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Timing and frequency are the critical factors affecting the impact of defoliation on long term growth of plantation eucalypts

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ABSTRACT

Insect defoliation of plantation *Eucalyptus* sp. is a ubiquitous problem, not only in their native Australia but also in many other countries where Australian defoliators have invaded the introduced eucalypt plantations. Although eucalypts are very resilient to defoliation, their growth suffers and reduces the economic benefits of the resource. An artificial defoliation trial investigated the critical factors relating to patterns of insect defoliation that affect the long-term growth of the plantation eucalypt, *E. nitens*, in Tasmania, Australia. Current season's adult-phase foliage was removed manually from two- to three-year-old trees to test four factors: severity (50% or 100% of current adult foliage, equivalent to 11% or 25% of total foliage); disbudding following defoliation (with or without disbudding), timing of defoliation (early or late in the summer) and frequency (for one or two consecutive years). Growth parameters of the trees were measured annually for four years after the initial defoliation, and again thirteen years later, before harvest. The most significant factors affecting the growth of the trees were timing and frequency of defoliation; severity of defoliation and disbudding did not have significant effects over the long term. Trees that received either light or heavy defoliation late in the season for two consecutive years were at least 17% smaller in diameter and MAI in diameter was reduced by at least 21% compared to untreated trees over one rotation. This means they would need to be grown for three to four more years to reach the same stand volume as undefoliated trees at harvest. This would have serious cost implications for plantation managers. To prevent these economic losses, an integrated pest management system should focus on protecting eucalypts from defoliation of 50% or more of current season's adult foliage late in the summer, and in particular, preventing defoliation from occurring in concurrent years. In addition, the continual decline in growth rates of defoliated trees relative to undefoliated trees beyond the initial four years of measurement also suggests that defoliation impacts predicted by models based on short term studies may need to be treated conservatively.

1. Introduction

Defoliation of eucalypts is ubiquitous in Australian native forests and plantations since they host numerous native defoliators (Elliott et al., 1998). In Tasmania and other Australian states, many insect species, but particularly chrysomelid leaf beetle species, have been recorded as causing chronic defoliation of native forests and eucalypt plantations (Bashford, 1993; Carne, 1966; de Little, 1989; Greaves, 1966; Loch and Floyd, 2001; Nahrung, 2006). Australian defoliating insects are also invading exotic eucalypt plantations around the world (Horgan, 2011; Paine et al., 2011; Rivera et al., 1999; Tribe and Cillie, 1997; Withers, 2001). Eucalypts are very resilient to defoliation. For example, a Western Australian eucalypt survived 100% defoliation annually for 13 years, although it stopped growing after three years of defoliation (Wills et al., 2004). While eucalypts are rarely killed by defoliation, their growth is retarded, which can make the difference between profit and loss in a commercial crop. Eyles et al. (2013) recently reviewed the numerous trials that have assessed the impact of defoliation of eucalypts on their growth, carried out on different species, ages, site conditions with different methods of assessment. Most trials assessed trees for less than seven years after defoliation and only four assessed the long term effects of defoliation. Wills et al. (2004) defoliated saplings annually for 15 years but only Loch and Matsuki (2010) have previously measured the impact of several years of early defoliation on growth of plantation eucalypts at harvest.

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Since defoliation damage is so ubiquitous in Australian plantations, it would not be cost-effective to prevent it altogether. Development of an Integrated Pest Management (IPM) system to prevent economic losses of a crop resource when it is attacked by insect defoliators, such as chrysomelid leaf beetles, requires evaluation of many components relating to the biology of the pest and its impact on the crop (e.g. Baker et al., 2002; Candy et al., 1992; Candy and Baker, 2002; Clarke et al., 1997; de Little, 1983; Elek, 1997; Elek and Patel, 2016; Fanning and Baars, 2014; Horgan, 2011; Nahrung, 2004; Nahrung and Allen, 2004; Nahrung et al., 2008b), interaction with their natural enemies (Baker et al., 2003; Bashford, 1999; de Little, 1982; de Little et al., 1990; Nahrung et al., 2008a; Murphy, 2006; Rice, 2005), as well as effective control measures and their relevant costs and benefits (Beveridge and Elek, 1999; Candy, 1999; Elek and Beveridge, 1999; Elek and Wardlaw, 2013; Elek et al., 2004, 2011; Elliott et al., 1992). Detection and identification of an insect pest should not be the only triggers for control measures, particularly if they are native insects in their home range. The economic injury level that should be used to trigger control measures requires evaluating the relationship between level of defoliation and growth loss. Growth loss is influenced, not only by the severity of the defoliation, but also by the pattern of defoliation over time, such as in what season the defoliation occurs and how often it is repeated.

