Rural Dieback in Australia and Subsequent Landscape Amelioration

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1 Introduction

"It's a Truffula Seed.
It's the last one of all!
You're in charge of the last of the Truffula seeds.
And Truffula trees are what everyone needs.
Plant a new Truffula. Treat it with care.
Give it clean water. And feed it fresh air.
Grow a forest. Protect it from axes that hack.
Then the Lorax
and all of his friends
may come back."
The Lorax, Dr. Seuss 1971 (Boston, MA: Random House)

The dieback syndrome in the New England district of Australia is considered to be one of the most severe tree declines worldwide (Heatwole and Lowman 1986; Mueller-Dombois 1990/91; Fig. 1). Over the last 100 years, dramatic alterations in land use and agricultural practices have resulted in a landscape devoid of living trees, and also devoid of seedlings. Australian rural holdings in the New England district were initially cleared in the late 1800s for purposes of sheep and cattle grazing. The cool winters and dry, warm summers made it ideal for the production of fine-wool Merino sheep. For obvious economic reasons, land owners aimed to maximize the number of sheep per acre, and the landscape underwent dramatic alterations: extensive tree clearing, application of fertilizers to the soil, plowing, and planting of non-native grasses. These changes led to biological imbalances in the numbers of trees, insects, birds, and subsequently of herbivores in relation to their host plants.

During the 1970s, farmers became alarmed at the lack of tree cover on their pastures. They raised funds to support research by scientists to determine the causes of New England dieback. This generous donation of money from the private rural sector gave the dieback crisis heightened media coverage, and served to generate interest in tree regeneration throughout Australia. Today, Australia has a national program aimed at planting 1 billion trees by the mid-1990s, an ambitious goal, but necessary to replace those trees lost to clearing or to the dieback syndrome.

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Huettl/Mueller-Dombois (Eds.).
Forest Decline in the Atlantic and Pacific Region

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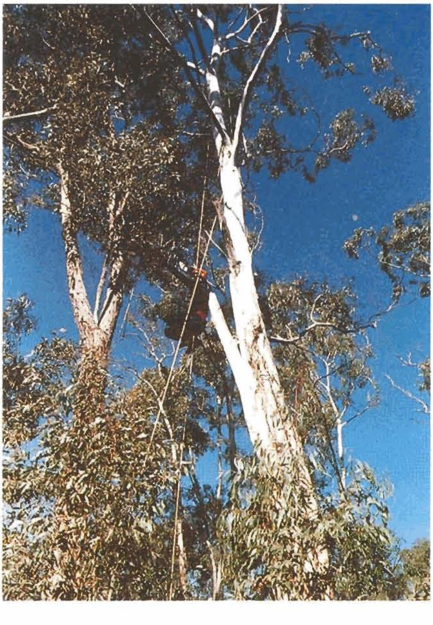

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Fig. 1. Eucalypt dieback is devastating most rural regions of Australia, resulting in a pastoral landscape that is devoid of trees. In the rural New England region of east-central Australia, dieback is particularly severe, and massive tree regeneration programs are underway

Fig. 2. Methods of access into eucalypt canopies included a cherry picker (**a**), and ropes with technical climbing hardware (**b**). This enabled measurements of defoliation from both upper and lower canopy regions

The solution to Australian dieback is twofold:

1. To determine the causes of tree declines;
2. To develop successful programs for the restoration of trees to rural regions affected by dieback.

This chapter attempts to quantify both of these aspects of rural dieback. First, we quantify herbivory of eucalypt canopies on a typical rural landscape in the New England district and relate insect damage to tree mortality. Second, we describe field trials on rural pastures, to illustrate the success and failures of establishing native species in dieback areas. We hope to generate interest in the ameliorative aspects of tree decline syndromes, not just the mechanisms involved in tree mortality alone.

2 Methods and Materials

2.1 Site and Species Selection

The New England district comprises a tableland of over 3.3 million ha in east-central Australia at 800–1500 m elevation (Walker 1977; Barker 1980). It is one of the major agricultural regions on the continent, supporting up to 13 d.s.e. (dry sheep equivalent) per ha with the addition of superphosphate to the soil. Due to a history of successful agriculture, the land has been altered significantly by man over the last 100 years. These changes – addition of fertilizers and superphosphate to the soils, clearing of trees, plowing, planting of non-native grasses to supplement stock feed, establishment of non-native trees as ornamentals, and depletion of many local bird and insect populations – have resulted in complex alterations to the original ecosystem (Heatwole and Lowman 1986). The increased stresses on remaining trees have led to a widespread dieback syndrome. Because the New England rural district is one of the most severely affected dieback regions in Australia, it was critical to undertake studies of tree decline in this region.

