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# Department of Conservation and Land Management

## Science and Information Division

Sustainable Resources Group

Tree Crops Section

**Entomology Report**

**Variation across provenance regions and families for damage to *Eucalyptus globulus* leaves by chewing insects.**

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**Summary**

1. A method of visually appraising damage by leaf chewing insects in *E. globulus* crowns was developed and tested. The amount of damage by leaf chewing insects varied significantly between three year old *E. globulus* trees originating from different provenance regions. Damage to the upper half of crowns trees about 8 to 10 m tall was positively correlated with the proportion of adult foliage carried.

2. Rankings of provenance regions based on damage to juvenile leaves in the lower half of crowns were similar to those reported in eastern Australia under conditions of severe damage. Rankings were similar between leaf age/position classes except for a King Island provenance whose rank changed from best to worst between oldest juvenile leaves in the lower crown and youngest, usually adult leaves in the upper crown. Provenances from the Furneaux Group in Bass Strait performed best overall and carried juvenile and adult foliage apparently resistant to chewing.

3. Significant edge effects were detected. Plantations less than 50m in width will probably suffer greater damage to upper foliage over their entire area compared to wider plantations.

**Implications for plantation management**

1. We hypothesize that leaf damage by insects is not likely to have contributed greatly to differences in growth rates during selection of breeding stock for superior growth rates. The families examined in this trial were selected for superior growth rates yet had measurable differences in leaf damage between families despite suffering relatively minor damage. **Plantations of *E. globulus* are certain to include trees susceptible, throughout the rotation, to damage by a range of leaf chewing insects.**

2. Significant edge effects were detected. **Plantations less than 50m in width will probably suffer greater damage to upper foliage over their entire area compared to wider plantations.** Where small plantations are necessary to redress soil degradation, the trees planted may need to be more resistant to insect damage than trees in larger plantations.

3. Leaves produced within 3 year old crowns during the first two years of growth were most damaged, indicating that **during the first two years after planting trees are most at risk of significant damage.** Long term risk of insect outbreaks remains unknown.

**Introduction**

Selection of desirable tree characteristics, usually relating to wood qualities and tree productivity, to include desirable traits in breeding stock is an important process in the development of commercial plantations of *Eucalyptus globulus* Labill. in Western Australia (Butcher 1990). Selection for resistance to damage by phytophagous insects has been suggested as a possible element of an Integrated Pest Management (IPM) approach to control of insect pests in eucalypt plantations (Floyd and Farrow 1994). A recent conference devoted to improving yields in eucalypt plantations did not include any papers appraising resistance to insect damage (Potts et al. 1995). Such an omission is surprising given the early recognition of the heritability of resistance to attack by particular insect species (Pryor 1953), and great interspecific and interprovenance variation in eucalypt susceptibility to insect damage (Richardson and Meakins 1986, Lowman and Heatwole 1987, Floyd et al. 1994).

Programs restricting selection criteria to high growth rates (and good form and wood qualities) implicitly assume that deleterious effects such as susceptibility to drought, or insect damage to leaves, will be selected against or will not impinge on growth rates. Susceptibilities of plantations to drought and insect damage are latent, though not insignificant hazards compared to the immediacy of rewards derived from selection for fast growth rates. Dutkowski (1995) reported a slight negative correlation between growth and drought susceptibility and concluded that 'in the absence of drought, selection for growth will only slightly decrease drought susceptibility.' The validity of these assumptions remain untested for the impact of insect damage in Western Australian *E. globulus* plantations.

Farrow et al. (1994) reported significant interprovenance variation in resistance of *E. globulus* juvenile foliage to feeding by *Mnesampela privata* (Guenée) and *Phylacteophaga froggatti* Riek larvae. These authors used visual estimates in conditions of severe damage to rate provenances. Severe damage is uncommon in *E. globulus* plantations in Western Australia (Abbott 1993) so a method for visually appraising relatively minor insect damage was developed and used to investigate interprovenance variation. Our objective was to confirm the reported variation, test for variation in damage to more developed crowns than those examined by Farrow et al. (1994), and thereby determine the susceptibility of *E. globulus* plantations in Western Australia to insect damage.

Observations elsewhere of the progress of infestations by leaf chewing insects led us to expect the possibility of edge effects and effects from proximity of remnant vegetation on amounts of leaf damage in the trial. The design of the trial allowed a flexibility to test for notional edge effects and effects of proximity to remnant vegetation.

These hypotheses were specifically tested: Insect damage in the plantation was not related to a) provenance of the trees; b) leaf age or position in the crown; c) leaf morphology; and d) location within the plantation.

**Methods**

Location of study

*E. globulus* trees from 84 families selected for superior growth characteristics were rated for damage by leaf chewing insects in November 1994. The trial, hand planted in winter 1992, was located 8 km south of Mount Barker (34°42'S, 117°40'E) in Western Australia. The soil is sand, mostly to more than 2 m deep, well drained but possibly waterlogged at depth (Harper 1991). The plantation is contiguous on its western margin with a railway reserve in which remnant vegetation is predominantly tall myrtaceous heath containing isolated stands of small marri (*E. calophylla*) and jarrah (*E. marginata*) trees and pockets of Banksia woodland.

Trees in the trial were derived from seedlots from open pollinated fruits in remnant forest. The trial was planted to a lattice design and intended to allow comparison of growth characteristics of superior families. About 70% of families were Victorian provenances (Table 1), with the remainder from the islands in Bass Strait or from eastern Tasmania.

