegetation composition and structure may increase the favourableness of trees stands to colonisation by these 'aggressive' honeyeaters. It should be noted that large forest blocks may act as fragments once changes initiated at edges become general within the forest block (see Laurence 1990).

Recher (pers comm., Jan. 2005) reported large areas of eucalypt woodland in his study sites in Western Australia (WA) are dominated by Yellow-plumed Honeyeaters. He noted that these sites are poor in other small passerines due to honeyeater aggression, but there is no evidence of psyllid (or other insect) outbreaks. There are many species of aggressive honeyeaters able to displace other species of birds at varying times or locations in Australia. However, the activity of the highly social Bell miner appears to be at one extreme of this continuum of exclusion. Thus it

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is possible that the food preferences or foraging behaviour of Bell miners differs sufficiently from other aggressive, colonial honeyeaters to result in shifts in arthropod faunas, and favour psyllids.

Bower (1998) reported observations of aggressive territorial behaviour of Bell miners in his studies in north-eastern NSW. He also noted that Bell miner aggression towards other birds differed with respect to the size and foraging habits of other species. For example, the King Parrot (*Alisterus scapularis*) and the Black-faced Cuckoo-shrike (*Coracina novaehollandiae*) were harassed with less frequency and veracity than smaller birds. Some species such as the Paradise Riflebird (*Ptiloris paradiseus*) were a good match for the Bell miners, while others such as the White-throated Treecreeper (*Cormobates leucophaeus*) were irregularly harassed. Some species such as the Crested Shrike-tit (*Falcunculus frontatus*), were never observed in Bell miner sites, but were consistently recorded from sites where Bell miners were absent. Similarly, the Brown Warbler (*Gerygone mouki*) was recorded over 22 times more frequently from sites where Bell miners were absent than from where they were present. Both the shrike-tit and warbler are foliage gleaners which take a similar array of prey to Bell miners, including lerp and psyllids.

As Bower (1998) observed, the level of aggression displayed by Bell miners to other birds was proportional to their competition for food. Only one species, the White-browed Scrubwren (*Sericornis frontalis*) was recorded more often from sites where Bell miners occurred than from where they were absent. This species nests and forages on the ground and in dense understorey, habitat that can be rendered more favourable by the opening of the overstorey canopy. Numbers of individuals of small insectivorous birds of the midstorey and overstorey were most different between sites with and without Bell miners in Bower's (1998) study.

Noisy Miners occur in habitats not favoured by Bell miners, that is, open woodlands with poorly developed understoreys (Poiani et al., 1990; Grey et al., 1997; Piper & Catterall 2002). In a study of heavily grazed stands of remnant woodland, Loyn (1985) attributed the severe insect defoliation of eucalypts to changes in their bird communities. In this case, the insectivorous bird community was dominated by Noisy Miners which were able to drive out most other small woodland birds because the grazed understorey offered little cover. Noisy Miners feed generally on canopy arthropods, including both the herbivorous insects as well as the invertebrate predators e.g. parasitoids, ants, spiders etc. Hence their foraging behaviour may break the tight regulatory link between invertebrate prey and predators. Grey et al. (1997, 1998) experimentally removed Noisy Miners from remnant patches of woodland and observed an influx of honeyeaters and other insectivorous birds to these sites in the following three months, not observed in matched control sites. These experiments demonstrated that Noisy Miners in open environments affect avian diversity and abundance by the aggressive exclusion of small birds in the same manner as Bell miners in eucalypt forest with shrubby understoreys.

Recher and Majer (in press) argued that restoration of degraded lands through revegetation and the rehabilitation of remnant native vegetation should be planned to maximise bird numbers and diversity. They recognised that while a rich avifauna will not prevent insect outbreaks, it may dampen arthropod abundances and limit damage from herbivory. The same argument could be made for more extensive habitats, including broad areas of forest and woodland, and a cessation of vegetation clearing. Generally, a rich avifauna in Australian forests and woodlands is encouraged by increased structural and floristic diversity. At Eden, where Recher and colleagues compared a broad range of forest types from the coast to the tablelands, bird species richness and abundance was correlated with site productivity (nutrients, moisture), structural complexity (number of equally dense vegetation layers, and number of tree genera (Kavanagh et al., 1991). Thus, for example, tall but structurally and floristically simple stands of Shining Gum (*E. nitens*) had a different avifauna with fewer species and individuals from more complex associations of eucalypts in the same general area.

There have been studies of the interactions between Bell miners and other bird species in various habitats. From the available literature, we have not been able to identify Bell miners as a primary cause of eucalypt dieback, nor to directly attribute blame on Bell miners as causes of psyllid outbreaks. Thus Bell miners are just one component of an interactive process. Thus all the right components are needed together at the one site for Bell Miner Associated Dieback to occur. If trees are exhibiting crown decline symptoms in the absence of Bell miner then they might be suffering dieback - but another form of dieback. The literature is clear, in demonstrating that colonies of Bell miners can exacerbate forest dieback, and can increase the impact of psyllid outbreaks in the regions where they occur. Furthermore, there is some quantification of the influence of Bell miners either directly or indirectly on other bird species and on the bird community as a whole. Because, there have only been limited attempts to link this material to environmental processes, we have not been able to establish Bell miners and psyllids as either a proximate or ultimate cause of BMAD in north-eastern NSW. We now consider the proximate and ultimate factors associated with insects, and with disturbance on BMAD in the north-eastern forests of NSW.

4. Proximate and ultimate factors associated with insects

In this section we refer to processes associated with herbivory in eucalypts, particularly psyllids, and consider host foliar factors that influence psyllid population performance. The suitability of their food is influenced by two leaf traits: the nutritional status of the leaves and the presence of defensive chemical and physical components (e.g. tannins, essential oils and leaf fibre). If the nutritional characteristics are optimal for a particular insect species then enhanced survival is anticipated in the absence of significant mortality factors (e.g. predators, adverse climatic conditions). There are a range of essential nutrients required by insects including nitrogen, particularly soluble nitrogen compounds in the form of certain amino acids (Peeters 2002). Numerous studies have demonstrated that insect populations benefit from elevated foliar concentrations of soluble nitrogen (e.g. Waring et al. 1992). What is more controversial is the identity of processes that result in elevated foliar nutrition. Several theories have been published which attempt to explain how different insects respond to variations in foliar quality with no single general theory matching the very diverse range of observed results.

4.1 Plant stress and vigour

There are two opposing sets of hypotheses and associated predictions concerning how herbivory varies with environmental conditions, for example, the Plant Stress Hypothesis (White 1984; Mattson & Haack 1987) and the Plant Vigour Hypothesis (Price 1991). Landsberg & Cork (1997) suggest that both concepts might apply to eucalypt systems depending on the environmental circumstances (Landsberg & Cork 1997). The extent to which these competing hypotheses explain the initiation and maintenance of psyllid outbreaks in BMAD affected areas may have relevance to appropriate management responses in susceptible eucalypt forests (Section 5.2).

The *Plant Stress Hypothesis* proposes that plant stresses increase survival and growth of herbivores principally by elevating concentrations of plant nutrients in the foliage, especially nitrogen (White 1969, 1984, 1993), but also phosphorus (Wardle et al., 2004). White's original formulation of the hypothesis was based on correlations between rainfall patterns and reported outbreaks of several species of psyllid (White 1969), but not on actual measurements of foliar chemistry and several authors have since challenged the conclusiveness of this theory (e.g. Watt 1997). A subsequent life-history study of *C. albitextura* on *E. blakelyi* (Clark & Dallwitz 1975) found that foliage availability of a suitable age and its synchronisation with adult emergence outweighed drought in their influence on insect abundance. Nevertheless, specific studies have demonstrated that certain environmental stresses can induce the mobilisation of nitrogen in plants (Stewart & Larher 1980). It is not unreasonable to assume an osmotic adjustment in response to water stress through increased concentrations of amino acids such as proline can occur in eucalypt leaves (Hopkins 1999; Marsh & Adams 1995).

In addition to climate, local site factors such as soil fertility and moisture content, altitude and disturbance including fire have been proposed as controlling the natural distribution of eucalypts (e.g. Turner et al., 1978; Ellis 1985; Wardell-Johnson et al., 1997). When any of these factors exceeds the usual range for a particular eucalypt, it is likely that conditions become stressful for that species. Stress can manifest itself in many ways (see Grime 1977). For example, highly competitive eucalypt species such as Sydney Blue Gum or Dunn's White Gum are likely to become stressed under mild drought conditions, but are competitive with elevated nutrients. Conversely, species more generally associated with disturbance and low nutrient sites such as Grey Ironbark (*E. siderophloia*) and Spotted Gum are unlikely to be stressed by mild drought. However, these species are likely to become stressed under conditions of elevated nutrients, which would make them less locally competitive than other species. We have not located literature which has specifically attempted to resolve the types of stress, and how they vary in different environments, for different species. However, Wardell-Johnson et al. (1997) has provided a review of eucalypt distribution at broad (continental to local), and site level, while Austin (1997) has reviewed the literature associated with modelling eucalypt species distributions in relation to direct and indirect resource gradients. However, neither of these studies can be used to predict the behaviour of plants under BMAD.

Stressful environmental conditions also influence the physiological function of leaves. The mobilisation of soluble nutrients, including free amino acids, is correlated with reduced photosynthesis (Brodbeck & Strong 1987; Stone in review). These authors also claim that, while increases in free amino acids usually follow stress, the total nitrogen concentration of plant tissue may not vary with stress.

The *Plant Vigour Hypothesis* (Price et al., 1990; Price 1991, 1992) predicts an association between high levels of herbivory and vigorous plants growing in favourable environments. Variations in food quality and herbivory in relation to availability of environmental resources are often consistent with this hypothesis (Landsberg and Cork 1997), but this more often been successfully applied to leaf-chewing, rather than sap-sucking insects.

Landsberg (1990b) examined whether differences in nutritional quality of foliage is genetically determined or caused by environmental stress. She found that most environmental stresses applied experimentally caused a reduction in foliar quality, and hypothesised that the enhanced nutritional quality found in trees affected by rural tree decline were a consequence of favourable growing conditions, rather than environmental stress.

Rural dieback is an example of the profound effects of prolonged herbivory on ecosystem function, and affects trees in isolated remnants of native vegetation in areas that have been extensively cleared and modified for agriculture and pastoralism (Landsberg & Cork 1997). Many different species of insect from many different feeding guilds are implicated. Research by Landsberg demonstrated that enrichment of tree foliage from fertiliser and animal droppings is the common factor. Enhanced food quality of re-growth foliage permits many groups of insects to repeatedly exploit this resource (Landsberg 1990a).

Stone (2001) tested the idea that intrinsically fast growing plants are able to tolerate relatively high levels of herbivory when not exposed to external stressful factors that reduce canopy growth and vigour. She examined three young eucalypt plantations stressed by a moisture deficit (River Red Gum) and by flooding and weed competition (Dunn's White Gum). She found that in all three cases, the stress-inducing agents reduced canopy growth rates and architecture so that the proportion of leaf tissue damaged by insects increased and the trees ability to tolerate the damage decreased. She concluded that alleviating tree stress through improved silvicultural practices or improved site selection may reduce the impact of insect herbivory.

Crown damage in areas of Bell Miner Associated Dieback is correlated with soil fertility (ammonium content - Stone 2005, in review). Numerous studies have reported that Bell miner colonies often commence in stands located in gullies or river flats, sites high in soil nutrition and soil moisture. In addition, if crown irradiation is also non-limiting, then under these circumstances these crowns are likely to be very vigorous and have the intrinsic potential to support high insect numbers, especially if other regulatory mechanisms are disrupted or removed such as the influence of natural enemies (e.g. Majer et al. 1992; Campbell 1992).

To maintain high densities (around 30 birds per hectare) Bell miners require not only tree crowns with the capacity to support high insect numbers but also suitable nesting sites, and the ability to defend their nests. This structure requirement is satisfied with the presence of dense but simplified understorey structure. If all of these components are present then the Bell miner colony is likely to become established, but numerous studies have shown that in the presence of Bell miners, some insect populations are able to reach outbreak levels. Psyllids are very common in eucalypt canopies but they are not the only common group of insects (e.g. Majer & Recher 1988).

A feature of psyllids, in particular *Glycaspis*, is their multivoltism. That is, they have many generations per year, with *Glycaspis* species having six or seven generations per year (Moore 1961) and hence the capacity to respond quickly to improved conditions and dominate the food resource. These elevated insect densities result in the rate of leaf consumption and damage exceeding the rate of leaf production within colonised crowns. When this starts to occur the crown slowly shifts from being vigorous to stressed, but continues to produce foliage of high nutritional status (Landsberg 1990). This continues until there is insufficient foliage to maintain the insect populations and the system 'crashes'.

The spatial and temporal behaviour of psyllid populations is directly influenced by the abundance of suitable foliage (bottom up effects) and the natural enemies (top-down effects). Local climatic conditions directly affect all three interactive components (i.e. the herbivorous insects, the host trees and natural enemies), while site factors directly affect the quality of foliage. Clark (1964) and Clark & Dallwitz (1975) demonstrated that for populations of *C. albitextura* on Blakely's Red Gum low population densities were regulated primarily by predation while high densities were regulated by host tree decline. A disruption to the regulatory mechanism operating at low densities resulted in elevated psyllid densities if sufficient suitable foliage existed to support the increasing psyllid population. Both stressed trees and trees growing vigorously can produce foliage of high nutritional quality.

4.2 The geographic distribution of herbivory

The nature of the links between environment, leaf quality and herbivores in eucalypt systems is poorly understood, particularly for insects (Landsberg and Cork 1997). However, there is evidence that high site quality contributes to high foliar nutritional status which in turn contributes to high insect abundance. This in turn can result in high levels of herbivory. In both temperate south-eastern Australia and the monsoon tropics, foliar nutrient concentrations in eucalypt and other forests and savannas are broadly related to nutrient concentrations or availability in the soil (Lambert & Turner 1983; Fensham & Bowman 1995), but there is debate about how leaf and soil nutrient composition influence one another (Fensham & Bowman 1995). Studies of the causes of rural tree decline among eucalypts in south-eastern Australia have linked environmental effects with leaf quality (Landsberg & Wylie 1988; Landsberg et al., 1990).

Most broad-scale surveys have failed to detect correlations between environmental variables and insect herbivory on eucalypts. However, Landsberg and Gillieson (1995) carried out a survey of regional and local variation in insect herbivory, vegetation and soils of eucalypt associations in contrasting landscape positions along a climatic gradient. They found that indicators of site productivity, such as soil nitrogen, tended to increase as climate becomes more favourable. Many such indicators were also higher in locally richer parts of the landscape. Rates of herbivory tended to increase with increasing site productivity and the associated changes in soil, vegetation and foliar properties.

These findings were in broad agreement with models relating herbivory to resource availability and plant vigour. They found no evidence to support models relating high herbivory to low-resource environments and plant stress. They also found that the level of herbivore damage on mature leaves was highest at intermediate levels of resources, possibly reflecting interactions between resource availability, rates of herbivory and rates of leaf replacement. They suggested that there is a trend toward high natural levels of herbivory in the tablelands region of NSW, which may be associated with the influence of climate on resource availability.

Majer et al. (1992) concluded that trends in foliar nutrients in canopy and sub-canopy foliage of eucalypt forests in south-western and south-eastern Australia were consistent with trends in the abundance and diversity of foliage arthropods and the use of trees as foraging substrates by birds. Surveys of arboreal mammals in south-eastern Australia have also found a general correlation between soil fertility and abundance of leaf-eating species (Braithwaite et al., 1983). This is also the case for birds, with the greatest abundances and species richness associated with more productive environments (e.g. Recher et al., 1991b).

The general geographic extent and pattern of distribution of BMAD was closely associated with the geographic distribution of established Bell miner colonies. However, the association between distribution of Bell miner colonies, forest vegetation types, level of disturbance and edaphic parameters has not been quantified. Hence it is not currently possible to relate the distribution of nutrients and BMAD at even the coarsest level of resolution. Until clear understanding (distribution patterns and biochemistry) of the development of outbreaks is achieved, the reasons for an expansion of BMAD outbreaks will continue to attract controversy.