Preliminary surveys were conducted throughout the district to determine the typical types of eucalypts, both in terms of habitats and structural forms, for study. Three types were selected as typical of the rural landscape:

1. Healthy trees in pastures, either growing in small clumps or as isolated individuals; they were remnants of previous clearing.
2. Dying trees in pastures, growing in similar situations to those above, but usually in pastures that have had a history of more intensive agricultural practice. Trees showed obvious signs of dieback such as epicormic shoots, reduced canopy size, dead branches, and degeneration of form.
3. Woodland trees, surrounded by neighbors in a shaded, natural ecosystem with shrubs and a variety of understory plants. This category was the most difficult to find due to widespread clearing on the tablelands.

Additional information on eucalypt species distributions, site selection, and tree selection can be found elsewhere (Lowman and Heatwole 1992).

2.2 Measurement of Insect Damage to Eucalypt Trees

Defoliation of leaf surface area was measured over 4 years, from 1982–1986, or for a shorter period if the tree died. Trees in the region were considered to be in a general phase of recovery following drought conditions and insect outbreaks during 1980–1982. Consequently, defoliation measurements in this study may be slightly lower than levels of defoliation suffered when insects were more abundant and foliage growth less prolific.

Leaves were replicated with respect to branch, height in the canopy, individual tree, species, site, type of site and time (months, years). Mature trees representing the most common species were selected at each site. For each tree, at least three branches with 8–15 leaves were marked at each of three height intervals: low (0–5 m), medium (5–8 m), and high (>8 m). Leaves were numbered sequentially from the base upwards, and subsequent leaves were numbered as they emerged. Each month, branches were monitored for amount of leaf damage, presence/absence of galls and miners, fruiting and flowering, and other phenological events.

Leaves were measured for herbivory using a Lambda area meter (Model 3000) or graph paper tracings. Access to canopies was gained with a cherry picker or technical climbing hardware and ropes (Lowman 1984; Fig. 2). More information on leaf measurements, field techniques, and data analyses is listed elsewhere (Lowman 1985; Lowman and Heatwole 1992).

Defoliation levels were expressed as proportions of total leaf area missing. This proved the most reliable method of comparison, since absolute leaf sizes may differ among species and individuals. Earlier studies confirmed that portions of leaf hole areas remain sufficiently consistent throughout the life of a leaf so that the measure gives a good approximation of defoliation (Lowman 1987; Landsberg 1989). Percentages have been shown to be more useful as a measure (than absolute area), because it is comparable to most of the existing literature on herbivory (Lowman 1985).

2.3 Planting Trials to Establish Native Trees on Rural Pastures

During the 1980s, many planting trials were undertaken on New England pastures, attempting to quantify the most successful methods of tree regeneration. The biological and logistic challenges of such trials are enormous, due to the high intra- and intersite variation among pastures, both in terms of local tree species as well as soil and microclimatic factors.

This trial involved the experimental planting of 360 seedlings on a fenced portion of typical rural pasture where all trees had been cleared for sheep grazing. Eighty seedlings of each of four species were planted: *E. viminalis*, *E. melliodora*, *E. blakelyi*, and *E. nicholii*. A split-plot design was used, with four treatments: dense and sparse planting, watering with trickle irrigators or no watering, single or mixed stands of species, and insecticide spraying or no spraying. Seedlings were measured for 2 years to determine the success of establishment. Measurement of seedling performance included: survival, height, number of apical meristems, and herbivory. More detailed information on the experimental design is available elsewhere (Lowman and Burgess, in prep.).

3 Results

Results are reported here in three sections: (1) insect herbivory among trees of the three habitats in the New England region of Australia (woodlands, pastures with healthy trees, pastures with dieback trees); (2) temporal and spatial variability in herbivory among species at a typical pasture site ("Newholme Farm"); and (3) regeneration trials of native species in a pasture. Herbivory data are reported as proportion (%) leaf surface area eaten annually, averaged for the entire canopy, unless otherwise stated.

3.1 Insect Damage in Eucalypts Among Eucalypt Canopies in Three Habitats in New England

Eucalypts exhibited a wide range of defoliation levels, varying between both species and habitats (Table 1). Woodland canopies of *E. blakelyi* had as low as

Table 1. A comparison of herbivory among habitats and species on the New England tablelands, Australia

Species	Mean annual herbivory in habitats[a] (% ± SE) Pastures with dieback trees	Pastures with healthy trees	Woods	$\bar{x}$[b]
E. blakelyi	87.6[c] (5.0)	16.0	7.5 (3.4)	49.7
E. bridgesiana	25.1 (3.1)	—	—	25.1
E. caliginosa	—	20.9	24.9 (4.4)	22.9
E. dalrympleana	—	19.0 (6.6)	—	19.0
E. melliodora	74.4 (4.4)	—	10.2 (0.5)	42.3
E. nova-anglica	—	60.5 (9.0)	—	60.5
E. stellulata	—	35.9 (8.4)	—	35.9
E. radiata	—	—	14.3 (1.3)	14.3
E. viminalis	53.7 (5.7)	52.6 (17.0)	19.8 (4.4)	42.0
E. youmanii	—	—	14.3 (3.5)	14.3
A. floribunda	—	17.0	8.1 (2.2)	12.6
	60.2 (13.6)	31.7 (7.0)	14.2 (2.6)	30.8