The aim of this paper is to evaluate what factors of defoliation have the greatest influence on growth of plantation eucalypts over their rotation. This was carried out by measuring the growth response of *Eucalyptus nitens* (Deane & Maiden) Maiden plantation trees after implementing various patterns of defoliation. Defoliation of adult-phase foliage was carried out manually to simulate defoliation by the leaf beetle *Paropsisterna bimaculata* (Olivier). Different treatments tested the severity of defoliation, the occurrence of disbudding, the seasonal timing and defoliation in consecutive years. This paper reports the detailed impact of the various treatments on the trees during the first four years after treatment and then just before harvest, thirteen years after defoliation.

2. Methods

2.1. Site description

This trial was carried out in a first rotation *Eucalyptus nitens*, Torongo provenance, plantation. The location was at Blue Gum Knob, near Moogara, southern Tasmania, Australia (42°50′S, 146°53′E), altitude 430 m, planted in 1992 by Australian Newsprint Mills. Trees were planted at 1250 stems per ha and fertilised at planting with 100 g of triple superphosphate per tree. The site index of the stand, defined as the mean dominant height at age 15, was estimated to be 27.2 m. The site was managed for pulpwood, with no pruning or thinning of trees after planting.

2.2. Treatments

Trees were selected in October 1994 within the height range 4–5.3 m with adult phase foliage (i.e. that susceptible to defoliation by *Paropsisterna bimaculata* which does not consume juvenile phase foliage of *E. nitens*) visually estimated to comprise greater than 5% of the total leaf area and greater than 20% of the total tree height. Twelve treatments and untreated controls were randomly assigned to the selected trees in blocks of 15 replicates. The treatment defoliations were carried out during the summers of 1994–95 and 1995–96 when the trees were age two and three years respectively. Treatments aimed to evaluate the importance of four factors on the growth of the trees: severity of defoliation, removal of new buds after initial defoliation, frequency and seasonal timing of defoliation (Table 1). The first two factors were chosen to test the range from mild to most severe cases of defoliation when older larvae and adult beetles, after eating all the current foliage, will eat the young buds and even the bark of new shoots. Disbudding had also been shown to have an impact in an earlier trial, as had the frequency and seasonality of defoliation (Candy et al., 1992). The defoliation season treatments were chosen to represent defoliation by larval (Early) and first generation adult (Late) *P. bimaculata* (pers. obs.).

Treatment details are as follows:

Controls:

UNTREATED CONTROLS - All block replicates included an untreated control (CONT). Some additional Control trees were allocated to each block which were used to replace trees that were damaged during the first year of treatment, or Control trees that could not be located during the last measurement.

Severity:

HEAVY defoliation involved a single removal of 100% of the current season's growth of adult foliage. The current season's foliage was soft and reddish to bright green in colour. The current season's fully expanded leaves were differentiated from the previous season's foliage by the greater toughness and darker green colour of the latter.

LIGHT defoliation involved removing 50% of current season's adult foliage.

The percentage foliage removed was estimated visually based on the percentage leaf area removed rather than the number of leaves. Biomass trees (see below) were used to determine the percentage of current season's and total foliage actually removed in these treatments.

Timing:

EARLY - defoliation was performed in December, to correspond to naturally occurring defoliation by third and fourth instar *P. bimaculata* larvae;

LATE - defoliation was performed in February, to correspond to naturally occurring defoliation by F1 adult *P. bimaculata.*

Table 1
Details of thirteen manual defoliation treatments, each randomly assigned within fifteen blocks.

Code	Treatment	Severity	Disbudding	Season	Frequency
CONT	Control	None	None	None	None
LE1	Light Early Yr1	Light	None	Early	1 year
LE2	Light Early Yrs1and2	Light	None	Early	2 years
LLa1	Light Late Yr1	Light	None	Late	1 year
LLa2	Light Late Yrs1and2	Light	None	Late	2 years
LDE1	Light Disbud Early Yr1	Light	Disbud	Early	1 year
LDLa1	Light Disbud Late Yr1	Light	Disbud	Late	1 year
HE1	Heavy Early Yr1	Heavy	None	Early	1 year
HE2	Heavy Early Yrs1and2	Heavy	None	Early	2 years
HLa1	Heavy Late Yr1	Heavy	None	Late	1 year
HLa2	Heavy Late Yrs1and2	Heavy	None	Late	2 years
HDE1	Heavy Disbud Early Yr1	Heavy	Disbud	Early	1 year
HDLa1	Heavy Disbud Late Yr1	Heavy	Disbud	Late	1 year