4.3 Psyllid dispersal and host location

Herbivorous insects use visual, taste and volatile chemical cues to locate suitable host plants (Brennan & Weinbaum 2001). The chemical composition of these volatiles can change if the plant is physiologically stressed (e.g. Metcalf 1987). Studies, mostly on bark beetles attacking conifers, have demonstrated that some insect species have evolved to recognise these stress-induced olfactory signals in order to locate weakened host trees (Hodges & Lorio 1975). Finlay-Doney & Walter (in press) found that adults of the psyllid *Heteropsylla cubana* distinguished between different varieties of *Leucaena* using olfactory cues. Brennan and Weinbaum (2001) demonstrated that two species of *Ctenarytaina* psyllids were significantly attracted to yellow coloured sticky traps in preference to other colours. The spatial influence of these plant cues is, however, related to the dispersal ability of the insect (Metcalf 1987).

Several researchers examining the biology of psyllids on eucalypts have reported that adult psyllids are agile on leaf surfaces and when disturbed take flight, but often return to the same tree crown (Clark 1962, Clark & Dallwitz 1975, Paul Angel unpublished PhD thesis data). White (1970) concluded that his observations of *C. densitexta* adults emerging in the summer and autumn months were similar to those of Clark's study of *C. albitextura*, claiming that emigration of female psyllids from their point of origin was often poor. Both authors also agreed that the pattern of psyllid dispersal is influenced considerably by wind direction. While only a small proportion of adults spread more than 100 meters from their nymphal sites, this would represent a large number of individuals in an outbreak event. Also, adults quickly detect when they have landed on unattractive foliage (i.e. the wrong leaf age or leaves that are already heavily damaged). They will then move again, thus dispersing from the original population. White (1970) also described a different pattern of adults emerging in spring, finding that these individuals appeared capable of dispersing greater distances possibly in the order of a couple of kilometres.

4.4 Nutritional status of foliage

The importance of young foliage to many herbivores reflects the generally poor dietary quality of older foliage. For insect herbivores on eucalypts, nitrogenous compounds, water content and leaf toughness (e.g. cellulose and lignin content) are the most important limitations on herbivory (Landsberg & Cork 1997; Peeters 2002, Stone in review). The majority of insect herbivores on eucalypts have a preference for immature foliage (Landsberg & Cork 1997). With respect to sap-sucking insects, White (1993) drew the distinction between senescence feeders (e.g. *Cardiaspina* spp.), and flush feeders (e.g. *Glycaspis* spp.). The former preferentially settle on mature eucalypt foliage and meet their nitrogen requirements from the slow flow of nitrogen leaving senescing leaves and by the secretion of enzymatic salvia which induces a breakdown of the mesophyll tissue, resulting in the liberation of soluble nitrogen at the feeding site (White 1970). The latter select young foliage and intercept the inflow of concentrated nitrogen (as amino acids and proteins).

For some eucalypt species it has been shown that replacement foliage has chemical and physical characteristics more in common with immature leaves than mature foliage. For example, Landsberg (1990a) demonstrated experimentally that dietary quality of regrowth foliage on clipped trees of Blakely's Red Gum was more similar to that of foliage on dieback affected trees. She argued that chronic herbivory associated with rural dieback is at least partly self-perpetuating. Where insect herbivory is a significant process, this is also likely to be the case with forest dieback.

For many deciduous and evergreen tree species, including eucalypts, regrowth foliage is at least as nutritious as the foliage it replaces. If regrowth is especially vigorous, there is potential for a positive feedback between defoliation and subsequent food resources regardless of whether stress or elevated nutrient loads led to the initial outbreak. The defoliation - regrowth - defoliation feedback is common in many tree species with the ability to produce vigorous regrowth foliage. Landsberg and Ohmart (1989) suggested that the term 'resource exploitation' described the relationship, which has been demonstrated for a browsing-re-growth feedback loop between an African psyllid and its host *Acacia* (Webb & Moran 1978). Epidemic increases in psyllid populations followed pruning of the host plant *A. karroo* (Webb & Moran 1978). Resource exploitation by insect herbivores also plays a major role in the dieback of eucalypts in rural Australia (Landsberg & Cork 1997).

While Clay and Majer (2001) found no significant difference in nitrogen levels between healthy and declining trees in their study of a psyllid outbreak in south-western Australia (although they did find significantly higher phosphorus levels in declining than in healthy trees), they suggested that nutrient enrichment of waterbodies may be a causal process by contributing to higher concentrations of nutrients, particularly nitrogen in tree foliage. They further postulated that these elevated concentrations may, in turn, encourage the outbreak of foliage feeding insects such as psyllids. Marsh and Adams (1995), however, did demonstrate that the xylem sap collected from declining trees of *E. tereticornis* was richer in nitrogenous solutes than that from healthy *E. tereticornis*. These authors also suggested that chronic insect infestations and periodic outbreaks may be supported by the high concentrations of nitrogenous solutes in sap and foliage.

Majer and Recher (pers comm., 2005) hypothesized that higher numbers of psyllids and lerp specialist birds in eucalypt forests is related to varying nitrogen levels in the leaves of different tree species, with the trees with highest levels being associated with high psyllid numbers. Majer and Recher (pers comm., 2005) reason that psyllids select trees with high foliar nitrogen levels for the same reasons folivorous arboreal mammals feed selectively on different species of trees. There is a cost in pumping sap through the digestive system and the lower the amount of nitrogen, the greater the amount of sap required. Thus, argue Recher and Majer (pers comm., Jan. 2005), anything process (e.g. soil nutrient levels, salinity, young replacement foliage) that leads to higher foliar nitrogen levels will lead to increased abundances and richness of sap-sucking arthropods.

Phloem feeders such as psyllids obtain their nitrogen nutrition from free amino acids, amides and small polypeptides (Brodbeck & Strong 1987; Stone in review). Hence, assays of total nitrogen do not indicate the nutritional quality for phloem feeders, as total nitrogen also includes compounds of little nutritional value to these insects (Mattson 1980). Localised cellular damage associated with insect feeding, leaf age, environmental stresses and soil nitrogen all influence the soluble nitrogen content of leaves in tree crowns (Adams et al., 1995; Stewart & Larher 1980; Brodbeck & Strong 1987; Stone in review). Many studies have shown that younger leaves have higher free amino acid content than mature leaves (Journet & Cochrane 1978; Adams et al., 1995; Stone in review).

Because most psyllids have several generations in a year (up to six or seven for *Glycaspis baileyi,* Moore 1961), they have the capacity to respond quickly to changes in foliage such as leaf-flushing events (Stone in review). While most eucalypt species have seasonal patterns of new leaf production, many are also opportunistic. Thus, a flush of epicormic growth can be initiated after rapid defoliation from insect outbreaks, drought, fire or frost (e.g. Gill 1997). Increased leaf production can also be induced by increasing light penetration of the canopy. Higher light environments can increase foliar nitrogen because of greater photosynthetic activity (Leuning et al., 1991; Sheriff & Nambier 1991; Stone in review).

The influence of increasing light penetration of tree canopies has been extensively studied in plantation environments (see Stone in review). For example, the thinning of Shining Gum (*E. nitens*) plantations improved sunlight to the lower leaves of tree crowns, resulting in the initiation of more leaves over a greater area of the crown (Medhurst 2000; Pinkard et al., 1998). Several studies have reported the positive response by sap-sucking insects to sunnier sections of tree crowns (e.g. White 1970; Appleton et al., 2003). According to Stone (in review), eucalypt tree crowns responding to increased sunlight in the canopy possess a greater proportion of expanding foliage favourable to psyllids, as well as many leaf chewing insects (Ohmart 1991) compared to similar crowns not exposed to the same light regime. Medhurst (2000) as reported in Stone (in review) demonstrated that the enhanced photosynthesis in the mid and lower sections of the Shining Gum crowns disappeared after canopy closure.

Most herbivorous insects on eucalypts lay their eggs on young expanding foliage (e.g. Steinbauer 1998). Steinbaur et al. (1998) suggested that the availability of expanding leaves (characterized by relatively higher amino acid content and water content and lower specific leaf weight compared to mature leaves) was an important influence upon the oviposition preference of the eucalypt leaf eating beetle, *Chrysophtharta bimaculata*. For species of psyllids that have an oviposition preference for younger foliage (e.g. *Glycaspis* spp.), it remains unclear as to whether they are initially attracted to physiologically-stressed hosts or respond opportunistically to the presence of abundant suitable foliage irrespective of the environmental circumstances resulting in the increased production of quality foliage. The linkage between various forms of environmental stress and resultant increases in concentrations of nitrogenous solutes in eucalypt foliage requires quantification. However, feedback loops may follow the production of expanding foliage, and it is apparent that once a psyllid population has successfully become established in susceptible host crowns, the pattern of defoliation and refoliation will continue to favour the outbreak population until the crown is unable to provide sufficient undamaged foliage for the insects.

Therefore we suggest that good light availability, in addition to high soil moisture and nutrients, enable inherently fast-growing eucalypts to produce (initially) a non-limiting amount of preferred foliage for a large suite of herbivorous insects including psyllids. However, this predisposing situation is not sufficient by itself to trigger elevated populations. The insect populations would need to be 'released' from the regulatory influence of their natural enemy complex. It is possible but untested that any activity which allows more light to penetrate the eucalypt canopy may contribute to the BMAD problem. Therefore, we now turn to discussion of environmental disturbances as potential proximate or ultimate causes of BMAD.

5 Proximal & ultimate factors associated with environmental disturbance

Many forms of disturbance have provided forces of evolutionary significance in Australia prior to European or Aboriginal settlement (Gill 1981; Burrows & Wardell-Johnson 2003; Wardell-Johnson et al., 2004). Abiotic disturbances such as drought, wind and floods, biotic processes (such as herbivory and predation), and interactive processes such as fire have all shaped the Australian biota.

However, the intensity and extent of some of these influences have been considerably exacerbated, and many new forms of disturbance have occurred since European settlement (e.g. Wardell-Johnson & Nichols 1991; Calver & Wardell-Johnson 2004). There is a substantial literature associated with the impacts of changed disturbance regimes on forests in Australia (see Lunney 2004).

Burrows and Wardell-Johnson (2003) argued that the interactions between various agents of disturbance might be of greater importance in nature conservation than the impacts resulting from any particular event. For example, convincing links have been hypothesized between plant disease, introduced species, fire and logging (e.g. Shearer & Tippett 1989; Wardell-Johnson & Nichols 1991; Young 1994; Garkaklis et al., 2004), and between nutrients, birds, fragmentation and rural dieback (e.g. Clarke & Schedvin 1999; Landsberg & Wylie 1991). Numerous authors (e.g. Landsberg & Wylie 1991; Wylie et al., 1993; Stone et al., 1995) have identified insect outbreaks as being associated with feedback loops associated with disturbance in Australian rural and forested landscapes.

There has been a general change and increase in disturbance in north-eastern NSW since European settlement, with further changes associated with agriculture, fire and logging since about 1970 (Flint et al., 2004; Lunney & Matthews 2004; Michelle - Woi Wei Richards pers comm., Feb. 2005). In this section, we review the adequacy of knowledge concerning the relationship between BMAD (and eucalypt dieback in general) and disturbance. We consider each of; land clearing and fragmentation (5.2.1); Logging and associated disturbances (5.2.2); Fire and grazing regimes (5.2.3); Weed establishment (5.2.4): Nutrient changes (5.2.5); Pathogenic factors (5.2.6); and, Hydrological factors (5.2.7), and recognize that these factors interact. They also interact with the various insect associated factors considered in section 4.

5.1 Land clearing and fragmentation

Forest fragmentation for rural and urban purposes is recognised as a major threat to biodiversity (e.g. Saunders et al., 1991; Laurance et al., 1998). Internal fragmentation occurs when natural habitat is subdivided by linear clearings (Goosem 1997), and takes the form of roads, highways, railways, powerline clearings and pipelines. As human populations and expectations expand, greater demands are placed on such facilities, which often traverse areas of otherwise relatively undisturbed natural habitat (Goosem 2004).

There is a long history of land clearing and fragmentation in north-eastern NSW, with lowland rainforests in particular being targeted for conversion to agriculture from about 1860 to the early part of the 20th century (Webb 1956; Kanowski et al., 2003). Lott and Duggin (1993) document the clearing of 99.3% of the 75 000 hectare Big Scrub subtropical rainforest

5 Proximal & ultimate factors associated with environmental disturbance

on the north coast of NSW. Similarly, dense forests of *Eucalyptus*, *Melaleuca* and *Allocasuarina*, and rainforests growing on the alluvial floodplains of coastal rivers were extensively cleared during the 19th and 20th Centuries (Benson 1989). Other forests in regions with high nutrient soils and high rainfall such as the Robertson Plateau on the Southern Tablelands (Benson 1999), northern suburbs of Sydney (Benson and Howell 1990) and coastal settlements such as Coffs Harbour were cleared for agriculture in the early decades of European settlement. Jurskis (2000) highlights the high levels of agricultural clearing of the open grassy woodlands of coastal valleys, tablelands and western slopes. Internal fragmentation through linear clearings and disturbances such as logging is also noteworthy in the forests of north-eastern NSW.

Apart from the loss of habitat, fragmentation (including internal fragmentation) is also associated with edge effects. Edge effects comprise a diverse array of biophysical changes that occur at and near abrupt, artificial margins between natural habitat and clearings. Elevated wind speed and turbulence and increased light penetration at edges result in greater air and soil temperature fluctuations than within the forest interior (Turton and Freiburger 1997). Eucalypt species that have evolve to be competitive in forests with a high leaf area index (e.g. *E. grandis*) might be more susceptible to stress from 'exposure' than natural woodland species such as *E. tereticornis.* Consequently, evaporation increases while relative humidity and soil moisture decrease (Murcia 1995). Higher light levels promote the growth of disturbance-adapted plants such as weeds, pioneer species and woody vines (Laurance 1991: Wardell-Johnson et al., 2005). Changes in species composition due to these habitat alterations may also have consequences for ecological processes such as pollination, dispersal, competition or predation (Murcia 1995: Kanowski et al., 2005).

The profound impacts of fragmentation have been demonstrated locally. For example, interactions of fragmentation with aggressive colonial birds have led to changes in bird composition and diversity (Catterall et al. 2002; Piper & Catterall 2003; Catterall 2004; Chan 2004). In particular, increases in populations of Noisy Miners (a species closely related to Bell miners but with different habitat requirements) have been strongly linked to edge effects (Catterall et al. 2002; Piper & Catterall 2003; Catterall 2004). It should be noted that large forest blocks may act as fragments once changes initiated at edges become more widespread in a forest block (Laurance 1990).

However, there have not been any studies on fragmentation directly associated with BMAD. Michael Clarke (pers comm., Jan. 2005) associates BMAD with habitat fragmentation and does not regard it as being associated with Bell miners in continuous forest. Clarke reaches this conclusion because he has noted that most Bell miner colonies are continually shifting, albeit short distances, something they are not able to do in small remnants. Harry Recher (unpublished data) has reached similar conclusions following observations of Bell miner colonies along the Hawkesbury River and in the Nadgee Nature Reserve on the south coast of NSW. Recher (unpublished data) has only noted tree decline in association with Bell miner colonies where the patches of forest are small and/or fragmented and argues that this restricts the ability of miner colonies to move about. Recher (unpublished data) has also formed the impression that the most affected stands are regenerating from some disturbance, and therefore tend not to be as tall as a mature canopy. Kavanagh and Stanton (2003) provide some evidence to support this view in a study of medium-term impacts of intensive logging in Eden, NSW. Nevertheless, there are situations, including contiguous forest where Bell miners have been known for a long time, and stayed until the death of the overstorey (Steve Rayson pers comm., Feb. 2005). For example, some of the affected forests in the Watagans and Richmond/Border Ranges of north-eastern NSW have been noted to 'ridge jump' by moving up one gully and down into the next (Stone unpublished data).