[a] Habitats studied and the sites included were: pastures with dieback trees ("Newholme " Farm, "Wood Park" Farm, near Armidale); pastures with healthy trees ("Ruby Hills" Farm near Walcha, University of New England hillside near Armidale); and woodlands (Eastwood State Forest near Armidale, and Bruce Woods near Walcha). For more information on sites and their selection, see Lowman and Heatwole (1992).

[b] Means are expressed in proportion to the relative abundance of each species throughout each habitat; E = *Eucalyptus*; A = *Angophora*.

[c] Expressed as proportion of leaf surface area eaten.

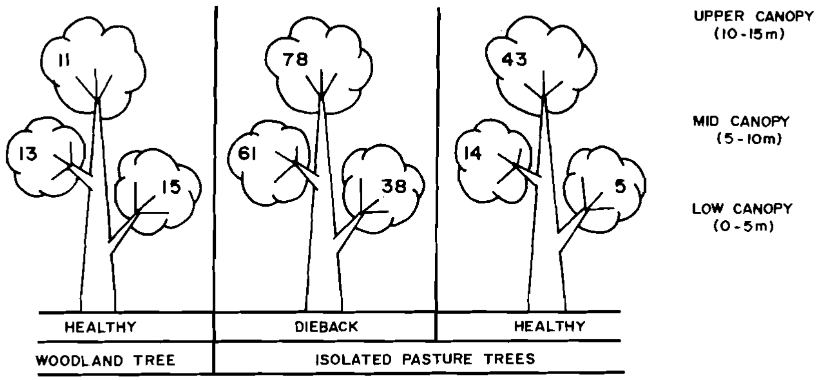

Fig. 3. Average annual herbivory (expressed as proportion leaf surface area removed) for the three major types of trees found on the New England tablelands, and for three canopy heights within each type of eucalypt. Data represent averages for 5 years, and for several thousand leaves (see Table 2)

7.5% leaf surface area removed annually, whereas the same species lost 87.6% in pastures where trees showed signs of dieback. Levels of defoliation varied among species, with *E. nova-anglica* suffering 60.5% herbivory. (It did not exist in woodlands or pastures with dieback, since all individuals in these habitats were dead; the only trees of this species remaining on the tablelands existed in pastures amongst healthy trees.) *E. viminalis* averaged 42% defoliation (individuals existed in all three habitats), and *E. dalrympleana* averaged only 19% leaf area loss (and remained in pasture sites only where trees were characteristically healthy).

Eucalypt canopies characteristically suffered higher herbivory in pasture habitats where dieback was obvious, and progressively lower herbivory in pastures containing non-dieback trees and in woodlands (Fig. 3). Average defoliation for dieback trees in pastures was 60.2%, as compared to 31.7 and 14.2% for healthy trees in pastures and in woodlands, respectively. Herbivory also varied significantly with height (Fig. 3). In pastures, herbivory was higher in the upper canopy; and in the woodlands, herbivory was lower in the upper canopy (Lowman and Heatwole 1992).

3.2 Spatial and Temporal Variability of Herbivory for Eucalypts in a Pasture

Even within one type of habitat, herbivory was extremely variable (Fig. 4). At Newholme Farm, a typical pasture area with tree decline, *E. bridgesiana* was relatively resistant to defoliation, averaging only 25.1% annual leaf area losses over the 6 years (Table 1), and branch cohorts undergoing 30 and 39.3% leaf area losses during 1982–1983 and 1983–1984 (Fig. 4). In contrast, neighboring *E. viminalis* canopies averaged 53.7% defoliation at this site, with individual cohorts showing the extremes of 31.8 and 274.8% leaf area losses in different years. The high defoliation for 1983–1984 was due to the fact that the canopies were eaten entirely (i.e. 100%) and leafed again during one season. Eucalypts are adapted to leaf repeatedly following defoliation and/or effects of fire (Heatwole and Lowman 1986), although eventually their reserves are depleted and the trees die, which occurred at this site.