Table 1. Representation of provenance regions in the trial.

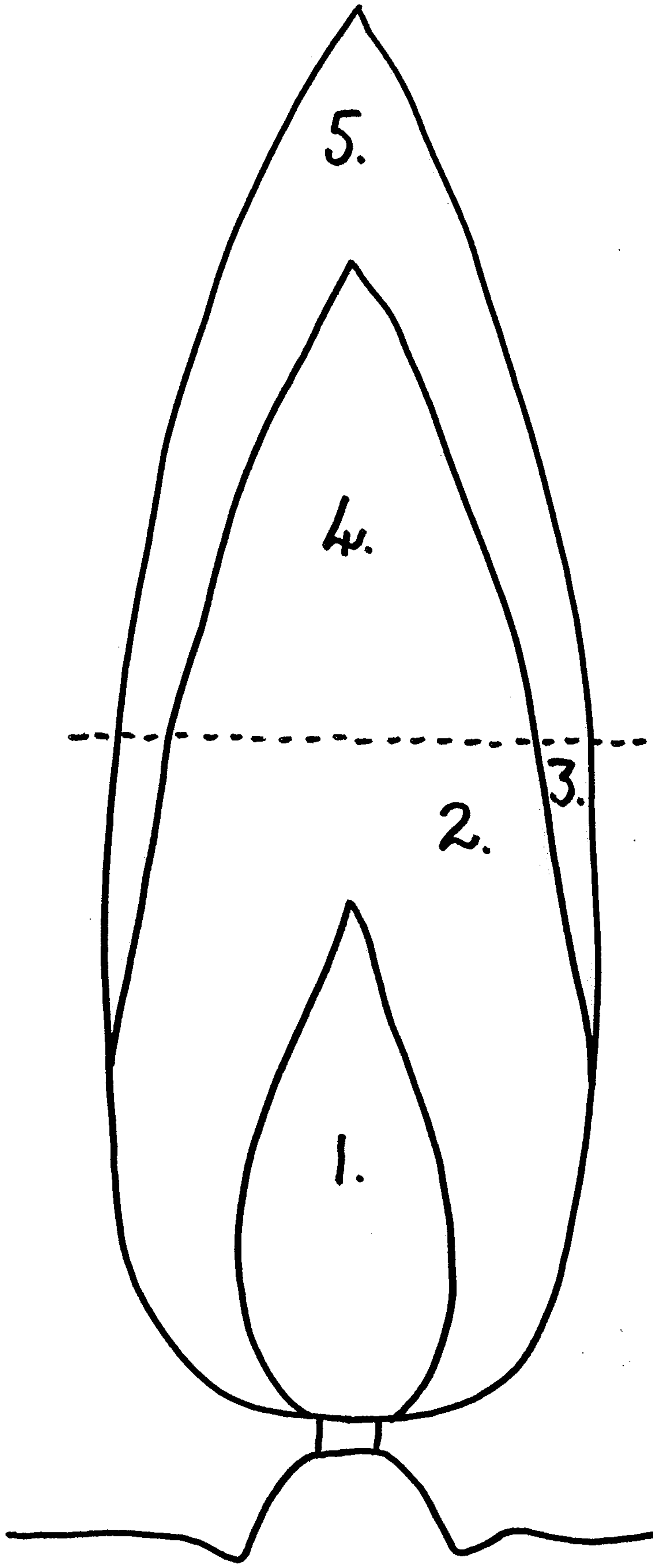
| Region | Provenances | Families |
|---|---|---|
| Victoria, Cape Otway to Lorne. | 17 | 38 |
| Victoria, South Gippsland. | 4 | 23 |
| Furneaux Group, Flinders Island. | 5 | 6 |
| Furneaux Group, Cape Barren Island. | 5 | 11 |
| King Island. | 1 | 2 |
| Tasmania, North East. | 1 | 1 |
| Tasmania, South East. | 2 | 3 |

Damage assessment

Five classes of leaf position/age were recognised. Leaves in each canopy were stratified according to their position in the crown and estimated age (Fig. 1). The boundaries of canopy strata were estimated from visual cues such as stage of leaf senescence, changes in leaf size and colour along branches, and by prior experience of size of the canopy at certain ages. The leaf morphology in each stratum was noted and 3 classes were recognised and assigned a value reflecting the presence of adult foliage. If the class contained all juvenile leaves the value 0 was assigned, mixed adult and juvenile leaves were assigned a value of 0.5, and all adult leaves assigned value 1.

Six damage categories were developed from a preliminary assessment of age class 2 leaves from 60 trees (Table 2). The ranges of damage within categories were set so that damage could easily be assigned to a class, and the modal damage categories were the middle classes of the range of damage classes. Damage categories were most sensitive to differences at small amounts of damage. The damage categories applied to age class 2 leaves were also applied to the other age classes of leaves.