Flat-topped Yate naturally occurs as isolated stands, being associated with swamp-lands and along water courses in south-coastal Western Australia. Due to extensive clearing of the native woodlands for broad acre agriculture, mainly since 1950, it survives largely as remnant stands on farms, but is also present in reserves and National Parks. Thus, the fragmentation and likely degradation of these remnant stands may have rendered them susceptible to psyllid outbreaks when previously they were not. Farr (pers comm., Dec. 2004) considers that a disruption of natural processes (e.g. reduction in natural enemies, increased nutritional status of the foliage, possibly from agricultural fertilisers) leading to an aging population of Flat-topped Yate with little recruitment is likely to be the primary causes of psyllid outbreaks. The rate of spread of the outbreak is notable in an area without the presence of aggressive, colonial honeyeaters, but where the total avifauna has been considerably reduced (Recher 1993).

Land clearing and fragmentation has led to profound impacts on the biodiversity of southern Australia (Saunders et al., 1991; Hobbs & Saunders 1993), and research by Landsberg and colleagues is instructive on the impacts of fragmentation on rural tree decline. However, studies specifically on the influence of fragmentation on either outbreaks of psyllids or Bell miners have yet to be initiated.

5.2 Logging and associated disturbances

Logging has profound effects on forest biota (e.g. Calver & Wardell-Johnson 2004; Lindenmayer & Gibbons 2004; Wardell-Johnson & Calver 2005) through marked alterations in age and size structure, species composition, understorey density, canopy cover and hydrology. However, logging and its associated activities are usually not the sole, nor the most significant factor in regional biodiversity changes (Braithwaite 2004). Rather, agricultural clearing and introduced species are more significant causes (Wardell-Johnson & Nichols 1991). Nevertheless, logging does leave a legacy of a younger, more open forest canopy and a strikingly different environment to that noted by the first European visitors to the forests (e.g. Calver & Wardell-Johnson 2004). More importantly, the changes associated with a broad-scale native forest timber industry has interacted with other threatening processes such as changed fire regimes, introduced species (Rhind 2004; Wardell-Johnson et al., 2004), and plant disease (Calver & Wardell-Johnson 2004, Garkaklis et al., 2004).

However, the response of forest ecosystems following logging differs from forest type to forest type, as well as the intensity, frequency, method (manual or mechanical) and type (e.g. selective or clear-felling) of logging. Calver and Wardell-Johnson (2004) argue that major biotic changes accompanied a sustained period of logging in Jarrah (*E. marginata*) forests, while Wardell-Johnson et al. (2004) argue that effects were more benign in Karri (*E. diversicolor*) forests; two adjacent eucalypt forest types in south-western Australia which differ in soil nutrients and rainfall. Thus, differences in the biotic composition and abiotic environments in adjacent eucalypt and rainforest environments are likely to lead to profound differences in the impacts of logging in these two environments. These circumstances may also be relevant to BMAD. In this section we review the literature associated with logging impacts directly relevant to BMAD.

There is an extensive literature on logging and the forest biota of north-eastern NSW, including EISs and management plans which refer to particular areas, species and biotic communities. The medium-term studies of the impacts of logging on rainforest of north-eastern NSW that have been carried out using permanent sampling plots (Kariuki & Kooyman in review; Kariuki et al., in review a, b.) are instructive examples. These authors found successional changes in floristics in both the understorey and overstorey 40 years after selection logging. These changes differed with respect to site and logging intensity. However, we are not aware of similar studies in neighbouring eucalypt forests, although these areas have been the subject of logging and associated activities during the period up to and beyond the time of the recognition of BMAD in the region (see Flint et al., 2004).

At sites marginal to rainforest, boundaries between species composition of the overstorey are likely to be continually changing (see Harrington et al., 2001 for documentation of impacts of rainforest boundary changes in north-eastern Queensland). It could be hypothesized that these transitional zones may be equally favourable to each forest type (rainforest and eucalypt forest), with dominance shifting in response to various environmental events or circumstances. Therefore, it is possible that the impacts of logging eucalypt forest will be more pronounced on the margins of rainforests than on sites where the dominant species composition is less transient. We are not aware of any research to test this proposition or the implications resulting from it.

Logging and associated disturbances affects the forest overstorey, midstorey and understorey structure and floristics (e.g. Kanowski et al., 2003; Kariuki et al., in review; a, b). Structural differences between different types of rainforest reforestation (and rainforest reference sites) were correlated with different measures of biodiversity in both subtropical and tropical sites (Kanowski et al., 2003). However, we are not aware of any similar studies in eucalypt forest in the area affected by BMAD. Potential impacts of logging of eucalypt forests include changes in species composition in the regeneration mix, the impacts of soil disturbance by machinery, changing light levels in the overstorey and understorey and changes to the hydrology. All of these effects can have profound impacts on weed invasion (see Kanowski et al., 2003; Wardell-Johnson et al., 2005, section 5.2.4) and fauna (see Kanowski et al., 2005).

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Many, if not all, of the impacts listed above are relevant to BMAD. For example, insect outbreaks are affected by changes in light intensity and leaf phenology (Stone in review). Similarly, a shrubby understorey dominated by Lantana (or any other aggressive plant coloniser of disturbed patches) has been shown to follow disturbance and the opening of forest stands, particularly in the region where Lantana is a widespread and common weed (see Wardell-Johnson et al., 2005). Changes in the fauna following logging have been widely documented (e.g. Gentle & Duggin 1997; Wardell-Johnson et al., 2004; Lunney 2004), including northern NSW (e.g. Lunney & Matthews 2004; Kanowski et al., 2005). Depending on forest type, these changes may not be lasting depending on post-logging management practices (e.g. fire management, thinning of regrowth), frequency and intensity of logging, and climate (e.g. Kavanagh & Stanton 2003).

Foliar nitrogen content has been suggested as an important factor in psyllid outbreaks in eucalypt forests (see Section 4). Therefore any activity or process that increases the levels of foliar nitrogen has the potential to allow expansion of a psyllid outbreak. Bower (1998) noted that his study sites which supported large Bell miner colonies appeared to have been highly disturbed by logging activities, and were often dominated by an almost impenetrable Lantana shrub layer. Bower (1998) argued that the conversion of large areas of mature stable environments to disturbed stands of regrowth causes simplification of the forest structure. Bower (1998) cited Turner and Lambert (1986) and Kutt (1996) to argue that disturbance of logging increases the availability of resources necessary for growth, thus promoting rapid growth of the understorey through utilisation and mobilisation of nutrients. In eucalypt forest, Lantana thickets increase the level of soil organic carbon and nitrogen in the form of nitrate which alters the natural nutrient cycle (Lamb 1980). Bower (1998) argued that it is probable that broad-scale habitat modification through intensive logging operations and subsequent Lantana domination has promoted conditions that favour the establishment of psyllids and Bell miner colonies.

Subtle changes associated with increased light levels in the overstorey due to tree removal may lead to an increase in young, vigorous shoot production, including epicormic shoot production, on the remaining trees (Stone 2005). Selective logging or the non-commercial thinning of stands also releases the remaining trees from stress from tree stand competition (Florence 1996). Much of the lowland forest of northern NSW was logged from the 1920's with steeper country becoming available to logging with the availability of bulldozers after World War 11 (Steve Rayson pers comm., Jan. 2005). Large rainforest tracts in the north-eastern region are restricted to mountain ranges and most have been logged to a greater or lesser degree. The 1980's saw a cessation of the logging of rainforest in the region, and most areas of rainforest are now in conservation reserves where logging is prohibited. However, this was accompanied by an increase in logging activity in adjacent eucalypt forest (Pugh & Flint 1999; Dailan Pugh pers comm., Jan. 2005; Jim Morrison pers comm., Jan 2005).

The 1980's was also a time of an increasing recognition of the commercial value of Brush Box (*Lophostemon confertus*) so that areas on the margins of rainforest (some of which had previously been selectively logged) were the target of more intensive logging operations. It should be noted that the total yield of high quality sawlogs from eucalypt forest in NSW has been reduced by approximately 50% since 1995 (Steve Rayson pers comm., Feb. 2005). Steve Rayson argues that this reduction is largely due to changes in the definition of harvestable area, and to significant tenure change. However, it is also likely that the history of logging has significantly reduced the availability of millable timber (see Pugh & Flint 1999; Flint et al., 2004). If logging history has affected the current or future availability of timber, then this may be a measure of forest disturbance and an indicator of the scale of change preceding and accompanying BMAD.

Turner (1998) in a review of the NSW forest resource and management system (FRAMES) data concluded that sampling errors appear uncomfortably high. Several authors (e.g. Pugh and Flint 1999; Flint et al., 2004) have argued that there has been considerable over allocation of timber and a lack of sensitivity to logging history in yield forecasts in the north-eastern NSW forests. Yield regulation becomes relevant to BMAD if logging (as one form of disturbance) is implicated in the initiation or expansion of the BMAD problem.

Compared to subtle factors such as increased light levels in the overstorey and understorey, the conversion of mixed age forest to regrowth forest following intensive logging represents a major structural change (see Calver & Wardell-Johnson 2004) that also affects hydrological processes in the short to medium term (e.g. Cornish 1993: Cornish & Vertessy 2001; Vertessy et al., 2001). Current quota commitments require relatively rapid return times in many north-eastern forests, leaving them dominated by trees less than 50 years old (see Flint et al., 2004). Although most references in this report have been to regrowth foliage rather than regrowth trees, it can be hypothesized that vegetation dominated by regrowth trees have a higher nutrient content than the same vegetation type dominated by older trees because the crowns are growing more vigorously.

For sites near Toonumbar National Park, Jim Morrison (pers comm., Jan 2005) suggested that the eucalypt dieback started at the eucalypt forest/ rainforest ecotone and spread from there. He argued that these sites had been dominated by tall large-boled eucalypts over a rainforest understorey. Morrison argued that once these eucalypts were removed, an unstable competition between Lantana, rainforest plants and eucalypts resulted. However, it should be noted that eucalypt emergents over rainforests are usually residual following a previous fire or other event. As time since fire lapses, rainforest species colonize the understorey and exclude further regeneration of eucalypts. In time, the eucalypts decline and disappear, with the site eventually becoming 'pure' rainforest (Florence 1996). Similar long-term patterns of vegetative succession occur in a variety of forest types (e.g. North American coniferous forests – Franklin & Hemstrom 1981; Lindenmayer & Franklin 2002).

Michelle -Woo Wei Richards (pers comm., Jan. 2005) regarded intensive logging as a primary issue associated with dieback in north-eastern NSW. She suggested that the controls on Bell miner dieback are removed by the disturbances associated with logging and argued that while Bell miners were always present in small colonies in the

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region, they are attracted by the vegetation that results following the disturbance created by logging. An alternative view emphasized the scrubbing up of the understorey as a response to a lack of fire (e.g. Jurskis & Turner 2002). Although we are aware that these alternative ideas are long-standing, we are not aware of any research to test them.

There have been many publications on logging impacts on the biota of eucalypt forests of north-eastern NSW and elsewhere in Australia (see reviews in Lunney 2004). However, few of these have addressed the BMAD problem. A notable exception was a study by Kavanagh and Stanton (2003) who measured bird abundance and species turnover during the medium term (13 and 22 years) after intensive alternate-coupe logging in a forest area that had been studied previously for short term impacts. They found that the Bell miners colonized regenerating forest that had been intensively logged (clear felled for woodchips) 22 years prior to the study, with increased numbers of the Bell miner on some logged coupes (from a total on all logged coupes of one bird in 1980, to four in 1989, and 46 in 1998). Increases were especially high on the two coupes situated in moist gully forest. During the same period, the total Bell miner counts on the coupes that were not logged were 1, 0 and 3.

Kavanagh and Stanton (2003) argued that their findings supported the hypothesis that the disturbance associated with logging can be a contributing factor in creating the habitat conditions required by Bell miners. Kavanagh and Stanton (2003) found no signs of eucalypt dieback on their study sites. Moreover, recovery had occurred for a large component of the avifauna within 22 years of intensive logging. They argued that increases in the number of species in the unlogged coupes over time as a result of forest regenerating on adjacent logged coupes indicates an effect at a landscape level, as well as at the level of individual coupes.

Despite the increased numbers of Bell miners 22 years following logging, and the presence of controls in Kavanagh and Stanton's (2003) study, Jurskis (2004b) was not convinced by the conclusion that these data supported the hypothesis that logging favours Bell miners and promotes eucalypt decline, and argued that fire management affects both forest health and Bell miner populations. This may be so, but there was no increase in Bell miners immediately following the recovery of the dense understorey within four years following logging) in the study area.. The structural complexity may be an issue here – i.e. the ability of Bell miners to adequately provide nests and defend their fledglings from predators – airborne and ground predators (e.g. goannas). However, there was an increase in other insectivorous birds that inhabit dense understorey vegetation. Hence, results from Kavanagh and Stantons (2003) study may lend support to hypotheses that a dense and structurally diverse understorey excludes Bell miner colonies.

Based on data presented by Kavanagh and Stanton (2003), it is apparent that the development of a dense shrubby understorey will not by itself lead to colonisation by Bell miners. Rather, a shrubby understorey in association with a suitable canopy (for feeding) is apparently necessary. However, the degree of complexity in the understorey favoured by a diverse avifauna has not been determined.

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Although anecdotal data abounds, we are not aware of any research (although see Stone et al., 1995; Bower 1998; Stone in review) that has sought to determine the form of forest structure most favoured by Bell miners.

The extent to which floristic simplification of the understorey through the dominance of Lantana reflects a structural simplification has not been examined in eucalypt forest. However, Stone (1999) suggested that selective logging without effective overstorey regeneration encouraged dense understorey development. She suggested that this provided conditions favouring the colonisation of Bell miners. Stone (1999) argued that Bell miners then trigger forest decline because they interfere with predators that would otherwise regulate folivorous insects. Although there are few cases where birds have been demonstrated to regulate insect numbers, Bell miners are considered the honeyeater extreme (Poiani 1990; see also Section 3.2). However, it is likely that Bell miners would be favoured by changes in the structure of a forest that provides increased food resources coincidentally with increased high quality nesting habitat. Hence, the creation of changes in the overstorey canopy may be sufficient to commence a spiral of dieback in some eucalypt forest sites.

The extent of logging operations (i.e., areas and years logged, volumes predicted and removed) can be ascertained from logging records held by Forests NSW. However, such data may only be approximate at the level of the local management unit (the compartment). Because yield forecasts have been considerably overestimated in north-eastern eucalypt forests (Turner 1998; Pugh & Flint 1999; Flint et al., 2004), future logging operations are likely to be both of reduced intensity, and more frequent because of the amount of timber available to meet contractual quotas to local mills. Hence, logging operations may be both implicated in the development of BMAD, and affected by changes in yield induced by BMAD. Nevertheless, the literature remains very limited concerning the impacts of logging and associated disturbance on the initiation or development of BMAD.

Representation from conservation groups concerning BMAD is associated with concerns regarding the impacts of logging (Dailan Pugh pers comm., Jan 2005; Jim Morrison pers comm., Jan. 2005). Despite differences of opinion in respect to the environmental effects of logging operations in the region, we have not been able to locate information concerning the impacts of logging on BMAD. We find it surprising that more information is not available concerning the direct and indirect impacts of logging, in the preferred Bell miner habitat of north-eastern NSW. The increase in the area of BMAD has potential not only for significant biodiversity loss, but also for significant reduction in timber yields from these eucalypt stands. These changes are likely in the medium-term as growth rates slow, weed species dominate, and species composition changes. Hence, we are concerned that research to test the various links concerning BMAD that can be readily be made from the literature has not been undertaken.