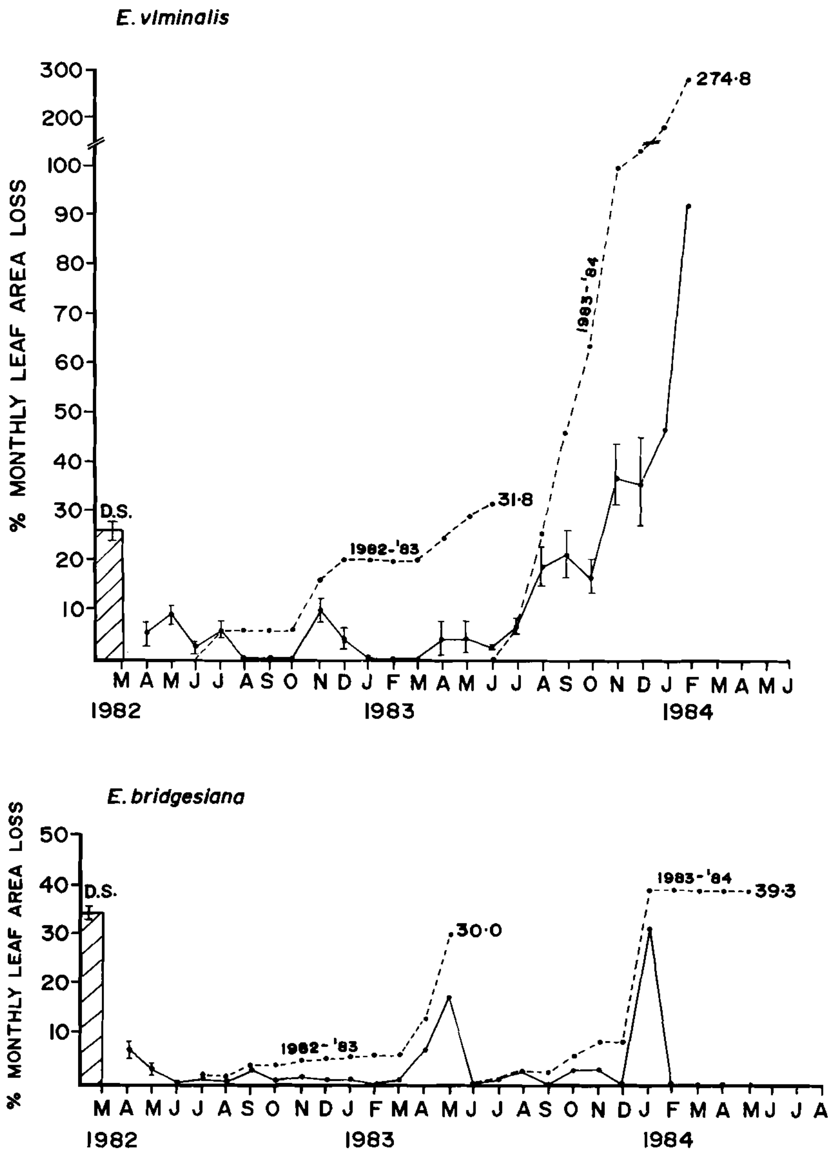

Fig. 4. Seasonal variation in herbivory for three species of eucalypts (A–C) at a typical New England pasture region ("Newholme Farm") that exhibited signs of dieback. Each *point* indicates the defoliation (expressed as proportion leaf surface area removed) accumulated during 1 month (*solid lines*); or the herbivory accumulated over 1 year (*dotted lines*). All trees underwent complete mortality by the end of 1984

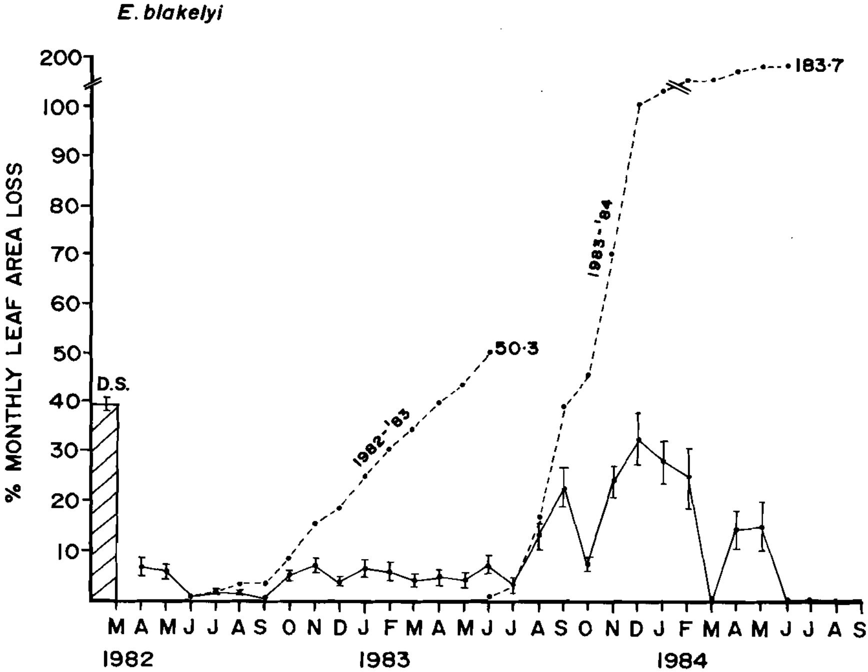

Fig. 4 (*Contd.*)

Defoliation was seasonal on the New England tablelands, with the majority of herbivory occurring during the summer (December–February) (Fig. 4). This temporal pattern was typical for eucalypts in all three habitats, not just at Newholme. Herbivory coincided with peaks in leaf flushing, although trees affected by dieback were observed to leaf again repeatedly with epicormic foliage until the entire canopy was dead.