Damage was regarded as the percentage of leaf area removed by leaf chewing insects for leaves expanding or chewed after expansion, or for fully expanded leaves that had been chewed before fully expanded, the percentage missing from the expected area. Only leaves remaining on the tree were assessed (ie damage due to complete removal of buds or leaves was not estimated). Complete removal of leaves by chewing appeared to be rare in the preliminary assessment but loss of leaves due to




**Legend**

1. Class 1 leaves, lower half of crown, produced 1992.

2. Class 2 leaves, lower half of crown, produced 1993.

3. Class 3 leaves, lower half of crown, produced 1994.

4. Class 4 leaves, upper half of crown, produced 1993 to 1994.

5. Class 5 leaves, upper half of crown, produced 1994.

Fig. 1. Diagrammatic arrangement of leaf classes in 3 year old crowns of *E. globulus* at Mt Barker, November 1994.

senescence was common in class 1 leaves. A leaf class for a tree was not rated for damage if more than 30% of leaves had fallen due to senescence. Standard trees were established for damage classes and these trees were appraised after each work break to maintain uniform standards across the trial. Each tree was rated independently by two observers, but large divergences in assignment to damage categories were discussed. Runted or dead trees were not assessed.

Table 2. Frequencies of damage categorisations by two assessors for Class 2 and Class 4 leaves.

| | CLASS 2 LEAVES | | CLASS 4 LEAVES | |
|---|---|---|---|---|
| AREA DAMAGED | ASSESSOR A | ASSESSOR B | ASSESSOR A | ASSESSOR B |
| Uncategorised (lost to senescence) | 179 | 180 | 172 | 172 |
| <1% | 0 | 1 | 14 | 18 |
| 1-5% | 276 | 234 | 1097 | 1083 |
| 6-10% | 506 | 461 | 151 | 163 |
| 11-25% | 345 | 471 | 6 | 4 |
| 26-50% | 133 | 88 | 0 | 0 |
| >50% | 1 | 5 | 0 | 0 |
| Total | 1440 | 1440 | 1440 | 1440 |

Visible chewing and sucking insects, and damage attributable to particular insects, were noted. Trees were assessed across family rows to minimise effects of assessor bias, and the provenance and family identity were unknown to the assessors. All observations were recorded on a Husky Hunter™ field computer. About 18 trees per hour were assessed in 8 working hours per day over 10 day's. The maximum rate of assessment was about 36 trees per hour after 10 days experience.

Analysis

Family plots were grouped into 6 blocks, of which blocks 1 and 6 had the longest perimeters not contiguous with other blocks, while block 1 was nearest to remnant vegetation and block 6 most distant. Leaf damage categories were converted to their range midpoint and the proportion of damage transformed by deriving the arcsin of its square root. Class 1 leaves were excluded from the analysis due to the large number of trees not assessed. Effects of block, leaf morphology and provenance region were investigated using ANOVA.

Family performances

Families were ranked according to four criteria: a) the average damage over the whole crown; b) damage to class 2 leaves; and damage to the upper half of the crown c) with, and d) without discounting the effect of leaf morphology.

## Results

Differences between assessors

Acquisition of data directly to a field computer allowed monitoring of differences between assessors as the trial progressed. The insignificance of differences between assessors for class 2 and 4 leaves (Table 2) reflects the closeness of the assessors' perceptions of damage.

Visible insects

A visual census of insects detected active leaf chewing insects relatively infrequently (Table 3). The amount of damage caused by insects was unrelated to their apparent abundance. *P. froggatti* mines were most frequently encountered, yet contributed a trivial amount to overall damage. *Catasarcus* sp. (Curculionidae) were next most recorded and, on the basis of their characteristic damage patterns on leaves, contributed much to damage in the upper half of crowns. Autumn gum moth *M. privata*, the jarrah leafminer *Perthida glyphopa* and chrysomelid larvae were next most frequently seen. Jarrah leafminer caused minuscule damage to *E. globulus* foliage, whereas chrysomelid larvae caused chronic damage but were seen infrequently relative to the abundance of their damage. Most damage in class 2 leaves appeared to be due to *M. privata.*

Leaf age/position and types of damage

A preliminary ANOVA indicated large differences in damage between provenance regions and between leaf classes to be highly significant (Table 4a). Leaf morphology was not important with the inclusion of leaf class in the analysis, reflecting a confounding of morphology with leaf class and very much greater variation between leaf classes. Leaf damage diminished as leaf age diminished and as elevation in the crown increased (Table 5). Greatest damage was to class 2 leaves, juvenile leaves in the bottom half of the canopy, while next most damaged leaves were class 3 leaves, youngest leaves in the bottom half of the canopy. Similarly, youngest leaves were least damaged in the upper canopy.

Table 3. Frequency of trees with visible insects or attributable damage. Damage by leaf tiers, 1993 damage by *M. privata* and presence of Psylloidea or Cicadellidae not recorded