5.3 Fire and grazing regimes

Fire is the most readily available, broad-scale management tool in Australian ecosystems (Gill 1981), but is widely seen as being a destructive agent, a view encouraged by the frequently emotional

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accounts of fires presented by the media. For this reason, fire management is one of the most contentious land management issues in Australia, and a vast literature is available (see reviews by Whelan 1995; Bradstock et al., 2002; Abbott & Burrows 2003). This literature has attracted a greater share of advocacy or statement papers than most other forest management issues, and management decisions are often based on few data. For example, Claridge and Trappe (2004) argued that some land management agencies, which use prescribed fire for hazard reduction or silvicultural purposes, selectively use speculative data about fire effects on hypogeous fungi to further justify the fire regimes they apply. There have been considerable debate concerning the role of fire in Australian ecosystems, and these have been reviewed for various forest ecosystems (e.g. see Burrows & Wardell-Johnson 2003 for south-western forests). In this section we review the literature associated with interactions of fire and BMAD. For the environments in which BMAD occurs, arguments have been presented suggesting a need both for more frequent (e.g. Jurskis 2000, 2002, 2004a,b), and for less frequent fire (e.g. Benson & Redpath 2000; Henderson & Keith 2002).

Jurskis (2004a) in a review based on a study tour of eucalypt decline in temperate Australian forests and woodlands, argued that the reinstatement of more frequent fire regimes would better protect the general health of eucalypt ecosystems. He also argued that research should focus on factors such as fire and grazing systems that can be managed rather than on particular pests that are symptomatic of declines. Jurskis (2000) presented a discussion paper on fire management and forests, and advocated active intervention as a conservative management regime in terms of the pre-European environment (pers comm., Jan. 2005). Jurskis (2004b) also argued that the reduction in fire frequency that accompanied recent forest management coincided with structural and floristic changes in forests, as well as with an apparent decline in the 'health' of many types of eucalypt forest.

Jurskis (2004b) argued that the reduction in fire frequency meant that 'healthy' open forests are being replaced by 'unhealthy forests' with dense understoreys. He further argued for the importance of maintaining the 'health' of open forests, because of their reduction by clearing for agriculture in contrast to less affected dense forests. Several publications (e.g. Jurskis 2000, 2002, 2003, 2004a,b) are advocatory for the increased incidence of fire as a management practice in forests of eastern Australia. These papers are along similar lines to Ward et al. (2001) in suggesting that fire was generally of more frequent occurrence in pre-European landscapes than it is today. However, Jurskis (2004b, pers comm., Jan. 2005) goes further in more generally linking soil environments, micro climates, forest structure, flora and fauna to forest health, and what he regards as the importance of re-establishing fire more frequently in forest ecosystems. In addition, anecdotal evidence was presented to advocate a major change in forest management. The mechanisms for linking these various components were not presented and we are unconvinced by the advocatory use of 'forest health' without explanation or qualification.

Steve Rayson (pers comm., Jan. 2005) argued that many areas of eucalypt forest with a shrubby understorey were once eucalypt forest with a grassy understorey.

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He cited as an example forest typed as dry open-forest type 37, which due to the replacement of the grassy understorey with shrubs would now be typed as wet sclerophyll forest type 36, although both types are dominated by Blackbutt (*E. pilularis*). Steve Rayson argued that a considerable amount of forest is 'scrubbing up' because the understorey is changing from a previously grassy understorey in many, but not all cases. He attributed this change to a change from more, to less frequent burning.

Several authors (e.g. Benson & Redpath 2000; Keith and Henderson 2002, Henderson and Keith 2002; Wardell-Johnson et al., 2004) have argued that the position concerning fire history is complex, and that fire regimes would have differed between vegetation types, location and region. Benson and Redpath (1997) emphasised that at the time of European settlement, there was a wide variety of vegetation types. These would have been associated with a variety of fire regimes – some frequent and some infrequent. Benson and Redpath (1997) challenged what they regarded as simplistic notions and unsubstantiated observations about the composition, structure and fire regimes in pre-European vegetation across south-eastern Australia depicted in Ryan et al. (1995) and Flannery (1994).

Benson and Redpath (1997) argued that Aborigines would have applied a mosaic-burning pattern to some types of vegetation including grasslands and grassy woodlands, but that shrubby forest and woodlands, heaths, inland *Acacia* and chenopod shrublands, alpine woodlands and herb fields were unlikely to have been burnt frequently. Benson and Redpath (2000) also provided only anecdotal data to support their claims, but argued that given that we now have a fragmented landscape where pre-European fire regimes are no more, fire management should be determined by management objectives. Benson and Redpath (2000) argued that burning is a legitimate land management practice irrespective of land tenure, but if the protection of biodiversity is a primary consideration, scientific evidence should underpin imposed and proposed fire regimes.

Henderson and Keith (2002) provided data and an elegant analytical framework to demonstrate that historical grazing and burning practices substantially simplified the woody understoreys of the forests of the north-eastern escarpment of NSW. Grazing and burning disturbance explained substantially more variation in vegetation than environmental (e.g. aspect) and spatial variables combined; species richness and population densities of woody species were lower where disturbance was more intensive. Henderson and Keith (2002) did not consider the herbaceous component of the flora, which may have behaved differently, and which may also have contributed considerable biodiversity to the sites.

Henderson and Keith (2002) considered the question of how changes in disturbance regime might lead to the restoration of forest understoreys. They recognised that the restoration of biodiversity may involve substantial time lags and practical difficulties if the ecosystem has reached a steady state unfavourable for elements of the pre-pastoral biota. They provided the example of how proliferation of grasses as a result of pastoral management may maintain high densities of macropods. They argued that these circumstances may have a continuing impact on shrub regeneration even when cattle are removed from the forest. They foreshadowed experimental manipulation of fire regimes and herbivore populations to shed light on the mechanisms involved in this process.

Other studies (e.g. Lunt 1998) also dealt with successional vegetation change due to changes in fire regimes over 20-30 years. Lunt (1998) advocated increased burning of an *Allocasuarina* community, but from an objective of enhancing local diversity at risk of invasion by fire-sensitive native species, to the detriment of rare species, ecosystem diversity and small mammal habitat. Ecologically oriented management objectives need to be derived from a broad-scale awareness of species ranges and relative abundance, as well as local diversity measures.

We are not aware of any research designed to resolve the issue of forest change or changes in fire regimes in north-eastern NSW. However, we are aware of the existence of data that may be helpful in such resolution. For example, quadrat-based floristic data exists for the region (Binns 1997; Doug Binns pers comm., Jan. 2005; Carmel Flint pers comm., Feb. 2005). A database held by the Department of Environment and Conservation holds over 5000 floristic sites. In addition, there is also a considerable amount of forest silvicultural treatment response data from permanent growth plots (PGPs) established and maintained by Forest NSW (FNSW - Rob Kooyman pers comm., Feb. 2005). These may also provide insight into the influence of fire on some of the plots. In addition, we understand that historical aerial photographic interpretation (API) maps and maps of forest structure derived through the comprehensive regional assessment (CRA) process during the mid 1990's also exist for north-eastern NSW. These maps and aerial photographs may be valuable tools to compare historical and current forest structure. However, claims of a 'scrubbing up' or otherwise of the north-eastern forests have not yet been tested by examination of the available data.

All authors, regardless of their position on the historical frequency of fire in particular vegetation types (or more generally across the landscape), acknowledge the importance of fire in the shaping of the Australian biota, and in continuing ecosystem management. Most authors have however, argued that there is a requirement for a better understanding of pre-European fire regimes and a clearer focus on what society wishes from its forests. The management objectives for the forests will therefore determine the types of fire regimes to be implemented. Defining the desired structure and floristic composition of forested environments is a larger issue than the debate about Bell Miner Associated Dieback. Recent advocacy literature, which provides anecdotal, rather than long-term, site-based survey or experimental evidence, has not contributed to effective resolution or advancement of the debate (see Wardell-Johnson et al., 2004). Despite the quantity of literature on fire, there is in fact relatively little information available that can be used to inform management programs concerning fire.

5.4 Weed establishment

The importance of invasive alien organisms as major agents of land transformation, disrupters of ecosystem functioning and as threats to biodiversity has increased rapidly over the last 200 years, but particularly during the 20th century (Richardson et al., 1997). A small proportion of introduced species is able to invade natural or semi-natural habitats. These are termed environmental weeds (Holzner & Humata 1982). There is a notable presence of several species of environmental weeds in north-eastern NSW. Therefore, in this section we review the information associated with weed establishment and BMAD.

The history of landscape-scale disturbance as well as the management of a site determines the future course of the species-mix of the vegetation of a region (Wardell-Johnson et al., 2005). Because of the long period since initial clearing, and because of the high fertility and rainfall of the general region, areas of north-eastern NSW subject to disturbance have been a haven for introduced plant species. Lantana in particular has become a dominant understorey plant in open areas of eucalypt forest in the region (Bower 1998: Wardell-Johnson et al., 2005). There have been many recent changes in agriculture and forest management in north-eastern NSW that have been associated with the spread and intensification of Lantana in particular, but also a wide range of other weedy species (see Kanowski et al., 2003; Wardell-Johnson et al., 2005). The simplification of the floristics and structure at a landscape-scale can affect the composition of the fauna (Kanowski et al., 2005, Wardell-Johnson et al., 2005).

Increases in light intensity and soil temperature stimulate the germination of Lantana seed and encourage vegetative propagation (Sharma et al., 1988). Under these conditions Lantana can dominate the understorey and suppress regeneration of native plant species. Therefore, as argued by Stone (in review), while Lantana may not be a primary causal factor initiating dieback of Sydney Blue Gum, its presence does seem to contribute to the persistence of this crown syndrome. It is also possible that the presence of Lantana reflects an increased crown opening, which in itself is the primary cause for providing abundant suitable foliage with the potential to support psyllid (and perhaps other insect) outbreaks. Newly founded Bell miner colonies then, benefit from the high supply of food and suitable structure for nesting. Gentle and Duggin (1997) suggested that management strategies to reduce weed encroachment and community degradation must identify and maintain ecological barriers to Lantana invasion to promote biodiversity conservation. However, Lantana is dominant in many locations impacted by BMAD. Because it can thrive in the relatively high light levels beneath a eucalypt canopy, other management strategies may need to be considered once Lantana becomes dominant.

Bower (1998) argued that the proliferation of Lantana in his study areas was largely associated with the disturbance associated with logging activities which improves the conditions for Lantana germination and recruitment. Bower (1998) further argued that while high intensity burns can be effective at controlling Lantana, many post-logging burns are of low to medium intensity and have often been found to be ineffective at controlling Lantana, which resprouts from basal stems. Bower (1998) argued that the inability of Lantana dominated areas to regenerate significantly impacts on the succession of a structurally complex forest ecosystem.

Gentle and Duggin (1997) evaluated the effects of fire and cattle grazing on the initiation of Lantana invasions in dry

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rainforest - open forest ecotones in the gorges of the Macleay River, NSW. This is habitat considered favourable to Bell miners and is also the type of habitat where psyllid outbreaks have been pronounced. They found that shading played a greater role as a limiting factor than any other and concluded that successful invasions of Lantana are likely to occur whenever canopy disturbances create patches of increased light availability. The effects of biomass reduction and soil disturbance associated with fire and cattle grazing are significant in the successful invasion of Lantana. However, there is evidence that rainforest patches can be better protected from the incidence of fire by forest with adjacent grassy understoreys than by forest with shrubby understoreys (see arguments presented by Wardell-Johnson et al., 2004). This is because fire burns at greater intensity in the latter environments.

Bower (1998) argued that Lantana cover had often been implicated as a factor related to dieback where Bell miners occur. Although Lantana cover tended to be higher in Bower's (1998) Bell miner sites, it was not significantly so ($P < 0.07$). Bower (1998) argued that Lantana appeared more prevalent and dense throughout most of his study sites where Bell miners occurred, although Lantana was dominant in some sites where Bell miners did not occur. However, he unexpectedly found that poor understorey foliage cover provided a predictor of Bell miner density. He argued that this finding may have been spurious, given research he cited indicating that the species favours areas with a dense and shrubby understorey that is often dominated by introduced weedy species. Actually, it is also possible that the habitat provided by Lantana in the understorey, while dense, may not be complex, thus disadvantaging those birds requiring a complex understorey structure. However, we are not aware of research which would resolve the issue of Bell miners, Lantana and understorey structure.

Because fire is a widely used and effective landscape management tool, Gentle and Duggin (1997) devoted considerable discussion to fire management in relation to the Lantana problem. They suggested that in the habitats they were considering, controlled low to moderate intensity fires used to prevent more destructive fires appear to increase the risk of successful invasion. They recommended active fire suppression as an effective preventative management strategy for reducing invasions. They also suggested the removal of cattle and feral herbivores from the vicinity of rainforest patches, as disturbances created by these animals will themselves increase the opportunity for Lantana invasion. While they argued for the control of Lantana and suggested a means to do so, no clear link has been drawn concerning the relationship between colonies of Bell miners and the occurrence of Lantana (although see Bower 1998). Stone et al. (1995) concluded that although presence of Lantana was commonly associated with the presence of Bell miners, it was not a linear trend and Bell miners appear to utilize a dense midstorey for nesting sites irrespective of plant species composition (Stone in review). However, she did not determine the degree of complexity in the dense Lantana understorey.

Steve Rayson (pers comm. Jan. 2005) pointed out that it is possible to observe sharp boundaries between dieback affected sites and those free of dieback in north-eastern NSW. In particular, he cited a regrowth stand immediately adjacent Donaldson State Forest, which has a dieback-free site with a grazed understorey that is dominated by introduced grasses. An adjacent previously selectively logged stand with a shrubby understorey is severely affected by dieback. There are many field sites that offer comparisons within the BMAD area. These sites may be useful in the design of a research program, but may be misleading if used in isolation to justify particular management directions. A similar situation relates to various attempts to control BMAD on private land. Two examples relating to weed invasion follow.

Bob O'Neil (pers comm., Jan. 2005) has carried out trials to ameliorate the impacts of eucalypt dieback on his property near the Toonumbar National Park. He clears underneath his forest stand, removes dead trees, converts to grass, grazes cattle and sprays to hold regrowth in check. As a result, the tops of trees that had previously been affected have regained vigour and the Bell miners have moved on. They now congregate in other areas of greater understorey cover nearby. He regards stands of eucalypts that include wattles in the understorey as accentuating the effects of dieback. Such a management regime may be effective in reducing canopy dieback, but could, if implemented more generally, have serious negative consequences for biodiversity conservation. While this example may appear to provide evidence to support a case for burning and grazing to decrease the incidence of BMAD, isolated examples are not a basis for a management strategy. Rather, in combination with contrary examples, they provide a basis for research and adaptive management.

Dailan Pugh (pers comm., Jan. 2005) purchased a property including, and bordering rainforest and ecotonal eucalypt forest in 1980. At this time, Bell miners occupied the lower part of the property. While the Bell miners are still in residence, there have been changes in the structure and composition of the forest. Thus, some patches of eucalypts have developed a dense rainforest understorey and no longer support Bell miners. Other nearby areas, adjacent to a dam have a dense understorey of Lantana and are gradually turning to a dense Lantana thicket as the overstorey declines. Pugh (pers comm., Jan. 2005) attributed some of the difference between recovery from BMAD to the presence of the dam which he suggested leads to a concentration of Bell miners. He has advocated the removal of permanent waterpoints from areas of susceptible habitat as a means of discouraging Bell miners. However, we are not aware of any data or published evidence that indicates that permanent water favours Bell miners.

The interaction between grazing, fire and weeds has major implications for biodiversity, not just an influence on whether or not Bell miners are favoured. For example, the number and diversity of insectivorous birds is reduced in remnant stands of rural dieback affected trees compared with healthy woodland, because of the loss of shrub cover from understoreys exposed to livestock (Ford & Bell 1981; Ford 1985; Loyn 1985; Landsberg et al., 1990). In relatively undisturbed eucalypt forest where the presence of Bell miner colonies is not associated with the dieback of the canopy, the understorey is often relatively diverse (Recher unpublished data). While, it is possible that a diverse understorey which favours a diverse avifauna will be antagonistic to Bell miner colonisation, it is likely that conversion of a diverse understorey to a grassy understorey with few shrubs will also be to the disadvantage of Bell miners. In the presence of high numbers of weeds in the flora, this process is likely to have severe consequences for biodiversity.