Despite the fact that Newholme Farm trees underwent dramatic fluctuations in defoliation levels, there was not a clear relationship between insect damage and tree mortality. Over the duration of study, slightly over one-third of the leaves were eaten entirely by herbivores (36.3%), leaving 63.7% that senesced naturally with an average life span of 2 years (Table 2). Leaves that received high (> 50%) defoliation during juvenile stages exhibited early senescence (mean life span of short-lived leaves = 5.8 months); whereas leaves that escaped herbivory as a juvenile had a life span of almost 2 years (long-lived leaves = 20.3 months) (Fig. 5). The average life span of a leaf in a eucalypt tree in a pasture situation with dieback was 13.1 months, approximately half the life span of eucalypt leaves in woodlands (Nadolny, Lowman and Heatwole unpubl. results). Nonetheless, the leaves of pasture trees affected by dieback were not literally being eaten up entirely as was hypothesized, nor were they severely affected by galls, fungal pathogens or other leaf characteristics often associated with tree decline (Table 2). They were, however, subject to repeated bouts of defoliation that oscillated in severity.

Table 2. Summary of herbivory and other events affecting the survival of canopy leaves in eucalypt trees of the New England region, N.S.W.

Site and species		With browning[a] (%)	With galls (%)	Associated with fruits or flowers (%)	Leaves totally eaten (%)	Leaves abscissed (%)	Leaves that turned colour (%)	New leaves that grew	Total number leaves	New leaves (%)	Leaves left
UNE Hill[b]	*E. viminalis*	11.7	1.3	0	14.3	85.7	9.1	42	154	27.3	0
	A. floribunda	24.9	1.5	0	16.4	83.6	7.5	76	201	37.8	0
	E. blakelyi	21.9	0	0	8.6	91.4	5.3	82	151	54.3	0
	Total for site	20	1	0	13.4	86.6	7.3	200	506	39.5	0
Wood Park	*E. viminalis*	3.7	4.5	0.7	35	65	12.2	159	403	39.5	0
	E. blakelyi	11.1	0	0.7	42.3	57.7	0.7	129	305	42.3	0
	Total for site	6.9	2.5	0.7	38.1	61.9	7.2	288	708	40.7	0
Newholme	*E. viminalis*	0	0	0	32.8	67.2	12.5	29	64	45.3	0
	E. blakelyi	21.3	0.7	0	52.7	47.3	7.3	66	150	44	0
	E. bridgesiana	18.9	1	0	38.3	61.7	10.4	45	201	22.4	0
	E. melliodora	15.5	0	0	30.2	69.8	11.6	34	129	26.4	0
	E. nova-anglica	0	0	0	14.9	85.1	14.9	40	87	46	0
	Total for site	14.3	0.5	0	36.3	63.7	10.8	214	631	33.9	0
Eastwood	*E. viminalis*	15.3	1.8	5.8	13.8	86.2	2.5	140	326	42.9	0
	E. blakelyi	29.3	2	5.7	9.1	90.9	6.7	80	297	26.9	0
	E. melliodora	22.4	1	6.6	5.6	94.4	25.5	178	392	45.4	0
	E. caliginosa	19.2	1.7	0.7	17.0	83	8.1	201	407	49.4	0
	Total for site	21	1.6	4.6	11.5	88.5	5	599	1422	42	0
Ruby Hills	*E. nova-anglica*	12.2	1.6	4.5	33.8	66.2	6.4	369	639	57.7	0
	E. dalrympleana	32.9	1.4	12.8	14.4	85.6	4.3	254	423	60	0
	E. stellulata	42.9	3.6	6.8	12.4	87.5	6.7	415	643	64.5	0
	E. caliginosa	35.3	0	0.8	15	85	8	77	133	57.9	0
	Total for site	29.4	2.1	7.0	20.5	79.5	6.0	1115	1838	60.7	0
Bruce woods	*E. youmanii*	61.7	1.7	0	8.9	91.1	18.9	61	180	33.9	0
	E. radiata	69	3	1	9	91	21	66	338	20	5
	Total for site	66	2.5	0.7	9	91	20.3	127	518	24.5	5
	Overall totals (mean per leaf)	25.3	1.8	3.6	20.5	79.5	7.9	2543	5623	45.2	

[a] Brown blotches due to leaf mining or fungal infection.
[b] Sites as follows: woodlands (Eastwood, Bruce); pastures with healthy trees (Ruby Hills, UNE Hill); pastures with unhealthy trees (Wood Park, Newholme). See text for descriptions.