| TROPHIC GROUP | NAME | COMMON NAME | FREQUENCY | % |
|---|---|---|---|---|
| CHEWER | *Phylacteophaga froggatti* | Leaf blister sawfly, mines. | 108 | 7.50 |
| CHEWER | *Catasarcus ?impressipennis* | Weevil. | 91 | 6.32 |
| CHEWER | *Mnesampela privata* | Autumn gum moth, damage and larvae 1994. | 80 | 5.56 |
| CHEWER | *Perthida glyphopa* | Jarrah leafminer, mines. | 70 | 4.86 |
| CHEWER | Chrysomelidae | Chrysomelid larvae. | 69 | 4.79 |
| CHEWER | Unknown, Lepidopteran? | Tip miner, mines. | 38 | 2.64 |
| CHEWER | Oecophoridae | Leaf tier larvae (damage without larvae not recorded). | 36 | 2.50 |
| CHEWER | Scarabaeidae | Spring beetles. | 18 | 1.25 |
| CHEWER | Chrysomelidae | Chrysomelid eggs. | 15 | 1.04 |
| CHEWER | Curculionidae | Weevil larvae. | 6 | 0.42 |
| CHEWER | Chrysomelidae | Chrysomelid adults. | 3 | 0.21 |
| CHEWER | *Perga sp.* | Gregarious sawfly larvae. | 2 | 0.14 |
| CHEWER | Curculionidae | Brown weevil. | 1 | 0.07 |
| CHEWER | *Perga sp.* | Gregarious sawfly eggs. | 1 | 0.07 |
| PARASITOID | | Galls | 1 | 0.07 |
| SAPSUCKER | | Shield bug | 41 | 2.85 |
| SAPSUCKER | | Leaf hopper | 2 | 0.14 |
| SAPSUCKER | | Coccid scales | 1 | 0.07 |
| PREDATOR | | Coccinelid adults | 11 | 0.76 |
| PREDATOR | | Coccinelid eggs | 3 | 0.21 |
| PREDATOR | | Coccinelid larvae | 3 | 0.21 |

Block, provenance region and leaf morphology effects

ANOVAs were performed on each leaf class separately to investigate the effect of leaf morphology and to simplify analysis of the block, provenance region and leaf morphology effects on leaf damage. Block effects were significant for class 4 and 5 leaves (Table 4b), with most damage sustained within the edge blocks 1 and 6 and least damage to the centre most blocks 3 and 4 (Table 5). There appeared to be no influence from proximity to remnant vegetation although class 2 and 3 leaves in block 6, the most distant from remnant vegetation, sustained least damage compared to other blocks.

Table 4a. Analysis of variance, including leaf classes 2 to 5, of the variable LDAM (transformed proportion of leaf damage).

| SOURCE | D.F. | Type III S.S. | M.S. | F Ratio | *P* of > F. |
|---|---|---|---|---|---|
| BLOCK | 5 | 0.00563 | 0.00112 | 1.31 | 0.2675 |
| REGION | 6 | 0.02497 | 0.00416 | 4.85 | 0.0003 |
| LEAF MORPHOLOGY | 1 | 0.00026 | 0.00026 | 0.30 | 0.5831 |
| LEAF CLASS | 3 | 0.34145 | 0.11382 | 132.25 | 0.0001 |
| REGION*LEAF CLASS | 18 | 0.02454 | 0.00136 | 1.58 | 0.0815 |
| BLOCK*REGION | 25 | 0.02253 | 0.00090 | 1.05 | 0.4194 |

Table 4b. F ratios and probabilities of greater ratios from ANOVAs of the variable LDAM for each leaf class based on type III sums of squares.

| | CLASS 2 | | CLASS 3 | | CLASS 4 | | CLASS 5 | |
|---|---|---|---|---|---|---|---|---|
| SOURCE | F Ratio | *P* of > F. | F Ratio | *P* of > F. | F Ratio | *P* of > F. | F Ratio | *P* of > F. |
| BLOCK | 2.40 | 0.0704 | 1.13 | 0.3719 | 3.95 | 0.0094 | 8.12 | 0.0001 |
| REGION | 4.16 | 0.0061 | 6.82 | 0.0003 | 5.70 | 0.0008 | 6.90 | 0.0002 |
| LEAF MORPH. | 0.30 | 0.5892 | 4.02 | 0.0563 | 15.72 | 0.0006 | 0.86 | 0.3618 |

Table 5. Least squares means of the variable LDAM for blocks and leaf classes. Individual ANOVAs performed for each leaf class.

| | LEAF CLASS | | | |
|---|---|---|---|---|
| BLOCK | CLASS 2 | CLASS 3 | CLASS 4 | CLASS 5 |
| 1 | 0.343 | 0.188 | 0.194 | 0.191 |
| 2 | 0.319 | 0.194 | 0.184 | 0.176 |
| 3 | 0.376 | 0.188 | 0.176 | 0.171 |
| 4 | 0.356 | 0.191 | 0.179 | 0.171 |
| 5 | 0.330 | 0.185 | 0.188 | 0.176 |
| 6 | 0.305 | 0.183 | 0.193 | 0.179 |

Provenance region effects were highly significant for all leaf classes. Least squares means of leaf damage were ranked for each leaf class, and the ranks summed for each region (Table 6). Trees from the Furneaux Group had the least damage (highest aggregates of ranks), while trees from north eastern Tasmania were most damaged. Next least damaged, in order of decreasing damage, were trees from the Otway region in Victoria, King Island and south east Tasmania region. Ranks of regions were similar between leaf classes, except for trees from King Island that ranked as least damaged for class 2 leaves and most damaged for class 5 leaves.