Clay and Majer (2001) found an association between the type of groundcover under the trees and the tree condition. Healthy trees occurred in disproportionately large numbers over groundcovers that contained some native species, as opposed to weedy or mown grass groundcovers. They attributed this to more natural groundcovers providing more food and shelter for the (arthropod) predators and parasitoids of foliage feeding insects, and therefore assisting natural control. However, most predators and parasitoids of canopy arthropods are other arthropods residing in the canopy, although use of the litter layer cannot be excluded. It is likely that a more natural ground cover simply reflects a 'healthier' ecosystem overall.

Although Lantana can persist for decades beneath a rainforest canopy (Rob Kooyman pers comm., Feb. 2005), John Hunter (pers comm. Jan. 2005) does not regards it as a long-term rainforest weed (for there it is naturally controlled by canopy closure – Wardell-Johnson et al., 2005), but rather as a weed of ecotonal eucalypt forest. In these situations, it cannot readily be controlled other than by frequent burning which pushes the forest towards a eucalypt forest with a grassy understorey. Thus, it is likely that the absence of fire facilitates the growth of Lantana on eucalypt forest sites near rainforest, particularly after disturbance and the opening of the canopy to light. However, Lantana can also act as a nursery species for the establishment of rainforest species in eucalypt forest at the rainforest edge in the long-term absence of fire (Kooyman 1996). In these situations, an absence of disturbance (particularly fire and grazing) will be necessary to facilitate a return to higher biodiversity values. In other areas, frequent fire may be the only or most appropriate management operation.

Steve Rayson (pers comm., Jan. 2005) is concerned by the demise of high quality wet sclerophyll forest to dieback. He provided the example of a once high quality pole stand of Sydney Blue Gum resulting from forestry operations in the 1960's at Toonumbar that is now dead. This site has a dense understorey of Lantana. John Hunter (pers comm., Jan. 2005) suggested that there were sites in Toonumbar National Park that included healthy forest, that were intermediate in health, and sites with a largely dead overstorey in the early 1990's. He maintained that Lantana dominated the understorey long before the death of the remaining overstorey. These sites had been intensively logged some years previously. While it is no surprise that Lantana proliferates as the eucalypt canopy opens or dies or that Lantana is associated with events which disturb the soil and open the ground to sunlight, this does not mean that Lantana is a cause of BMAD.

It should be noted that, substantial areas of regrowth have appeared on cleared land as a result of the decline in the dairy industry during the 1970's. In former rainforest sites this has been dominated by Camphor Laurel (*Cinnamomun camphora*) and other woody weeds (see Wardell-Johnson et al., 1995). In less fertile sites, stands of regrowth eucalypts such as Spotted Gum, often in association with an understorey dominated by Lantana have become prominent.

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Bower (1998) argued that, while the influence of vegetation structure in providing habitat for Bell miners is not completely understood, he nevertheless advocated controlling Lantana to disrupt Bell miner colonies and to stimulate a more complex native flora. He argued for removal of Lantana thickets to initiate, release and facilitate the natural regenerative processes to promote the establishment of structurally complex mid and lower strata. However, to prevent reinvasion of a site by Lantana requires the establishment of a dense shade producing canopy by undertaking a regular and systematic follow-up maintenance program (Kooyman 1996). Hence the management of Lantana requires a more integrated solution than simply relying on a change in the fire regime.

5.5 Nutrient and other soil factors

There is a considerable literature associated with forest soils and their influence on floristic composition. We do not review this literature in its totality, but note that several papers have linked nutrients and forest health, areas relevant to BMAD.

Jurskis and Turner (2002) proposed a model of eucalypt dieback that they regarded as accounting for both rural and forest dieback, including a broad range of susceptible species and sites. This model associated eucalypt dieback with increased soil moisture and nitrogen status that stresses the roots of established eucalypt trees. However, under these conditions some eucalypt species can grow well over 30 m^3 ha^{-1} mean annual increment (MAI), and are definitely not unhealthy (e.g. most eucalypt plantations in which species are selected for their inherent rapid growth -, most having a requirement for a high resource environment). They argued that these changes affect the physiology of the trees and encourage high rates of folivory and/or fungal pathogenicity. They argued that such a model can encompass dieback from a diverse array of sources including dryland salinity, high-altitude dieback in Tasmania, Bell miner dieback, Koala dieback, phasmatid outbreaks and possibly regrowth dieback in Tasmania. They argued that the reduced application of low-intensity fire is a common agent of changed soil conditions and that additional factors that may apply are fertilisers and modifications to runoff and soil drainage.

Jurskis and Turner (2002) suggested that exclusion of low-intensity fire from forests that evolved with fire leads to their progressive decline and that any massive disturbance by wildfire is unlikely to regenerate these eucalypt forests because insufficient seed is available and the weakened trees are less able to resprout. Jurskis and Turner (2002) argued that intensive disturbance such as clearing and plantation establishment would be required to re-establish eucalypt ecosystems on sites where 'mesic' dieback is well advanced. Jurskis and Turner (2002) did not present any data to allow the validation or testing of the model that they presented, but suggested that validation of changed processes in forest soils and litter, as well as physiological changes in trees, on dieback sites compared to healthy sites would confirm the model. They also proposed that monitoring of tree health after cutting and burning understorey vegetation in mesic dieback areas on the NSW coast could be used to test the model.

Stone (in review) has attempted to test the model presented by Jurskis and Turner (2002) by linking dieback, leaf

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and soil properties. Stone (in review) used a survey approach to compare leaf, tree and soil properties associated with moist sclerophyll forest exhibiting canopy dieback in Cumberland State Forest at West Pennant Hills, NSW. She carried out detailed measures on six 20 m radius plots and found that the plot permanently colonised by Bell miners also had Sydney Blue Gum in the poorest condition. While no consistent relationship of stand condition with either Lantana or the soil pathogen *Phytophthora cinnamomi* could be found, there were significant correlations among foliar traits of insect damage, free amino acid content and relative chlorophyll content. While this study has limited numbers of sample sites, Stone (in review) demonstrated that models, such as that presented by Jurskis and Turner (2002), can be tested.

Stone (in review) referred to research on soil nitrogen mineralisation concerning the interaction of site condition and available nitrogen. Mineralisation of organic nitrogen and organic phosphorus in forest soils is mediated by soil micro-organisms which in turn are directly influenced by soil moisture content and temperature. Adams and Attiwill (1986) suggested that soil nitrification is likely to occur for forest soils with low C/N ratios (< 15). These authors argued that in moist sclerophyll forests the establishment of a dense mesophytic understorey after disturbance also contributes to lowering the C/N ratio and nitrogen turnover, and thus maintain soil conditions favourable for nitrification. High nitrate/ammonium ratios in the soil may result in elevated levels of free amino acid content in eucalypt foliage (Adams & Atkinson 1991) .

Conversely, the dominant form of inorganic nitrogen in many Australian eucalypt forests is ammonium (Adams & Attiwill 1986). In these situations the soils commonly have a C/N ratio in the range 15-30. Many eucalypt species obtain their nitrogen as ammonium through associations with myccorrhizae (Adams & Attiwill 1982). Numerous studies have demonstrated that concentration of ammonium in the topsoil can be promoted by fire (e.g. Polglase et al., 1986; Weston & Attiwill 1990; Neave & Raison 1999). However, the effect is only temporary due to the rapid immobilisation of ammonium by soil microfauna (Adams & Attiwill 1986; Weston & Attiwill 1990).

Thus, argued Stone (in review) opportunities for ammonium assimilating eucalypt species are provided immediately after a fire providing that other site factors such as adequate soil moisture, sunlight and viable seed are also available (e.g. King 1985; Nicholson 1999). Frequent low-intensity fires would result in replacing a mesic understorey with fire-tolerant species producing litter of higher C/N ratios (e.g. Guinto et al., 2001) and reduced soil moisture (e.g. York 1999). Stone (in review) suggested that these soil conditions would promote the ammonifying heterotrophic component of the soil microflora and reduce the activity of the nitrifying autotrophs, thereby providing a competitive advantage to eucalypt species that assimilate ammonium. Reducing the tendency towards nitrification may provide a mechanism for facilitating the dominance by eucalypts in frequently burnt sites that are otherwise suitable to eucalypts and rainforest.

There is a vast literature on nutrients and plant growth and also considerable literature exploring forms of nitrogen in soils and vegetation. For example, there have been many studies that have demonstrated changes nitrogen mineralisation associated with forest management activities (e.g. Adams & Attiwill 1982). There have also been studies that have demonstrated that some herbivorous insect species can respond to changes in foliar nutrition as a consequence of silvicultural practices (Waring et al. 1992). However, with the exception of a pilot study by Stone (in review), we are not aware of any studies that have attempted to resolve the interactions between forest management, soil nitrogen content, foliar nutrition, insect populations and Bell miners, either through field-based research, or experimentally.

The literature associated with nutrients in relation to BMAD is at best equivocal and will continue to attract controversy. Of particular importance is the relative weight that should be given to nutrient-related issues, floristics and structure in the BMAD problem. We suggest that research associated with gross physical forest structure will be more enlightening for the management of the BMAD problem than research on more subtle processes. We argue that gross physical structure influences many interrelated forest processes (including nutrients and other chemical constituents) that have bearing on the BMAD problem.

5.6 Pathological factors

Soil pathogens have considerable influence on the health of forest stands. Many pathogens have become widespread through the transport of soil in road building, mining, logging operations and fire control, and continue to spread and intensify (e.g. Garkaklis et al., 2004). Bushwalking and other activities responsible for limited soil movements have also been implicated in the spread of pathogens (Garkaklis et al., 2004). The impacts of the introduced plant pathogen *Phytophthora cinnamomi* on Australian forest flora are considered significant on a global scale (Brian Shearer pers comm., Nov. 2004). A recent review (Garkaklis et al., 2004) argued that some impacts on forest fauna have been noted, and the potential threats to fauna through structural and floristic changes are likely to be pronounced. *Phytophthora cinnamomi* is now widespread in a variety of vegetation communities in the more humid areas of all Australian States (not the Northern Territory).

Edgar et al. (1976) noted the widespread occurrence, symptoms and impact of a dieback disease in selectively logged mixed forests of central Victoria, and the presence of *Armillaria* fungus associated with dead or dying trees. They suggested that disease development was associated with selective cutting in pole stage or mature stands, but not associated with site or other silvicultural factors. They suggested that drought stress may have influenced disease development in some areas.

Various pathogens, such as species of *Phytophthora*, *Armillaria*, *Pythium*, and *Fusarium*, have been sampled from stands of Sydney Blue Gum affected by psyllid associated dieback in NSW, as well as from areas of healthy forest (Stone et al., 1995). In addition, wood-boring insects (e.g. termites, hepialid and cossid moths, longicorn beetle larvae) are also commonly found in the stems of eucalypts with crown dieback (Stone et al., 1995), suggesting that once canopy dieback has commenced, many other interacting factors facilitate canopy decline. There has not been any study to separate the affects of various factors in the development of canopy dieback. The incidence and impacts of *Phytophthora*, which was once considered a serious problem largely in south-western Australia and Tasmania, are now more widely recognised in south-eastern Australia. Any activity which increases soil movement or soil disturbance has the potential to increase the impact of soil borne pathogens on a forest stand. A healthy and diverse community may be the best insurance against attack from potential insect pests and fungal pathogens.

Clarke & Schedvin (1999) noted that conclusions concerning the impacts of Bell miners in their study in Victoria were compromised by the presence of *Phytophthora* in their study sites. *Phytophthora cinnamomi* was detected in five of the six of Stone's (in review) Bell miner sites but the presence of this soil pathogen was not well correlated to crown condition of *E.saligna*. Thus, it is likely that *Phytophthora* and other pathogens are more common and widespread than generally believed. There has been no study of the impacts of disease or interactions of disease and other agents of disturbance hypothesised to be associated with BMAD. This is despite convincing links having been shown between plant disease, introduced species, fire and logging elsewhere (e.g. Shearer & Tippett 1989; Wardell-Johnson & Nichols 1991; Young 1994; Garkaklis et al., 2004).

5.7 Hydrological factors

There is evidence that total evapotranspiration in regrowth forests exceed that in old growth forests or forests dominated by older trees. This, in turn results in reductions in water yields from regrowth forests (e.g. Cornish 1993: Cornish & Vertessy 2001; Vertessy et al., 2001). Carmel Flint (pers comm., Feb. 2005) argued that a 'regrowth-induced drought' may affect the concentration of foliar nutrients (i.e., resulting in increased concentrations due to decreased water availability, or alternatively resulting in increased environmental stress). While these hypotheses may seem relevant to the BMAD problem, we are not aware of any research directly associated with regrowth forests, BMAD and hydrological factors.

It has been increasingly recognised that pathogen related problems are closely linked with hydrology. Many forms of disturbance including road-building, mining and logging can have implications for the hydrology of a site. Davison (1997) suggested that death of Jarrah trees in south-western Australia attributed to pathogenic invasion may actually have been due to waterlogging. Jarrah dieback has occurred on sites not infected by *Phytophthora*, and silvicultural practices in combination with site topography and soil profile characteristics may lead to reduced interception of rainfall and reduced evapotranspiration. This ultimately causes increased incidence and severity of waterlogging in occasional wet years and the loss of jarrah on wetter sites. Davison (1997) stated that such deaths are likely to become more frequent with more intensive forest management and the reduction of mean basal areas of trees.

The issue of changes in hydrology has not been investigated with respect to BMAD, although some concern has been expressed by high densities of regeneration in the north-eastern forests of NSW (Florence 1996; Carmel Flint pers comm., Feb. 2005; Jim Morrison pers comm., Jan. 2005).

Morrison and Flint argue that regeneration uses more water at a site than mature forest, causing soil moisture drought (as opposed to climatic drought). Indeed young regrowth does use more water than mature stands (see references cited earlier), leading to a policy of thinning regrowth stands of Jarrah in some of Perth's (WA) water catchment areas as a means to promote water production. While the period of increased water use by regrowth may vary with species and site, catchments covered with old growth stands of Mountain Ash used almost twice the amount of water annually as those with regrowth stands of age 25 years. Hence the period over which regrowth reduces water yield may be relevant to the stress of stands. However, we are not aware of research designed to test this hypothesis. As these ideas have been around for some time, we are concerned by the lack of literature specifically addressing BMAD, forest structure and growth at the stand level.

5.8 Conclusion

There is a vast literature relevant to disturbance and BMAD, although relatively little directly illuminating the various debates that surround it. The evidence from linking several fields suggests that management practices which create habitats with a structure and floristic composition favouring the establishment of Bell miner colonies are more likely to favour the establishment of psyllid outbreaks, and vice versa. In such situations, colonisation by Bell miners will lead to the exclusion of other avian insectivores, resulting in an increase in the numbers of psyllids. However, the generally poor understanding of the geographic distribution of BMAD prevents the disentangling of alternative hypotheses.

There is a need to investigate the structure and floristics of the habitat favoured by Bell miners, regardless as to whether they are the proximal or ultimate causes of a eucalypt forest dieback problem. It may be appropriate for management to prevent the creation of habitat that is preferred by the Bell miner, as such habitat will also facilitate the primary cause of eucalypt dieback. However, to attempt such management intervention in isolation from an understanding of both the processes and the behaviour of Bell miners under different levels of disturbance may compound the problem.

6 Synthesis

BMAD is a nationally significant conservation problem that has the potential to reduce the chances of achieving sustainable forest management in north-eastern NSW. There is a strong likelihood for significant biodiversity loss in the medium future in the region, as well as reduced available timber volumes. Blaming Bell miners for the problem will not lead to its resolution.

There are serious deficiencies in the information base for most issues concerning BMAD. Despite the activity of talented researchers, research has not yet targeted solutions for the BMAD problem. While the literature has demonstrated a clear interaction between Bell miners and psyllids, there are many other, less well quantified interactions that may be of greater significance to the development of the problem. It is suggested that management and research efforts towards solutions should urgently target disturbances that lead to changes in forest canopy structure.