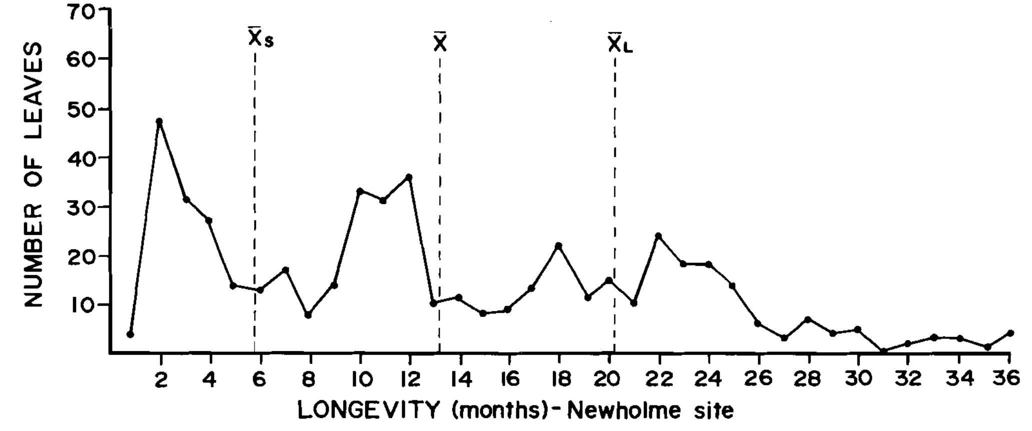

Fig. 5. Leaf longevity for canopies of trees exhibiting signs of dieback at "Newholme Farm" near Armidale NSW, Australia. Each *point* represents the number of leaves that lived a given number of months, from a sample of 27 branches (3 species × 3 individuals × 3 branches = 27 branches total). There were no replications with canopy height here since the trees had no upper canopy still alive during the course of study. Because juvenile leaves were susceptible to early mortality, they were averaged separately ($\bar{X}_s$), and leaves that escape juvenile mortality were also averaged separately ($\bar{X}_L$). $\bar{X}$ represents the average for an entire canopy

3.3 Trials to Establish Native Trees on Dieback Pastures

Over 2 years, 46% of the seedlings survived. The proportions varied greatly among the four species tested, with *E. viminalis* the most successful (89%), followed by *E. nicholli* (54%), *E. blakelyi* (25%), and *E. melliodora* (13%) (Table 3). The survivors averaged 43.4 cm height growth, produced 42 apical meristems, and suffered 2.3% leaf area loss to grazing insects. Survival rates were higher when seedlings were grown in mixed stands (vs pure) and when they were not watered (vs watered), although the latter result may be altered in drought conditions, which did not occur through the duration of this trial. Consequently, only two of the four species that originally grew in this local pasture were successfully re-established from seedlings.

This trial was in essence a pilot study to stimulate future trials and methodological testing for seedling regeneration. Further trials are underway, with increased sample size, different factors and species tested, and long-term monitoring.

4 Discussion

Dieback in the New England Region of Australia is an ecological illness of great magnitude, enormous complexity and the result of a variety of causes. It was not deliberately brought about by human activity, but in many cases the pattern and intensity of land use appear to be the major causes, abetted by secondary factors

Table 3. Survival and growth over 2 years of eucalypt seedlings near Walcha, N.S.W., with respect to five experimental treatments

Factor (*n*)	Survival (%)	Δ Height growth (cm ± SE)		Δ Apical meristems[a] (±SE)		Δ Herbivory (0–5 ranking)[b]
Species						
E. viminalis (80)	88.8	93.1	(4.1)	78.7^{+}		0.7
E. nicholli (80)	53.8	36.0	(3.3)	60.7^{+}		0.6
E. blakelyi (80)	25.0	10.7	(3.5)	1.0	(0.2)	0.5
E. melliodora (72)[c]	12.5	16.8	(3.4)	6.8	(2.6)	0
Total 312	46%	43.4		42.0		
Insecticide						
Spray	47.4	63.5	(5.7)	58.6	(4.6)	0.5
Not sprayed	44.2	55.4	(4.7)	56.6	(4.8)	0.7
Irrigation						
Watered	40.0	59.1	(5.0)	65.7	(4.2)	0.4
Not watered	52.0	60.0	(5.4)	51.1	(4.9)	0.8
Stand density						
Dense	46.4	59.7	(4.4)	59.8	(3.8)	0.6
Sparse	44.2	59.1	(6.6)	50.5	(6.8)	0.8
Stand composition						
Pure	43.4	59.8	(4.3)	57.3	(3.8)	0.6
Mixed	55.7	58.9	(7.4)	58.6	(7.0)	0.6