Table 6. Least squares means for each provenance region of the variable LDAM. Rank of each mean in parentheses. Individual ANOVAs performed for each leaf class.

| REGION | LEAF CLASS CLASS 2 | CLASS 3 | CLASS 4 | CLASS 5 | Sum of ranks. |
|---|---|---|---|---|---|
| Vic. C. Otway. | 0.387 (2) | 0.195 (2) | 0.187 (3) | 0.185 (1) | 8 |
| Vic. South Gipps. | 0.341 (3) | 0.188 (3) | 0.186 (4) | 0.180 (3) | 13 |
| Furn. Flinders I. | 0.293 (6) | 0.178 (6) | 0.170 (7) | 0.171 (6) | 25 |
| Furn. C. Barren I. | 0.319 (5) | 0.176 (7) | 0.178 (5) | 0.168 (7) | 24 |
| King I | 0.292 (7) | 0.185 (4) | 0.193 (2) | 0.185 (1) | 14 |
| Tas. NE. | 0.415 (1) | 0.216 (1) | 0.206 (1) | 0.178 (4) | 7 |
| Tas. SE. | 0.323 (4) | 0.180 (5) | 0.178 (5) | 0.174 (5) | 19 |

Leaf morphology significantly affected damage to class 4 leaves while the effect on damage to classes 2, 3 and 5 leaves was not significant. Damage to class 4 leaves was positively correlated with the proportion of adult foliage.

Types of leaf damage were not attributed to leaf age classes but it was noted that the most frequent damage pattern on leaves in class 2 was typical of chewing by large caterpillars, presumably autumn gum moth active during winter 1993 or winter 1994. It was apparent from damage patterns on leaves that weevil adults of *Catasarcus* sp. and chrysomelid beetles and larvae were most active on expanding or newly expanded adult foliage. Damage typical of these insect groups was trivial on juvenile leaves in the lower half of the canopy.

Performance of families

Families from the Furneaux Group fell within the quartile of lowest damage more frequently than families from other regions (Table 7). The performance of seven families from five Furneaux provenances was consistently highly ranked, rating in the top quartile of all four performance criteria. A single family from another region, south east Tasmania, fell within the quartile of least damage for all four criteria. Eight families from seven Otway provenances fell within the highest damage quartiles for all four criteria.

**Discussion**

Amounts of damage reported from this trial are comparable to amounts of insect damage usually observed in commercial plantations in south west Australia. The observed damage was also very much less than the 90% loss of functional leaf area reported from species trials including *E. globulus* at Shepparton in Victoria by Floyd and Farrow (1994) and less than leaf damage to between 60% to 95% of leaf area in an *E. globulus* provenance trial at Tatura in Victoria (Farrow et al. 1994).

Despite the unremarkable overall amounts of damage to the Mt Barker plantation, significant edge effects on the distribution of damage to the upper half of the canopy across the trial were detected. The presence of edge effects has implications for plantation planning and management, particularly since a proportion of the *E. globulus* estate in Western Australia is in small plantations with relatively large perimeter to area ratios. Considering the scale of plots measured in this trial, plantations less than about 50 m width would show greatest increase in damage over the whole plantation, due to edge effect. In other plantations we have observed greatest damage by *M. privata* on edges nearest remnant vegetation. No such pattern of damage was detected in this trial, possibly because damage to juvenile leaves in the lower half of the canopy in 1994 obscured differences in distribution of earlier damage.

There was significant variation in damage between provenance regions. The performances of provenance regions as rated by this study broadly concur with reported variation across provenance regions in susceptibility of juvenile *E. globulus* leaves to damage by the leaf chewing caterpillars of *Mnesampela privata* and leaf mining larvae of *Phylacteophaga froggatti* in Victorian trials (Farrow et al. 1994). In particular, juvenile leaves of Bass Strait Island provenances sustained substantially less

Table 7. Summary of Regions, Provenances and Families: Number of trees assessed, average leaf morphology scores, and best (B) and worst (W) quartiles for damage criteria.