There is likely to be no single or simple management solution. In managing forests, it is necessary to recognise that there is a complexity of connections and interactions, many of which have yet to be deciphered. Because BMAD is associated with interacting disturbances, concentration on particular management regimes in isolation is unlikely to resolve the BMAD problem. Rather, an integrated management program will be necessary.

7 References

Abbott, I. & Burrows, N. (eds.) (2003). *Fire in Ecosystems of South-West Western Australia: Impacts and Management.* Backhuys Publishers, Leyden.

Adams M. A. & Atkinson P. I. (1991). Nitrogen supply and insect herbivory in eucalypts: the role of nitrogen assimilation and transport processes. In: *Productivity in Perspective. Proceedings Third Australian Forest Soils and Nutrition Conference* (ed. P. J. Ryan) pp. 67-75. Forestry Commission of NSW, Sydney.

Adams M. A. & Attiwill P. M. (1982). Nitrogen mineralization and nitrate reduction in forests. *Soil Biology and Biochemistry* **14**: 197-202.

Adams M. A. & Attiwill P. M. (1984). Role of Acacia spp. in nutrient balance and cycling in regenerating Eucalyptus regnans F. Muell. Forests I. Temporal changes in biomass and nutrient content. *Australian Journal of Botany* **32**: 205-215.

Adams M. A. & Attiwill P. M. (1986). Nutrient cycling and nitrogen mineralization in eucalypt forests of south-eastern Australia. II Indices of nitrogen mineralization. *Plant Soil* **92**: 341-362.

Adams, M. A., Attiwill, P. M. & Wang, L. M. (1995). Effects of phosphorous supply on growth and nitrogenous fractions in xylem sap and foliage of Eucalyptus regnans (F.Muell.), E. nitens (Maiden) and *E. globulus* (Labill.) seedlings: implications for herbivory. *Trees* **9**: 324-331.

Appleton, C., Gresham, B. A. & Zydenbos, S. M. (2003). Monitoring Essigella californica populations in Bay of Plenty forests. *New Zealand Plant Protection*. **56**: 45-50.

Bamber, R. K. & Humphreys, F. R. (1965). Variations in sapwood starch levels in some Australian forest species. *Australian Forestry* **29**: 15-23.

Barrett, G. (2003). *The New Atlas of Australian Birds.* Royal Australasian Ornithologists Union, Hawthorne East.

Baur, G. N. (1962). Silvicultural practices in rainforests of Northern New South Wales. *Forestry Commission of NSW Research Note No. 9.*

Benson, D. H. & Howell, J. (1990). *Taken for granted: the bushland of Sydney and its suburbs.* Kangaroo Press, Kenthurst.

Benson, J. S. (1999). Establishing priorities for the conservation of rare or threatened plants and plant associations in New South Wales. In: *The conservation of threatened species and their habitats* (eds M. Hicks and P. Eiser) pp 17-82. Australian Committee for IUCN, Canberra.

Benson, J. S., Redpath, P. A. (1997). The nature of pre-European native vegetation in Australia: A critique of Ryan, D. G., Ryan, J. R. and Starr, B.J. (1995). Australian Landscape: Observations of Explorers and Early Settlers. *Cunninghamia* **5**: 285-328.

Benson, J. S., Redpath, P. A. (2000). 1. Vegetation and fire. Response to V. Jurskis in Volume 63(3). *Australian Forestry* **64(1)**: 64-65.

Bernays, E. A. & Chapman, R. F. (1994). *Host-Plant Selection by Phytophagous Insects*, first edition. Chapman & Hall, London.

7 References

Billyard, R. (2004). BMAD Working Group perspective on forest decline and potential management solutions. In: *Fundamental causes of eucalypt forest decline and possible management solutions* (eds White, T.C.R. & Jurskis, V) pp 31-32. Proceedings of colloquium, November 18-19, 2003, Batemans Bay, NSW. State Forests of NSW.

Binns, D. L. (1995). Flora survey Urbanville Management Area Northern Region, N.S.W. Research Division, State Forests of New South Wales, Sydney.

Binns, D. L. (1997). Floristics and vegetation patterns of Coolah Tops, New South Wales. *Cunninghamia* **5(1)**: 233-274.

Birks, H. J. B. & Birks, H. H. (2004). The rise and fall of forests. *Science* **305:** 484-485.

Bower, H. (1998). *For Whom the Bell Tolls: interactions between Bell miners, eucalypt dieback and bird communities in North-east NSW*. Honours Thesis, Southern Cross University, Lismore, NSW.

Bradstock, R. A., Williams, J. E. & Gill, A. M. (eds.) (2002). *Flammable Australia*. Cambridge University Press, Cambridge.

Braithwaite, W. (2004). Do current forestry practices threaten forest fauna? A perspective. In (Ed. D. Lunney) *Conservation of Australia's Forest Fauna*, Royal Zoological Society of New South Wales, Mosman. pp 513-536.

Braithwaite, L. W., Dudzinski, M. L. & Turner, J. (1983). Studies of the arboreal marsupial fauna of eucalypt forests being harvested for woodchip at Eden, New South Wales. 11 Relationship between the fauna density, richness and diversity, and measured variables of the habitat. *Australian Wildlife Research* **10**: 231-47.

Brodbeck, B. & Strong, D. (1987). Amino acid nutrition of herbivorous insects and stress to host plants. In: *Insect Outbreaks* (eds P. Barbosa & J.C. Schultz) pp. 347-363. Academic Press Inc., San Diego.

Burrows, N. & Wardell-Johnson, G. (2004). *Implementing fire mosaics to enhance ecosystem health and prevent large wildfires*. AFAC Conference, Perth October 2004.

Burrows, N. & Wardell-Johnson, G. W. (2003). Fire and plant interactions in forested ecosystems of south-west Australia; a review. In: *Fire in ecosystems of south-west Western Australia: impacts and management* (eds I. Abbott and N. Burrows) pp 225-268 Backhuys Publishers, Leiden, The Netherlands.

Burrows, N., Liddelow, G., Green, D., Bain, K., Middleton, E., Freebury, G. & Shedley, E. (2003). *Fire-induced habitat mosaics in south-west landscapes: The fire Mosaic Project*. Unpublished Report, Science Division, Department of Conservation and Land Management, Western Australia, Perth.

Calver, M. & Wardell-Johnson, G. (2004). Sustained unsustainability? An evaluation of evidence for a history of overcutting in the jarrah forests of Western Australia and its consequences for fauna conservation. In: (Ed. D. Lunney) *Conservation of Australia's Forest Fauna*, Royal Zoological Society of New South Wales, Mosman. pp 94-114.

Campbell, K. G. & Moore, K. M. (1957). An investigation of the food of the bell miner *Manorina melanophrys* Latham. *Proceedings of the Zoological Society of New South Wales* 1955-56: 72-73.

7 References

Campbell, K. G. (1992). The biology and population ecology of two species of *Cardiaspina* (Hemiptera: Psyllidae) in plague numbers on *Eucalyptus grandis* in New South Wales. *Proceedings of the Linnean Society of New South Wales* **113**: 135-150.

Carnegie, A. J. & Angel, P. (2005) *Creiis lituratus* (Froggatt) (Hemiptera: Psyllidae): a new insect pest of *Eucalyptus dunnii* plantations in sub-tropical Australia. *Australian Forestry* **68:** 58-63.

Carter, R. N. & Prince, S. D. (1989). Distribution limits from a demographic viewpoint. In: *Plant population ecology 28th Symposium of the British Ecological Society* (ed. J. Davy, M. J. Hutchings and A. R. Watkinson) pp 165-84. Blackwell Scientific Publications, Oxford.

Catterall, C.P., 2004. Birds, garden plots and suburban bushlots: where good intentions meet unexpected outcomes. In: *Urban Wildlife: more than meets the eye* (eds Lunney, D., Burgin, S.) pp. 21-31. Royal Zoological Society of New South Wales, Mosman, NSW.

Catterall, C.P., Piper, S.D. & Goodall, K. (2002). Noisy miner irruptions associated with land use by humans in south-east Queensland: causes, effects and management implications. In: *Landscape Health in Queensland* (eds. A. Franks, J. Playford, A. Shapcott) pp 117-127. Royal Society of Queensland, Brisbane.

Chan, K. (2004). Effect of patch size and bird aggression on bird species richness: a community-based project in tropical/subtropical eucalypt woodland. *Proceedings of the Royal Society of Queensland* **111**: 1-11.

Claridge, A. W. & Trappe, J. M. (2004). Managing habitat for mycophagous (fungus-feeding) mammals: a burning issue? In: *Conservation of Australia's Forest Fauna* (ed. D. Lunney) pp 936- 946. Royal Zoological Society of New South Wales, Mosman.

Clark, L. R. (1964). Predation of birds in relation to the population density of *Cardiaspina albitextura* (Psyllidae). *Australian Journal of Zoology* 18: 427-437.

Clark, L. R. & Dallwitz, M. J. (1975). The life system of *Cardiaspina albitextura* (Psyllidae), 1950-1974. *Australian Journal of Zoology* **23**: 523-61.

Clarke, M. F. & Fitz Gerald, G. F. (1994). Spatial-Organization of the Cooperatively Breeding Bell Miner *Manorina melanophrys*. *Emu* **94**: 96-105.

Clarke, M. F. & Schedvin, N. (1999). Removal of bell miners *Manorina melanophrys* from Eucalyptus radiata forest and its effect on avian diversity, psyllids and tree health. *Biological Conservation* **88**: 111-120.

Clay, R. & Majer, J. (2001). Flooded Gum (*Eucalyptus rudis*) decline in the Perth Metropolitan Area: a preliminary Assessment. *School of Environmental Biology, Bulletin No. 19*, Curtin University of Technology. 50 pp.

Collett, N. (2001). Biology and control of psyllids, and the possible causes for defoliation of *Eucalyptus camaldulensis* Dehn. (river red gum) in south-eastern Australia – a review. *Australian Forestry* **64**: 88-95.

Coops, N. C., Stone C., Culvenor D. S. & Chisholm L. (2004). Assessment of crown condition in eucalypt vegetation by remotely sensed optical indices. *Journal of Environmental Quality* **33**: 956-964.

7 References

Coops, N. C., Stone C., Culvenor D. S., Chisholm L. A. & Merton R. N. (2003). Chlorophyll content in eucalypt vegetation at the leaf and canopy scales as derived from high resolution spectral data. *Tree Physiology* **23**: 23-31.

Cornish, P. M. (1993). The effects of logging and forest regeneration on water yields in a moist eucalypt forest in NSW. *Journal of Hydrology* **150**: 301-322.

Cornish, P. M. & Vertessy, R. A. (2001). Forest age-induced changes in evapotranspiration and water yield in a eucalypt forest. *Journal of Hydrology* **242**: 43-63.

Davison, E. M. (1997). Are jarrah (*Eucalyptus marginata*) trees killed by *Phytopthora cinnamomi* or waterlogging? *Australian Forestry* **60 (2)**: 116-124.

Ellis, R. C. (1985) The relationships among eucalypt forest, grassland and rainforest in a highland area in north-eastern Tasmania. *Australian Journal of Ecology* **10**: 297-314.

Ellis, R. C., Mount, A. B. & Mattay, J. P. (1980). Recovery of *Eucalyptus delegatensis* from high altitude dieback after felling and burning the understorey. *Australian Forestry* **43**: 29-35.

Ewen, J. G., Crozier, R. H., Cassey, P., Ward-Smith, T., Painter, J. N., Robertson, R. J., Jones, D. A. & Clarke, M. F. (2003). Facultative control of offspring sex in the cooperatively breeding bell miner, *Manorina melanophrys*. *Behavioral Ecology* **14**: 157-164.

Farr, J. (1992). Lerps, Bugs and Gum-leaves. *Landscope* **8(1)**: 50-53.

Farr, J. (1999). Flat-topped Yate – What is rural tree decline? *Western Wildlife* **3 (3):** 3-4.

Farr, J. D. & Dick, S. G. (IN REVIEW). Biology of *Cardiaspina jerramungae* (Hemiptera: psyllidae) on *Eucalyptus occidentalis* in the lower Great Southern of Western Australia. *Austral Ecology*.

Fensham R. J. (1994). Phytophagous Insect Woody Sprout Interactions in Tropical Eucalypt Forest .1. Insect Herbivory. *Australian Journal of Ecology* **19**: 178-188.

Fensham, R. J. & Bowman, D. M. J. S. (1995). A comparison of foliar nutrient concentrations in trees from monsoon rainforest and savanna in northern Australia. *Australian Journal of Ecology* **20**: 335-9.

Finlay-Doney, M. & Walter, G. H. (IN PRESS). Discrimination among host plants (*Leucaena* species and accessions) by the psyllid pest *Heteropsylla cubana* and implications for understanding resistance. *Austral Ecology*.

Finlay-Doney, M. (2004). *Discrimination between Leucaena host plants by the psyllid pest Heteropsylla cubana and implications for understanding resistance*. Seminar text.

Fitt, G. P. (1986). The influence of a shortage of hosts on the specificity of oviposition behaviour in species of *Dacus* (Diptera: Tephritidae). *Physiological Entomology* **11**: 133-143.

Flannery, T. (1994). *The Future Eaters.* Reed books, Melbourne.

Flint, C., Pugh, D. & Beaver, D. (2004). The good, the bad and the ugly: science, process and politics in forestry reform and the implications for conservation of forest fauna in north-east New South Wales. In: *Conservation of Australia's Forest Fauna* (Ed. D. Lunney), pp 222- 255. Royal Zoological Society of New South Wales, Mosman.

Florence, R. (2004) *Dieback in eucalypt forests: a personal perspective*. Unpublished report.

7 References

Floyd, A. G. (1990). *Australian rainforests in New South Wales*. Surrey Beatty and Sons, Sydney. Vol 1, 136 pp. Vol 2, 180 pp.

Ford, H. A. & Bell, H. (1981). Density of Birds in Eucalypt Woodland Affected to Varying Degrees by Dieback. *Emu* **81**: 202-208.

Ford, H. A. (1985). The bird community in eucalypt woodland and eucalypt dieback in the northern tablelands of New South Wales. In: *Birds of Eucalypt forests and woodlands: ecology, conservation and management* (eds A. Keast, H. F. Recher, H. Ford & D. Saunders) pp. 333-340. Surrey Beatty & Sons and the Royal Australasian Ornithologists Union, Sydney.

Forestry Commission of NSW (1984). *Management plan for Murwillumbah Management Area*. Forestry Commission of NSW, Sydney.

Franklin, J. F. & Hemstrom, M. A. (1981). Aspects of succession in the coniferous forests of the Pacific Northwest. In: *Forest succession; concepts and application* (ed. D. C. West, H. H. Shugart & D. B. Botkin) pp 212-229. Springer-Verlag, New York.

Garkaklis, M. J., Calver, M. C., Wilson, B. A. & Hardy, G. E. St. J. (2004). Habitat alteration caused by introduced plant disease: a significant threat to the conservation of Australian forest fauna. In: *Conservation of Australia's forest fauna 2nd edition* (ed D. Lunney) pp. 899-913. Royal Zoological Society of New South Wales, Mosman.

Gentle, C. B. & Duggin, J. A. (1997). *Lantana camara* L. invasions in dry rainforest-open forest ecotones: the role of disturbances associated with fire and cattle grazing. *Australian Journal of Ecology* **22**: 298-306.

Gill A. M. (1997). Eucalypts and fires: interdependent or independent? In: *Eucalypt ecology: individuals to ecosystems* (eds J.E. Williams & J. C. Z. Woinarski) pp.151-167. Cambridge University Press, Cambridge.

Gill, A. M. (1981). Adaptive responses of Australian vascular plant species to fire. In: *Fire and the Australian Biota* (eds A. M. Gill, R. H. Groves and I. Noble) pp 243-272. Australian Academy of Science, Canberra.