[a] In cases where apical buds numbered more than 100 on an individual seedling, it was averaged as 100, but a plus sign (+) was included in the mean.
[b] See text for ranking values.
[c] Eight trees erroneously labelled and sold as *E. melliodora*, but grew up to be other species. Therefore, they were omitted from calculations.

such as insect defoliators. The suite of environmental changes that accompanies agriculture – in the case of grazing, these included increased numbers of stock (Sindon et al. 1983), trampling of soil, consumption of seedlings by stock, clearing of trees, ringbarking of trees by cattle, aerial spraying of fertilizers (especially superphosphate), alterations of the water table, planting of non-native grasses for winter feed supplements, and plowing of pastures for crops – has severely altered the original ecosystems in this region (reviewed by Heatwole and Lowman 1986).

The changes in soil that accompany clearing and agriculture create conditions conducive for epidemics of certain scarab beetles (*Anoplognathes* sp.), sawfly larvae, and other defoliators. Due to clearing, fewer trees remain as food sources. Subsequently, the beetles – with their gregarious feeding behavior – defoliate the remaining trees. This scenario may be repeated over several years, and in the case of the Newholme Farm data, eventually result in complete dieback of a region.

It is difficult, however, to implicate insects as the major cause of dieback. It may be a chicken-and-egg situation: which comes first – the insect defoliation leading to tree decline, or the environmental stresses on a tree leading to increased defoliation? Other studies have indicated that the stress comes first, with depleted soils a primary progenitor in the Pacific basin diebacks (Mueller-Dombois 1990/91). The dietary quality of foliage of dieback *E. blakelyi* was generally superior to those from healthy trees (Landsberg 1990). Nonetheless, why are some individuals more susceptible to dieback than their neighbors? Genetic variation may be largely responsible, but this has not yet been examined. This study showed high variation among species in susceptibility to defoliation (e.g. *E. nova-anglica* vs *E. bridgesiana*), despite the fact that they live in close proximity. It is possible that stresses vary on a microscale, with factors such as numbers of emerging scarab beetles, chances of a tree being encountered by sawfly larvae, and livestock pressures (soil compaction, ringbarking). If trees undergo a suite of stresses, obviously this creates deteriorating conditions that enhance susceptibility to defoliation.

Our fieldwork shows, however, that the observations of farmers in the New England region over the last century were correct: insect defoliation is significantly higher on trees exhibiting dieback, and lower on healthy trees.

Defoliation is not the only cause of canopy decline. A proportionally high number of leaves undergo apparently natural senescence despite the high amounts of defoliation incurred (Table 3). Insects may be, in a sense, the *coup de grace* for rural eucalypts. Severe outbreaks of herbivores may simply represent an overload of stresses on the trees. Continual loss of photosynthetic capacity to a plant that is already stressed must ultimately lead to mortality. In the case of eucalypts, however, it is proving difficult to predict how many defoliations are required to cause mortality. In an ongoing field experiment, saplings in rural pastures have undergone >5 artificial defoliations and are still growing and leafing again (Lowman unpubl. data). Perhaps the unusual lignotuberous habit confers upon the eucalypts an amazing capacity to endure stresses and still possess the metabolic reserves to recover. In general, eucalypts tolerate relatively high rates of herbivory (Fox and Morrow 1986; Lowman and Heatwole 1992; but see Ohmart 1984; Landsberg and Ohmart 1989).

In addition to the stress of defoliation, insects have other deleterious effects on eucalypts. Scarab beetle larvae (and other soil organisms) fed on tree roots, and can remove over half the root system of a dying *E. nova-anglica*, as compared to a healthy individual (Lowman et al. 1987). The numbers of beetle larvae appear higher in pasture soils than elsewhere (biomass up to 179 g per 100 m of furrow, Roberts et al. 1982). Stem borers and sap-sucking insects have not yet been studied in relation to dieback, nor have fungal pathogens (but see Nadolny 1984), so it is possible that some stresses have not even been identified.

Planting trials are still in their infant stages, and success will only be measureable over long-term time frames. For increased survival, we advocate careful selection of species, as well as preparation of site. Maintenance of plots by weeding may also increase our survival rates, and more extensive trials are underway to test this (Curtis and Nadolny 1990).