| REGION | PROVENANCE | FAMILY | LATDD | LONDD | NUMBER ASSESSED | MORPHOLOGY ALL CLASSES | MORPHOLOGY CLASSES 4&5 | BEST AND WORST QUARTILES | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | ALL CLASSES MEAN LDAM | CLASS 2 LDAM | CLASSES 4&5 LDAM | CLASSES 4&5 RESIDUALS |
| FURN. CAPE BARREN I. | 16416 | 67 | 40.317 | 148.317 | 20 | 0.43 | 0.74 | B | B | B | B |
| FURN. CAPE BARREN I. | 16416 | 74 | 40.317 | 148.317 | 20 | 0.30 | 0.58 | B | B | B | B |
| FURN. CAPE BARREN I. | 16417 | 53 | 40.367 | 148.217 | 16 | 0.38 | 0.69 | B | | B | B |
| FURN. CAPE BARREN I. | 16417 | 64 | 40.367 | 148.217 | 13 | 0.38 | 0.71 | B | | B | B |
| FURN. CAPE BARREN I. | 16419 | 31 | 40.350 | 148.117 | 12 | 0.26 | 0.48 | B | B | B | |
| FURN. CAPE BARREN I. | 16419 | 49 | 40.350 | 148.117 | 15 | 0.37 | 0.62 | | | | |
| FURN. CAPE BARREN I. | 16419 | 58 | 40.350 | 148.117 | 11 | 0.33 | 0.66 | B | B | B | B |
| FURN. CAPE BARREN I. | 16420 | 8 | 40.367 | 148.083 | 17 | 0.24 | 0.46 | | | | W |
| FURN. CAPE BARREN I. | 16420 | 25 | 40.367 | 148.083 | 8 | 0.30 | 0.59 | | | B | B |
| FURN. CAPE BARREN I. | 16420 | 55 | 40.367 | 148.083 | 15 | 0.41 | 0.73 | W | W | B | B |
| FURN. CAPE BARREN I. | 16421 | 60 | 40.433 | 148.050 | 15 | 0.43 | 0.78 | | | B | B |
| FURN. FLINDERS I. | 16425 | 13 | 40.233 | 148.133 | 14 | 0.29 | 0.57 | B | B | B | B |
| FURN. FLINDERS I. | 16427 | 65 | 39.750 | 147.950 | 15 | 0.43 | 0.75 | B | | B | B |
| FURN. FLINDERS I. | 16429 | 43 | 39.917 | 147.950 | 14 | 0.35 | 0.68 | B | B | B | B |
| FURN. FLINDERS I. | 16431 | 27 | 40.033 | 148.017 | 15 | 0.40 | 0.73 | B | B | B | B |
| FURN. FLINDERS I. | 16431 | 69 | 40.033 | 148.017 | 19 | 0.39 | 0.72 | B | B | B | B |
| FURN. FLINDERS I. | 16433 | 48 | 40.067 | 148.067 | 18 | 0.41 | 0.76 | | | | B |
| KING I. | 16424 | 51 | 40.000 | 144.000 | 18 | 0.30 | 0.60 | B | B | | W |
| KING I. | 16424 | 73 | 40.000 | 144.000 | 19 | 0.38 | 0.72 | | | | |
| TASMANIA NE | 16074 | 2 | 41.633 | 147.850 | 14 | 0.13 | 0.25 | | W | B | W |
| TASMANIA SE | 16082 | 37 | 42.933 | 147.267 | 15 | 0.32 | 0.60 | B | B | | |
| TASMANIA SE | 16083 | 4 | 43.367 | 147.283 | 15 | 0.38 | 0.73 | B | B | B | B |
| TASMANIA SE | 16083 | 39 | 43.367 | 147.283 | 13 | 0.34 | 0.65 | | | | |
| VICTORIA CAPE OTWAY to LORNE | 16052 | 5 | 38.733 | 143.433 | 12 | 0.42 | 0.69 | | | | |
| VICTORIA CAPE OTWAY to LORNE | 16052 | 9 | 38.733 | 143.433 | 17 | 0.46 | 0.76 | | | | |
| VICTORIA CAPE OTWAY to LORNE | 16052 | 12 | 38.733 | 143.433 | 17 | 0.51 | 0.84 | W | W | W | W |
| VICTORIA CAPE OTWAY to LORNE | 16052 | 38 | 38.733 | 143.433 | 19 | 0.44 | 0.76 | W | W | W | W |
| VICTORIA CAPE OTWAY to LORNE | 16053 | 50 | 38.750 | 143.433 | 20 | 0.44 | 0.78 | B | B | | |
| VICTORIA CAPE OTWAY to LORNE | 16054 | 26 | 38.750 | 143.417 | 9 | 0.49 | 0.80 | W | W | | |
| VICTORIA CAPE OTWAY to LORNE | 16055 | 24 | 38.767 | 143.417 | 18 | 0.20 | 0.39 | B | B | | W |
| VICTORIA CAPE OTWAY to LORNE | 16056 | 14 | 38.817 | 143.567 | 13 | 0.43 | 0.73 | W | W | | |
| VICTORIA CAPE OTWAY to LORNE | 16056 | 34 | 38.817 | 143.567 | 14 | 0.21 | 0.43 | | | B | |
| VICTORIA CAPE OTWAY to LORNE | 16056 | 44 | 38.817 | 143.567 | 15 | 0.49 | 0.80 | W | | W | W |
| VICTORIA CAPE OTWAY to LORNE | 16056 | 63 | 38.817 | 143.567 | 15 | 0.39 | 0.70 | W | W | W | W |
| VICTORIA CAPE OTWAY to LORNE | 16059 | 11 | 38.850 | 143.550 | 13 | 0.35 | 0.62 | | | B | B |
| VICTORIA CAPE OTWAY to LORNE | 16060 | 22 | 38.683 | 143.833 | 19 | 0.46 | 0.80 | W | W | W | W |
| VICTORIA CAPE OTWAY to LORNE | 16224 | 1 | 38.817 | 143.567 | 12 | 0.42 | 0.77 | | | W | |
| VICTORIA CAPE OTWAY to LORNE | 16224 | 6 | 38.817 | 143.567 | 15 | 0.55 | 0.92 | W | W | W | |
| VICTORIA CAPE OTWAY to LORNE | 16224 | 32 | 38.817 | 143.567 | 19 | 0.38 | 0.70 | | | | |
| VICTORIA CAPE OTWAY to LORNE | 16224 | 41 | 38.817 | 143.567 | 19 | 0.38 | 0.71 | | W | | |
| VICTORIA CAPE OTWAY to LORNE | 16224 | 78 | 38.817 | 143.567 | 19 | 0.39 | 0.74 | | B | | |
| VICTORIA CAPE OTWAY to LORNE | 16225 | 23 | 38.783 | 143.583 | 12 | 0.50 | 0.88 | | | W | |
| VICTORIA CAPE OTWAY to LORNE | 16225 | 82 | 38.783 | 143.583 | 15 | 0.48 | 0.80 | W | W | W | W |
| VICTORIA CAPE OTWAY to LORNE | 16226 | 33 | 38.800 | 143.617 | 17 | 0.44 | 0.81 | | | W | W |

Cont.