Goosem, M. (1997).Internal fragmentation: the effects of roads, highways and powerline clearings on movements and mortality of rainforest vertebrates. In: *Tropical Forest Remnants: Ecology, Management and Conservation of Fragmented Communities* (eds W. F Laurance & R. O. Bierregaard, Jr.) pp 241-255. University of Chicago Press: Chicago.

Goosem, M. (2004). Linear infrastructure in the tropical rainforests of far north Queensland: mitigating impacts on fauna of roads and powerline clearings. In: *Conservation of Australia's Forest Fauna* (ed. D. Lunney),pp 418-434. Royal Zoological Society of New South Wales, Mosman.

Grey, M. J, Clarke M. F. & Loyn R. H. (1997). Initial changes in the avian communities of remnant eucalypt woodlands following a reduction in the abundance of noisy miners, *Manorina melanocephala*. *Wildlife Research* **24**: 631-648.

Grey, M. J, Clarke M. F. & Loyn, R. H. (1998). Influence of Noisy Miner on avian diversity and abundance in remnant Grey Box woodland. *Pacific Conservation Biology* **4**: 55-69.

Grime, J. P, (1977). Evidence for the existance of three primary strategies in plants and its relevance to ecological and evolutionary theory. *American Naturalist* **111**: 1169-94.

7 References

Groves, R. H., Austin, M. P. & Kaye, P. E. (2003). Competition between Australian native and introduced grasses along a nutrient gradient. *Austral Ecology* **28(5)**: 491-498.

Guinto, D. F., Zu, Z. H., House, A.P.N. & P. G. Saffigna (2001). Soil chemical properties and forest floor nutrients under repeated prescribed-burning in eucalypt forests of south-east Queensland, Australia. *New Zealand Journal of Forestry Science* **31(2)**: 170-187.

Hammack, L. (2001). Single and blended maize volatiles as attractants for diabroticite corn rootworm beetles. *Journal of Chemical Ecology* **27**: 1373-1390.

Harrington, G. N., Freeman, A. N. D. & Crome, F. H. J. (2001). The effect of fragmentation of an Australian tropical rainforest on populations and assemblages of small mammals. *Journal of tropical Ecology* **17**: 225-240.

Heatwole, H. & Lowman, M. (1986). *Dieback: Death of an Australian Landscape*. Reed, Frenchs Forest NSW.

Henderson, M. K. & Keith, D. A. (2002). Correlation of burning and grazing indicators with composition of woody understorey flora of dells in a temperate eucalypt forest. *Austral Ecology* **27(2)**: 121-131.

Hengveld, R. & Haeck, J. (1982). The distribution of abundance 1. measurements. *Journal of Biogeography* **9**: 303-16.

Hobbs, R. J. & Saunders, D. J. (1993). Effects of landscape fragmentation in agricultural areas. In: *Conservation Biology in Australia and Oceania* (eds C. Moritz & J. Kikkawa) pp 77-95. Surrey Beatty & Sons, Chipping Norton.

Hodges, J.D. & Lorio, P.L. (1975) Moisture stress and composition of xylem oleoresin in loblolly pine. *Forest Science* **21**: 283-290.

Holzner, W. & Humata, N. (Eds) (1982). Biology and control of Weeds. *The Hague: Junk*.

Hopkin, W.G. (1999) *Introduction to Plant Physiology. 2nd Edition* John Wiley & Sons, Inc., New York.

Inderjit, Dakshini, K. M. & Foy, C. L., eds (1999). Principles and practices in plant ecology. *Allelochemical interactions, first edition*, pp. 589. CRC Press LLC, Florida, USA.

Journet, A. R. P. & Cochrane P. M. (1978). Free amino acids in leaf tissue of Eucalyptus blakelyi. *Phytochemistry* **17**: 1789-1790.

Jurskis, V. (2000). Vegetation changes since European settlement of Australia: an attempt to clear up some burning issues. *Australian Forestry* **63(3)**: 166-173.

Jurskis, V. (2002). Restoring the prepastoral condition. *Austral Ecology* **27(6)**: 689-690.

Jurskis, V. (2003). Assessing the ecological implications of prescribed burning: where do you start? In: *Conference Proceedings 3rd International Wildland Fire Conference and Exhibition*. Sydney.

Jurskis, V. (2004a). Observations of eucalypt decline in temperate Australian forests and woodlands. *2004 Gottstein Fellowship Report*, unpublished.

Jurskis, V. (2004b). The role of changed fire regimes in the apparent decline of eucalypts in temperate Australia. In: *11th Annual AFAC Conference and Inaugural Bushfire CRC Conference*. 7-9 October 2004. Perth, Western Australia.

7 References

Jurskis, V. & Turner, J. (2002). Eucalypt dieback in eastern Australia: a simple model. *Australian Forestry* **65 (2)**: 87-98.

Kanowski, J., Catterall, C.P., Wardell-Johnson, G.W., Proctor, H. & Reis, T. (2003). Development of forest structure on cleared rainforest land in eastern Australia under different styles of reforestation. *Forest Ecology and Management* **183**:265-280.

Kariuki, M. & Kooyman, R. M. (in review). Floristic changes and regeneration patterns for a 12 year period during the 3th and 4th decades following selection logging in a subtropical rainforest. *Austral Ecology*.

Kariuki, M. R. M. Kooyman, G. Smith, G**.** Wardell-Johnson & J. K. Vanclay. (IN REVIEW). Chronological ecological recovery pattern and trends of change in response to disturbance in subtropical rainforests north-east New South Wales, Australia. *Austral Ecology.*

Kariuki, M., Kooyman, R., Wardell-Johnson, G. & Vanclay, J.K. (IN REVIEW). Long-term changes in floristic patterns following logging vary with site and logging intensity in subtropical rainforests. *Austral Ecology*.

Kavanagh, R. P. & Stanton M. A. (2003). Bird population recovery 22 years after intensive logging near Eden, New South Wales. *Emu* **103**: 221-231.

Keith, D. A. & Henderson, M. K. (2002). Restoring the prepastoral condition: Response to Jurskis. *Austral Ecology* **27(6)**: 691-693.

King, G. C. (1985). Natural regeneration in wet sclerophyll forest with an overstorey of *Eucalyptus microcorys*, *E. saligna*, and *Lophostemon confertus*. *Australian Forestry* **48:** 54-62.

Kooyman, R. M. (1996). Growing rainforest: Rainforest Restoration and regeneration. Recommendations for the humid sub-tropical region of northern NSW and southeast Qld. *Greening Australia and State Forests of NSW*.

Kutt, A. S. (1996). Bird population density in thinned, unthinned and old lowland regrowth forest, East Gippsland, Victoria. *Emu* **96**: 280-284.

Lamb, D. (1980). Soil nitrogen mineralisation in a secondary rainforest succession. *Oecologia* **47**: 257-263.

Lamb, D., Keenan, R. & Gould, K., (2001). Historical background to plantation development in the tropics: a north Queensland case study. In: *Sustainable Farm Forestry in the Tropics* (eds Harrison, S.R., Herbohn, J.L) pp. 9-20. Edward Elgar, Cheltenham.

Lambert, M. J. & Turner, J. (1983). Soil nutrient-vegetation relationships in the Eden area, N.S.W.. 111. Foliage nutrient relationships with particular reference to *Eucalyptus* subgenera. *Australian Forestry* **46**: 200-209.

Landsberg, J. (1990a). Dieback of Rural Eucalypts - Does Insect Herbivory Relate to Dietary Quality of Tree Foliage. *Australian Journal of Ecology* **15:** 73-87.

Landsberg, J. (1990b). Dieback of Rural Eucalypts - the Effect of Stress on the Nutritional Quality of Foliage. *Australian Journal of Ecology* **15**: 97-107.

Landsberg, J. & Gillieson D. S. (1995). Regional and Local Variation in Insect Herbivory, Vegetation and Soils of Eucalypt Associations in Contrasted Landscape Positions Along a Climatic Gradient. *Australian Journal of Ecology* **20**: 299-315.

7 References

Landsberg, J. & Ohmart C. (1989). Levels of Insect Defoliation in Forests - Patterns and Concepts. *Trends in Ecology & Evolution* **4**: 96-100.

Landsberg, J. & Wylie, F.R. (1983). Water Stress, Leaf Nutrients and Defoliation: a Model of Dieback of Rural Eucalypts. *Australian Journal of Ecology* **8**: 27-41.

Landsberg, J. & Wylie, F.R. (1988). Dieback of rural trees in Australia. *GeoJournal* **17**: 231-237.

Landsberg, J. Morse, J. & Khanna, P. (1990). Tree dieback and insect dynamics in remnants of native woodlands on farms. *Proceedings of the Ecological Society of Australia* **16**: 149–165.

Landsberg, J. & Cork, S. J. (1997). Herbivory: Interactions between eucalypts and the vertebrates and invertebrates that feed on them. In: *Eucalypt Ecology: Individuals to Ecosystems* (eds Williams, J. & Woinarski, J.) pp. 342-372. Cambridge Univ. Press, Cambridge.

Landsberg, J. & Wylie, F. R. (1991). A revew of rural dieback in Australia. In: *Growback '91'* pp. 3-11. Growback Publications and Greening Australia, Melbourne.

Larsson, S. (1989). Stressful times for the plant stress – insect performance hypothesis. *Oikos* **56**: 277-82.

Laurance, W. F. (1990). Comparative responses of five arboreal marsupials to tropical forest fragmentation. *Journal of Mammalogy* **71**: 641-653.

Laurance, W. F. (1991). Edge effects in tropical forest fragments: application of a model for the design of nature reserves. *Biological Conservation* **57**: 205-219.

Laurance, W. E., Ferreira, L. V., Rankine-de Merona, J. M. & Laurance, S. G. (1998). Rain forest fragmentation and the dynamics of Amazonian tree communities. *Ecology* **79**: 2032-2044.

Leuning, R., Cromer R.N. & Rance S. (1991). Spatial distributions of foliar nitrogen and phosphorus in crowns of *Eucalyptus grandis*. *Oecologia* **88,** 504-510.

Lindenmayer, D. & Franklin, J. (2003). *Conserving forest Biodiversity: a Comprehensive Multiscaled Approach*. Island Press, Washington.

Lindenmayer, D. & Gibbons, P. (2004). On charcoal, the increased intensity of logging and a flawed Environmental Impact process. In: *Conservation of Australia's Forest Fauna* (ed. D. Lunney) pp 56-62.Royal Zoological Society of New South Wales, Mosman.

Lott, R. H. & Duggin, J. A. (1993). Conservation significance and long-term viability of sub-tropical remnants of the Big Scrub, north-eastern New South Wales. *Report to Australian Heritage Commission and Department of Planning* (NEP 90/36) (Department of Ecosystem Management: University of New England).

Lowman, M. D. & Heatwole H. (1992). Spatial and Temporal Variability in Defoliation of Australian Eucalypts. *Ecology* **73**: 129-142.

Loyn, R. H. (1985). Bird Populations in Successional Forests of Mountain Ash Eucalyptus-Regnans in Central Victoria. *Emu* **85**: 213-230.

Loyn, R. H., Runnalls R. G., Forward G. Y. & Tyers J. (1983). Territorial Bell Miners and Other Birds Affecting Populations of Insect Prey. *Science* **221:** 1411-1413.

7 References

Lunney, D - editor (2004). *Conservation of Australia's Forest Fauna*, The Royal Zoological Society of New South Wales, Mosman, New South Wales.

Lunney, D. & Matthews, A. (2004). Conserving the forest mammals of New South Wales. In: *Conservation of Australia's Forest Fauna* (second edition ed. D. Lunney) pp 988-1021 Royal Zoological Society of New South Wales, Mosman, NSW.

Lunt, I.D. (1998). Two hundred years of land use and vegetation change in a remnant coastal woodland in southern Australia. *Australian Journal of Botany* **46:** 629-647.

Majer, J.D. & Recher, H.F. (1988) Invertebrate communities on Western Australian communities: A comparison of branch clipping and chemical knockdown procedures. *Australian Journal of Ecology* **13**: 269-279.

Majer, J. D., Recher, H. F. & Ganeshanandam, S. (1992). Variation in the foliar nutrients and its relation to arthropod communities on Eucalyptus trees in eastern and Western Australia. *Australian Journal of Ecology* **17**: 383-394.

Majer, J. D., Recher, H. F., Perriman, W. S. & Achuthan, N. (1989). Spatial variation of invertebrate abundance within the canopies of Australian eucalypt forests. *Studies in Avian Biology* **13**: 65-72.

Majer, J.D., Recher, H.F., Wellington, A.B., Woinarski, J.C.Z. & Yen, A.L. (1997) Invertebrates of eucalypt formations. In: *Eucalypt Ecology: Individuals to Ecosystems* (eds Williams, J and Woinarski, J.) pp 278-302. Cambridge University Press, Cambridge.

Margules, C. R., Nicholls, A. O., Austin, M. P. (1987). Diversity of *Eucalyptus* Species Predicted by a Multi-Variable Environmental Gradient. *Oecologia* **71(2)**: 229-232.

Marsh, N.R. & Adams M.A. (1995) Decline of *Eucalyptus tereticornis* near Bairnsdale, Victoria: Insect herbivory and nitrogen fractions in sap and foliage. *Australian Journal of Botany* **43**: 39-50.

Mattson, W. (1980). Herbivory in relation to plant nitrogen content. *Annual Review of Ecology and Systematics* **11:** 119-161.

Mattson, W. J. & Haack, R. A. (1987). The role of drought in outbreaks of plant-eating insects. *BioScience* **37**: 110-18.

McDonald, W. J., Young, P. A. & Watson, M. A. (1998). Distribution and status of the rainforest communities of south-east Queensland. In: *Rainforest Recovery for the New Millenium* (ed. Boyes, B.) pp. 28-66. World Wildlife Fund, Sydney.

Medhurst, J. L. (2000). *Growth and physiology of Eucalyptus nitens in plantations following thinning*. PhD Thesis. School of Plant Science, University of Tasmania.

Metcalf, R.L. (1987) Plant volatiles as insect attractants. *Critical Review in Plant Sciences* **5**: 251-301.

Moore, K. M. (1961). Observations on some Australian forest insects. 8. The biology and occurrence of *Glycaspis baileyi* Moore in New South Wales. *Proceedings of the Linnean Society of NSW* **86(2)**: 185-200.

Morgan, F. D. & Taylor, G. S. (1988). The white lace lerp in southeastern Australia. In: *Dynamics of forest insect populations* (ed. A. A. Berryman) pp 129-139. Plenum Publishing Corporation.

7 References

Morgan, F. D. (1984). *Psylloideae of South Austrralia*. Government Printer, South Australia.

Murcia, C. (1995). Edge effects in fragmented forests: implications for conservation. *Trends in Ecology and Evolution* **10**: 58-62.

Neave, I. A. & Raison R. J. (1999), Soil nitrogen availability under forests of contrasting composition and structure in south eastern New South Wales, and the effects of simulated harvesting disturbance and fire. *Australian Forestry* **62:** 1-8.

Nicholson, E. (1999). Winds of change for silvicultural practice in NSW native forests. *Australian Forestry* **62:** 223-235.

Ohmart, C.P. (1991). Role of food quality in the population dynamics of chrysomelid beetles feeding on *Eucalyptus*. *Forest Ecology.and Management*. **39:** 35-46.

Paton, D. C. (1980). The importance of manna, honeydew and lerp in the diet of honeyeaters. *Emu* **80**: 213-226.

Painter, R. H. (1951). *Insect Resistance in Crop Plants*, first edn. Macmillan, New York.

Peeters, P.J. (2002) Correlations between leaf constituent levels and the densities of herbivorous insect guilds in an Australian forest. *Austral Ecology* **27:** 658-671.

Pinkard, E. A., Beadle C. L., Davidson N. J. & Battaglia M. (1998) Photosynthetic responses of *Eucalyptus nitens* (Deane and Maiden) Maiden to green pruning. *Trees* **12:** 119-129.