Rural dieback in Australia has transformed the landscape, yet the majority of research still centers around the causal aspects of the problem. Very little research has tackled the etiology of dieback and the applied ecological questions of reversing tree decline. Trials to test methods of planting, methods of ground preparation, maintenance of species, and success of different species are underway and have provided some encouraging signs that indigenous species can indeed be re-established on areas with severe tree decline (Curtis 1989; Curtis and Nadolny 1990; Nadolny 1991). Many more field trials are needed. The pooling of results is imperative, if farmers are to work together to restore trees to the dieback landscape that predominates Australia. It is not only a battle for funds and for public attention, but it is also a battle against time. The longer rural regions remain treeless, the more difficult it will be to transform sections of the landscape back to their original dry sclerophyll ecosystems.

Diebacks are worldwide and have various origins and etiologies (Mueller-Dombois 1986, 1987). The Australian dieback is particularly severe and directly related to land use changes and insect outbreaks. Australians have an opportunity to make an impact on their environment during the 1990s, by aiding in the regeneration of native trees. The Greening of Australia project (Nadolny 1991), to plant 1 billion trees this decade, will require the enthusiastic participation of many individuals, and require the continued maintenance of the plantings during years to come. This ameliorative aspect of dieback research in Australia may set a worldwide precedent illustrating how scientists and laymen can work together toward an important environmental goal, the reversal of tree decline.

References

Barker T (1980) Armidale, a cathedral city of education and the arts. Cassell Australia, North Ryde, Australia

Curtis DJ (1989) Re-establishment of eucalypts on the northern tablelands of New South Wales. MSc Thesis, University of New England, Australia

Curtis DJ, Nadolny C (1990) *Eucalyptus* regeneration program. Northern tablelands of New South Wales Tree Decline and Revegetation. Newsletter 2:42

Fox LR, Morrow PA (1986) On comparing herbivore damage in Australian and north temperate systems. Aust J Ecol 11:387–394

Heatwole HH, Lowman MD (1986) Dieback, death of an Australian landscape. Reed Books, Sydney, Australia

Landsberg J (1989) A comparison of methods for assessing defoliation, tested on eucalypt trees. Aust J Ecol 14:423–441

Landsberg J (1990) Dieback of rural eucalypts: does insect herbivory relate to dietary quality of tree foliage? Aust J Ecol 15:73–87

Landsberg J, Ohmart C (1989) Levels of insect defoliation in forests: patterns and concepts. Trends Ecol Evol 4:96–100

Lowman MD (1984) An assessment of techniques for measuring herbivory: is rainforest defoliation more intense than we thought? Biotropica 16:264–268

Lowman MD (1985) Temporal and spatial variability in insect grazing of the canopies of five Australian rainforest species. Aust J Ecol 10:7–24

Lowman MD (1987) Relationships between leaf growth and holes caused by herbivores. Aust J Ecol 12:189–191

Lowman MD, Burgess AD, Experimental growth of native seedlings in pastures affected by dieback. Aust Range Exp Manage J (in prep)

Lowman MD, Heatwole HH (1992) Spatial and temporal variability in defoliation of Australian eucalypts. Ecology 73:129–142

Lowman MD, Burgess AD, Higgins WD (1987) The biomass of New England peppermint (*Eucalyptus nova-anglica*) in relation to insect damage associated with rural dieback. Aust J Ecol 12:361–372

Mueller-Dombois D (1986) Perspectives for an etiology of stand-level dieback. Annu Rev Ecol Syst 17:221–243

Mueller-Dombois D (1987) Natural dieback in forests. Bioscience 37:575–583

Mueller-Dombois D (1990/91) Forest decline and soil nutritional problems in Pacific areas. Water Air Soil Pollut 54:195–207

Nadolny C (1984) Eucalypt dieback on the northern tablelands of New South Wales. MSc Thesis, University of New England, Armidale NSW

Nadolny C (1991) The dilemma of rural tree clearing. Search 22:43–46

Ohmart CP (1984) Is insect defoliation in eucalypt forests greater than that in other temperate forests? Aust J Ecol 9:413–418

Ohmart CP, Landsberg J (1990) Insect herbivory in Australian forests. Trends Ecol Evol 2:400–402

Roberts RJ, Campbell AJ, Porter MR, Sawtell NL (1982) The distribution and abundance of pasture scarabs in relation to *Eucalyptus* trees. In: Lee KL (ed) Proceedings of the 3rd Australasian Conference on Grassland Invertebrate Ecology, Adelaide, 30 Nov–4 Dec 1981. South Australian Govt Printer, Adelaide South Australia, pp 207–214

Sindon JA, Jones AD, Fleming PJ (1983) Relationships between eucalypt dieback and farm income, stocking rate and land value in southeastern New England, NSW. University of New England, Armidale 112 pp

Walker GT (1977) Relief. In: Lea DAM, Pigram JJ, Greenwood L (eds) An atlas of New England, Department of Geography, University of New England, Armidale NSW, Australia