Table 7. Continued.

| REGION | PROVENANCE | FAMILY | LATDD | LONDD | NUMBER ASSESSED | MORPHOLOGY ALL CLASSES | MORPHOLOGY CLASSES 4&5 | BEST AND WORST QUARTILES ALL CLASSES MEAN LDAM | CLASS 2 LDAM | CLASSES 4&5 LDAM | CLASSES 4&5 RESIDUALS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| VICTORIA CAPE OTWAY to LORNE | 16226 | 56 | 38.800 | 143.617 | 14 | 0.49 | 0.86 | W | | | |
| VICTORIA CAPE OTWAY to LORNE | 16226 | 79 | 38.800 | 143.617 | 15 | 0.46 | 0.77 | | | | B |
| VICTORIA CAPE OTWAY to LORNE | 16227 | 84 | 38.783 | 143.617 | 19 | 0.56 | 0.90 | W | | W | W |
| VICTORIA CAPE OTWAY to LORNE | 16240 | 3 | 38.750 | 143.450 | 15 | 0.47 | 0.78 | W | | W | W |
| VICTORIA CAPE OTWAY to LORNE | 16240 | 19 | 38.750 | 143.450 | 14 | 0.34 | 0.61 | | | | |
| VICTORIA CAPE OTWAY to LORNE | 16240 | 29 | 38.750 | 143.450 | 12 | 0.44 | 0.73 | W | | W | W |
| VICTORIA CAPE OTWAY to LORNE | 16240 | 35 | 38.750 | 143.450 | 9 | 0.29 | 0.56 | | W | | W |
| VICTORIA CAPE OTWAY to LORNE | 16240 | 36 | 38.750 | 143.450 | 14 | 0.59 | 0.89 | W | | | B |
| VICTORIA CAPE OTWAY to LORNE | 16240 | 81 | 38.750 | 143.450 | 14 | 0.44 | 0.79 | | | | |
| VICTORIA CAPE OTWAY to LORNE | 16240 | 83 | 38.750 | 143.450 | 9 | 0.35 | 0.61 | W | W | W | W |
| VICTORIA CAPE OTWAY to LORNE | 16241 | 68 | 38.733 | 143.300 | 14 | 0.47 | 0.82 | W | W | W | |
| VICTORIA CAPE OTWAY to LORNE | 16401 | 20 | 38.667 | 143.800 | 14 | 0.49 | 0.82 | W | W | W | W |
| VICTORIA CAPE OTWAY to LORNE | 16401 | 80 | 38.667 | 143.800 | 12 | 0.49 | 0.85 | W | | W | W |
| VICTORIA CAPE OTWAY to LORNE | 16402 | 76 | 38.650 | 143.800 | 12 | 0.48 | 0.77 | W | W | W | |
| VICTORIA CAPE OTWAY to LORNE | 16402 | 77 | 38.650 | 143.800 | 19 | 0.42 | 0.72 | W | W | W | W |
| VICTORIA CAPE OTWAY to LORNE | 16405 | 10 | 38.600 | 143.900 | 17 | 0.45 | 0.81 | | | | |
| VICTORIA CAPE OTWAY to LORNE | 16407 | 46 | 38.533 | 143.933 | 15 | 0.53 | 0.87 | W | W | W | |
| VICTORIA SOUTH GIPPSLAND | 16066 | 18 | 38.333 | 146.500 | 15 | 0.30 | 0.57 | | B | | W |
| VICTORIA SOUTH GIPPSLAND | 16066 | 21 | 38.333 | 146.500 | 15 | 0.38 | 0.72 | | | W | W |
| VICTORIA SOUTH GIPPSLAND | 16066 | 47 | 38.333 | 146.500 | 17 | 0.36 | 0.63 | | | | |
| VICTORIA SOUTH GIPPSLAND | 16066 | 59 | 38.333 | 146.500 | 14 | 0.25 | 0.46 | | | B | |
| VICTORIA SOUTH GIPPSLAND | 16066 | 61 | 38.333 | 146.500 | 11 | 0.31 | 0.57 | | B | | W |
| VICTORIA SOUTH GIPPSLAND | 16066 | 71 | 38.333 | 146.500 | 14 | 0.30 | 0.55 | | W | | |
| VICTORIA SOUTH GIPPSLAND | 16068 | 16 | 38.333 | 146.550 | 20 | 0.31 | 0.56 | B | B | | |
| VICTORIA SOUTH GIPPSLAND | 16068 | 28 | 38.333 | 146.550 | 13 | 0.35 | 0.63 | B | B | | |
| VICTORIA SOUTH GIPPSLAND | 16068 | 30 | 38.333 | 146.550 | 14 | 0.36 | 0.64 | | | | |
| VICTORIA SOUTH GIPPSLAND | 16068 | 57 | 38.333 | 146.550 | 13 | 0.39 | 0.67 | W | W | | |
| VICTORIA SOUTH GIPPSLAND | 16319 | 7 | 38.317 | 146.550 | 16 | 0.51 | 0.80 | W | W | | B |
| VICTORIA SOUTH GIPPSLAND | 16319 | 15 | 38.317 | 146.550 | 15 | 0.42 | 0.72 | B | B | | |
| VICTORIA SOUTH GIPPSLAND | 16319 | 17 | 38.317 | 146.550 | 10 | 0.24 | 0.40 | | W | B | |
| VICTORIA SOUTH GIPPSLAND | 16319 | 42 | 38.317 | 146.550 | 15 | 0.42 | 0.75 | | | | B |
| VICTORIA SOUTH GIPPSLAND | 16319 | 45 | 38.317 | 146.550 | 13 | 0.32 | 0.56 | B | | B | |
| VICTORIA SOUTH GIPPSLAND | 16319 | 52 | 38.317 | 146.550 | 18 | 0.32 | 0.57 | | | | |
| VICTORIA SOUTH GIPPSLAND | 16319 | 54 | 38.317 | 146.550 | 12 | 0.45 | 0.69 | | | | |
| VICTORIA SOUTH GIPPSLAND | 16319 | 62 | 38.317 | 146.550 | 16 | 0.30 | 0.55 | B | B | | |
| VICTORIA SOUTH GIPPSLAND | 16319 | 66 | 38.317 | 146.550 | 12 | 0.42 | 0.75 | | | | |
| VICTORIA SOUTH GIPPSLAND | 16319 | 70 | 38.317 | 146.550 | 19 | 0.38 | 0.70 | | | | B |
| VICTORIA SOUTH GIPPSLAND | 16319 | 72 | 38.317 | 146.550 | 19 | 0.46 | 0.75 | | | | |
| VICTORIA SOUTH GIPPSLAND | 16319 | 75 | 38.317 | 146.550 | 14 | 0.41 | 0.70 | | | | |
| VICTORIA SOUTH GIPPSLAND | 16400 | 40 | 38.617 | 146.350 | 18 | 0.47 | 0.81 | | B | W | |