Piper, S. D. &, Catterall C. P. (2003). A particular case and a general pattern: hyperaggressive behaviour by one species may mediate avifaunal decreases in fragmented Australian forests. *Oikos* **101**: 602-614.

Pizzey, G. &, Knight, F. (2003). *The Field Guide to the Birds of Australia.* Seventh Edition. Harper Collins, Sydney.

Poiani, A., Rogers, A., Rogers, K. & Rogers, D. (1990). Asymmetrical Competition between the Bell Miner (*Manorina melanophrys*, Meliphagidae) and Other Honeyeaters - Evidence from Southeastern Victoria, Australia. *Oecologia* **85**: 250-256.

Polglase, P. J., Attiwill P. M. & Adams M. A. (1986). Immobilization of soil nitrogen following wildfire in two eucalypt forests of south-eastern Australia. *Acta Oecologia* **7:** 261-271.

Price, P. W. (1991). The plant vigor hypothesis and herbivore attack. *Oikos* **62**: 244-51.

Price, P. W. (1992). Plant resources as the mechanistic basis for insect herbivore population dynamics. In: *Effects of resource Distribution on Animal-Plant Interactions* (eds M. D. Hunter, T. Ohgushi and P. W. Price) pp 139-73. (Academic Press: San Diego).

Price, P. W., Cobb, N., Craig, T. P., Fernandes, G. W., Itami, J. K., Mopper, S. & Prezzler, R. W. (1990). Insect herbivore population dynamics on tree and shrubs: new approaches relevant to latent and eruptive species and life table development. In: *Insect-Plant Interactions*. Vol. 2 (ed. E. A. Bernays) pp 1-38. (CRC Press: Boca Raton).

Pugh, D. & Flint, C. (1999). *The Magic Pudding, the 'cut –an-come-again' forests, a preliminary appraisal of State Forests' Forest Resource and Management System (FRAMES)*. Unpublished report for the North East Forest Alliance. 174 pp.

7 References

Recher, H. F. (1993). The loss of biological diversity and landscape restoration: conservation, management, survival: an Australian perspective. In: *Nature Conservation 3: Reconstruction of fragmented Ecosystems* (eds D. A. Saunders, R. J. Hobbs and P. R. Ehrlich) pp 141-151. Surrey Beatty & Sons, Chipping Norton.

Recher, H. F. & Majer, J. D. (IN PRESS). Effects of bird predation on canopy arthropods in wandoo *Eucalyptus wandoo* woodland. *Austral Ecology*.

Recher, H. F. & Majer, J. D. (1994). On the selection of tree species by Acanthizid warblers in open-forest near Sydney, New South Wales. *Emu* **94:** 239-45.

Recher, H. F., Kavanagh, R. P., Shields, J. M. & Lind, P. (1991a). Ecological association of habitats and bird species during the breeding season in southeastern New South Wales. *Australian Journal of Ecology* **16**: 337-52.

Recher, H. F., Majer, J. & Ford, H. A. (1991b). Temporal and spatial variation in the abundance of eucalypt canopy invertebrates: the response of forest birds. *Proceedings of the International Ornithology Congress.* **20**: 1568-75.

Recher, H. F., Majer, J. D., & Ganeshanandam, S. (1996). Birds, insects and eucalypts, On the relation between foliar nutrients and species richness. *Forest Ecology and Management* **85**: 177-96.

Rhind, S. G. (2004). Direct impacts of logging and forest management on the brush-tailed Phascogale *Phascogale tapoatafa* and other arboreal marsupials in a jarrah forest of Western Australia. In (Ed. D. Lunney) *Conservation of Australia's Forest Fauna*, Royal Zoological Society of New South Wales, Mosman. pp 639 - 655.

Richardson, D. M., Macdonald, L. A. W., Hoffmann, J. H. & Henderson, L. (1997). Alien Plant Invasions. In: *Vegetation of Southern Africa* (eds Cowling, R. M., Richardson, D. M. & Pierce, S. M.) pp 535-570. Cambridge University Press, Cambridge.

Ryan, D. G., Ryan, J .E. & Starr, B. J. (1995). *The Australian landscape – observations of explorers and early settlers* (Murrumbidgee Catchment Management Committee: Wagga Wagga NSW).

Saunders, D. A., Hobbs, R. J. & Margules, C. R. (1991). Biological consequences of ecosystem fragmentation. *Conservation Biology* **5**: 18-32.

Sharma, O. P., Makkar H. P. S. & Dawra R. K. (1988). A review of the noxious plant *Lantana camara*. *Toxicon* **26:** 975-987.

Shearer, B. L. & Tippett, J. T. (1989). Jarrah dieback: The dynamics and management of *Phytophthora cinnamomi* in the Jarrah (*Eucalyptus marginata*) forest of south-western Australia. *Research Bulletin No 3*, Department of Conservation and Land Management, Perth, Western Australia.

Sheriff, D. W. & Nambier E. K. S. (1991). Nitrogen nutrition, growth and gas exchange in *Eucalyptus globulus* Labill. Seedlings. *Australian Journal of Plant Physiology* **22:** 1015-1026.

Smith, I. W. (2004). Overview of dieback and decline in Victoria. NSW Forest Health Advisory Committee (2004) In *Fundamental causes of eucalypt forest decline and possible management solutions, Proceedings of colloquium*, November 18-19, 2003, Batemans Bay, NSW. (eds White, T. C. R &, Jurskis, V.) pp. 8-10. State Forests of NSW.

7 References

Steinbauer, M.J., Clarke, A.R. & Madden, J.L. (1998) Oviposition preference of a Eucalyptus herbivore and the importance of leaf age on interspecific host choice. *Ecological Entomology* **23**: 201-206.

Steinbauer, M. J. (2001). The ecology, research and management implications of insect-eucalypt interactions: Symposium introduction. *Austral Ecology* **26**: 445-446.

Stewart, G. R. & Larher F. (1980). Accumulation of amino acids and related compounds in relation to environmental stress. In: *The Biochemistry of Plants vol. 5* (ed. B.J. Miflin) pp. 609-635. Academic Press, Inc., New York.

Stone, C. (1996). The role of psyllids (Hemiptera: Psyllidae) and bell miners (*Manorina melanophrys*) in canopy dieback of Sydney blue gum (*Eucalyptus saligna* Sm). *Australian Journal of Ecology* **21:** 450-458.

Stone, C. (2001). Reducing the impact of insect herbivory in eucalypt plantations through management of extrinsic influences on tree vigour. *Austral Ecology* **26**: 482-488.

Stone, C. & Coops, N.C. (2004). Assessment and monitoring of damage from insects in Australian eucalypt forests and commercial plantations. *Australian Journal of Entomology* **43**: 283-292.

Stone, C. (1999). Assessment and monitoring of decline and dieback of forest eucalypts in relation to ecologically sustainable forest management: a review with case study. *Australian Forestry* **62:** 51-58.

Stone, C. (2005). Bell miner associated dieback at the tree crown scale: A multitrophic process. *Australian Forestry* (Dec 2005).

Stone, C. (in review). Comparison of leaf, tree and soil properties associated with *Eucalyptus saligna* in a moist sclerophyll forest exhibiting canopy dieback. *Cunninghamia.*

Stone, C., Spolc, D & Urquhart, C.A. (1995). Survey of Crown Dieback in Moist Hardwood Forests in the Central and Northern Regions of NSW State Forests (Psyllid/Bell miner Research Programme). *Research Paper No. 28. Research Division, State Forests of NSW*. Sydney.

Stone, C., Simpson, J.A. & Eldridge R.H. (1997) Insect and fungal damage of young eucalypt trial plantings in northern New South Wales. *Australian Forestry* **61**: 7-20.

Stone, C., Simpson, J.A. & Gittins R. (1998) Differential impact of insect herbivores and fungal pathogens on the *Eucalyptus* subgenera Monocalyptus and Symphyomyrtus and genus *Corymbia*. *Australia Journal of Botany* **46**: 723-734.

Stone, C., Wardlaw, T., Floyd, R., Carnegie, A., Wylie, R. & de Little, D. (2003). Harmonisation of methods for the assessment and reporting of forest health in Australia - a starting point. *Australian Forestry* **66(4):** 233-246.

Taylor, G. S. (1997). Effect of plant compounds on the population dynamics of the lerp insect, *Cardiaspina albitextura* Taylor (Psylloidea: Spondyliaspidae) on Eucalypts. Pp 37-57 In: *Ecology and evolution of plant-feeding insects in natural and man-made environments* (ed. A. Raman), International Scientific Publications, New Delhi.

Turner, J., Kelly, J. & Newman, L. A. (1978). Soil nutrient-vegetation relationships in the Eden area 11. Vegetation-soil associations. *Australian Forestry* **41**: 223-231.

7 References

Turner, B. (1998). *Review of the FRAMES data for the Upper North East and Lower North East RFA Regions of NSW*. Unpublished consultants report for State Forests of NSW and Bureau of Rural Sciences Commonwealth DPIE.

Turton, S. M. & Freiburger, H. J. (1997). Edge and aspect effects on the microclimate of a small tropical forest remnant on the Atherton Tableland, Northeastern Australia. In: *Tropical Forest Remnants: Ecology, Management and Conservation of Fragmented Communities* (eds W. F Laurance & R. O. Bierregaard, Jr.) pp 45-54. University of Chicago Press: Chicago.

Vertessy, R.A., Watson, F.G.R. & O'Sullivan, S.K. (2001). Factors determining relations between stand age and catchment water balance in Mountain Ash forests. *Forest Ecology & Management* **143**: 13-26.

Ward D. J., Lamont B. B. & Burrows C. L. (2001). Grasstrees reveal contrasting fire regimes in eucalypt forest before and after European settlement of southwestern Australia. *Forest Ecology and Management* **150**: 323-329.

Wardell-Johnson G. & Burrows N. (2004). Towards fire management for a conservation culture: innovations for protecting biodiversity assets in the Tingle Mosaic, south-western Australia. In: *Bushfires in a changing world*, Sydney.

Wardell-Johnson, G. and Calver, M. (2005). Toward sustainable management: southern Africa's Afromontane, and Western Australia's jarrah forests. In: *Towards a Forest Consciencesness* (eds Calver, M. C., Bigler-Cole, H., Bolton, G.C. Gaynor, A., Horwitz, P. Mills, J., Wardell-Johnson G.W.) pp 729-39. Millpress, Rotterdam.

Wardell-Johnson, G. & Lynch, A. J. J. (2005). Landscape processes and eucalypt dieback associated with Bell Miner habitat in south-eastern Australia. *Australian Forestry* (Dec 2005).

Wardell-Johnson, G. & Nichols, O. (1991). Forest wildlife and habitat management in southwestern Australia: knowledge, research and direction. In: *Conservation of Australias forest fauna* (ed. D. Lunney) pp 161-192 The Royal Zoological Society of New South Wales, Mosman, New South Wales.

Wardell-Johnson, G. & Williams, M. (1996). A floristic survey of the Tingle Mosaic, south-western Australia. *Journal of the Royal Society of Western Australia.* **79**: 249-276.

Wardell-Johnson, G. W. Kanowski, J. Catterall, C. P. McKenna, S. Piper, S. & Lamb, D. 2005 (In Press). Chapter 11. Rainforest timber plantations and the restoration of plant biodiversity in tropical and subtropical Australia. In: *Reforestation in the tropics and sub-tropics of Australia using rainforest tree species* (eds Erskine, P.D., Lamb, D. and Bristow, M.) pp 162-182. Rural Industries Research and Development Corporation, Canberra, and the Rainforest CRC, Cairns.

Wardell-Johnson, G., Calver, M., Saunders, D., Conroy, S. & Jones, B. (2004). Why the integration of demographic and site-based studies of disturbance is essential for the conservation of jarrah forest fauna. In: *Conservation of Australia's Forest Fauna* (ed. D. Lunney) pp 394- 417. Royal Zoological Society of New South Wales, Mosman.

Wardell-Johnson, G, Stone, C., Recher, H. & Lynch, A. J. J. (2005). A review of eucalypt dieback associated with Bell Miner habitat in south-eastern Australia. *Australian Forestry* (Dec 2005).

7 References

Wardell-Johnson, G., Williams, J., Hill, K. & Cummings, R. (1997). Evolutionary biogeography and contemporary distribution of eucalypts. In: *Eucalypt Ecology: Individuals to Ecosystems* (eds Williams, J. & Woinowski, J.) pp 92-128. Cambridge University Press.

Wardell-Johnson, G. W., Williams, M., Mellican, A, & Annells, A**.** (2004). Floristic patterns and disturbance history in karri forest, south-western Australia: 1. Environment and species richness. *Forest Ecology and Management* **199**: 449-460.

Wardle, D. A., Walker, L. R. & Bardgett, R. D. (2004). Ecosystem properties and forest decline in contrasting long term chronosequences. *Science* **305**: 509-513.

Watt A. D. (1997). The relevance of the stress hypothesis to insects feeding on tree foliage. In: *Individuals, Populations and Patterns in Ecology* (eds. Leather, S.R., Watt, A.D., Mills, N.J. & Walters) pp. K.F.A. Intercept Press, Hamsphire, U.K.

Waring R. H., Savage, T., Cromack, & Rose, C. (1992) Thinning and nitrogen fertilization in a grand fir stand infested with western spruce budworm. Part IV: An ecosystem management perspective. *Forest Science* **38**: 275-286.

Webb, J. W. & Moran, V. C. (1978). The influence of the host plant on the population dynamics of *Acizzia rusellae* (Homoptera: Psyllidae). *Ecological Entomology* **3**: 313-21.

Webb, L. J., (1956). The rape of the forests. In: *The Great Extermination. A Guide to Anglo-Australian Stupidity, Wickedness and Waste* (ed. Marshall A.J..) pp. 156-205. Heinemann, London.

Weston, C .J. & Attiwill P. M. (1990). Effect of fire and harvesting on nitrogen transformations and ionic mobility in soils of *Eucalyptus regnans* forests of south-eastern Australia. *Oecologia* **83:** 20-26.

Whelan, R. (1995). *The Ecology of Fire*. Cambridge University Press, Cambridge.

White, T. C. R. (1969). An index to measure weather-induced stress of trees associated with outbreaks of psyllids in Australia. *Ecology* **50**: 905-9.

White, T. C. R. (1970) Some aspects of the life history, host selection, dispersal, and oviposition of adult *Cardiaspina densitexta* (Homoptera: Psyllidae). *Australian Journal of Zoology* **18:** 105-117.

White, T. C. R. (1984). The abundance of invertebrate herbivores in relation to the availability of nitrogen in stressed food plants. *Oecologia* **63B**: 90-105.

White, T. C. R. (1993). *The Inadequate Environment: Nitrogen and the Abundance of Animals.* Springer-Verlag, Berlin.

White, T. C. R. (2003). *Report on visit to South east forests Eden Management Area, 10-13 February, 2003*. Unpublished report.

Williams, J. B. & Nadolny, C. (1981). A survey of eucalypt species involved in New England dieback. In: *Eucalypt Dieback in Forests and Woodlands* (eds K. M. Old, G. A. Kie and C. P. Ohmart) pp 74-86. CSIRO: Melbourne.

Woinarski, J. C. Z., Recher, H. F. & Majer, J. D. (1997). Vertebrates of eucalypt formations. In: *Eucalypt Ecology: Individuals to Ecosystems* (eds Williams, J. and Woinowski, J.) pp 303-341 Cambridge University Press.

7 References

Wylie, F. R., Johnston, P. J. M. & Eisemann, R. L. (1993). A survey of native tree dieback in Queensland. *Research paper (Queensland. Forest Service); no. 16. Queensland Department of Primary Industries, Forest Service.* Brisbane.

York, A. (1999). Long-term effects of frequent low-intensity burning on the abundance of litter-dwelling invertebrates in coastal blackbutt forests of southeastern Australia. *Journal of Insect Conservation* **3:** 191-199.

Young, J. T. (1994). The future – effects of plant disease on society. *Journal of the Royal Society of Western Australia* **77**: 185-186.

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