damage than mainland provenances, except for south east Tasmanian provenances that also performed well. The single north east Tasmanian provenance sustained greater damage to juvenile leaves than other provenance regions, contrasting with observations on thirteen north east Tasmanian provenances by Farrow et al. (1994) who found this provenance region ranked as third best of eight regions considered.

The positive correlation between proportion of adult foliage and damage is paradoxical considering class 2 leaves, which were virtually all juvenile morphology, had greatest damage. These observations probably indicate changes over time to the suite of leaf chewing insects present and their feeding preferences in terms of position in the canopy, leaf age and leaf morphology.

The insignificance of a leaf morphology effect in leaf classes 2 and 5, and to a lesser extent leaf class 3, could be explained by the unbalanced distribution of leaf morphology scores in these leaf classes. Tree crowns had all juvenile foliage in leaf class 2 except two cases and leaves were predominantly of adult morphology in leaf class 5. Foliage in leaf class 3 consisted mainly of a mixture of adult and juvenile morphologies, with relatively few cases of only adult foliage or only juvenile foliage.

Selection for resistance to damage by phytophagous insects is often regarded as difficult for several reasons. Temporal uncertainty of sufficient damage to allow measurable variation between genotypes has been perceived as a constraint (Floyd and Farrow 1994), and most identifications of insect resistant stock have been consequent upon outbreak damage by single pest species. The observations reported here show consistent and significant variation between provenance regions and families at small but chronic amounts of damage usual in Western Australian plantations of *E. globulus*.

A broad suite of phytophagous insects were active in the plantation. We believe, from knowledge of distinct differences between insect groups in feeding preferences of foliage morphology and age, and the appearance of damage they cause, that the leaf classes assessed at Mt Barker were subject to differently structured suites of chewing insects. In particular, larvae of *M. privata* were most important in the lower half of crowns while *Catasarcus* spp and Chrysomelid beetles and larvae were most important in the upper half of crowns. It is surprising, given differences in leaf morphology across leaf classes, that the relative performance of provenance regions was consistent regardless of leaf age and position in the crown. The King Island provenance was exceptional by showing a complete reversal of rank from least damaged old juvenile leaves to most damaged young, usually adult leaves in the top half of their crowns.

Farrow et al. (1994) rated damage to juvenile leaves of *E. globulus* at two sites in Victoria, one where *M. privata* was active while at the other both *M. privata* and *P. froggatti* were active. Consistency of ranks across trials of provenance regions common to both trials was interpreted by the authors as evidence of cross resistance to the two insect species. The superior performance of Furneaux Group families in the current study, especially with the effect of leaf morphology removed, is indicative of inherent resistance to damage by leaf chewing insects of both adult and juvenile foliage, and is characteristic of this provenance region. In the absence of a demonstrated mechanism of resistance and only an inferred history of attack by leaf chewing species, we hypothesize that families from this provenance region exhibit resistance to chewing by several insect species.

There is scant knowledge of the links between eucalyptus leaf qualities and damage by insect phytophages (briefly reviewed by Floyd and Farrow 1994). We classified leaves according to age, gross morphology and position in the crown and found all three variables influenced the amount of leaf damage. The significant provenance region effect, in the presence of a leaf morphology effect on variation in leaf damage in each leaf age class, points to other leaf qualities affecting leaf damage. Understanding these qualities is vital to properly balancing the selective pressures on insect populations and anticipating the effects of tree selection and breeding on the structure of insect populations in plantations.

Selection for superior growth rates may coincidentally select for resistance to insect damage in conditions of outbreak defoliation due to the impact of defoliation on growth (Raymond 1995). At the small amount of damage observed at Mt Barker, and given the young age of the trees, leaf damage is probably only weakly correlated with growth. We are unable to test the validity of the assumption implicit in selecting for high growth rates, that such a selection minimises the effects of damage by leaf insects. An analysis awaits the gathering of growth data from the Mt Barker trial.

Further investigation of regional differences in insect population structures is planned, whereby damage and insect populations on standard *E. globulus* families would be analysed from geographically dispersed plantations.

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