



Effect of stem guying on the incidence of resin pockets

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ARTICLE INFO

Article history:

Received 15 April 2009

Received in revised form 2 July 2009

Accepted 16 July 2009

Keywords:

Dendrometers

Pinus radiata

Resin pockets

ABSTRACT

Although resin pockets are a major cause of degrade for appearance grade timber, little is known about the environmental conditions that control the incidence of these defects. Water stress and mechanical bending stress due to tree sway in strong winds are thought to contribute to the formation of resin pockets, but this is based on anecdotal evidence from observations of resin pocket occurrence. Controlled experiments are required to better understand the factors leading to resin pocket formation.

In this study data were analysed from an experiment on a dryland site, where 14-year-old *Pinus radiata* D. Don trees were guyed or left in an untreated unguyed condition from July 2006 to September 2008. Measurements of stem diameter were taken on all trees using dendrometer bands. At the end of the experiment in September 2008 resin pocket frequency was determined by cutting the lower 6 m of each tree into 50 mm sections. Each of these sections was then imaged and resin pockets were identified and allocated to a type, height and year of occurrence. Using these data, the aims of this research were to (i) determine how the reduction of tree sway through guying influences tree diameter increment and (ii) investigate the main and interactive effects of tree height, year of formation and guying on the incidence of both Type 1 and Type 2 resin pockets.

Treatment divergence in cumulative diameter increment occurred 6 months after guying was applied and by the end of the experiment cumulative diameter increment of unguyed trees significantly ($P = 0.046$) exceeded that of guyed trees by 34% (19.3 vs. 14.3 mm). Differences in increment rate between treatments were significant on four of the monthly measurement intervals, with increment rate of unguyed trees exceeding that of guyed trees on all four occasions, by up to 184% (0.044 vs. 0.015 mm day⁻¹). Differences in increment rate between treatments were most marked during periods of low rainfall.

Compared to the unguyed control, guying significantly ($P = 0.049$) reduced the incidence of Type 1 resin pockets by on average 54% (3.73 vs. 1.73 resin pockets year⁻¹). Although the incidence of Type 2 resin pockets was also reduced through guying by 45% (2.20 vs. 1.20 resin pockets year⁻¹) this reduction was not significant ($P = 0.28$). Both tree height and year of occurrence had a highly significant ($P < 0.001$) influence on frequency of both resin pocket types.

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1. Introduction

Resin pockets are found in the xylem of conifers that have resin ducts (e.g. *Pinus* spp. and *Picea* spp.). In New Zealand resin pockets are a major cause of degrade in the clearwood zone of pruned *Pinus radiata* D. Don logs (Park and Parker, 1982). A national survey of resin pockets was undertaken by Cown (1973), based on a questionnaire sent to forest managers throughout New Zealand. It was found that resin pockets are present in nearly all exotic forests, but epidemic levels were only reached in Canterbury, which is a

dry and windy region. However, recent studies by the Plantation Management Cooperative (Cox and Tomblason, 2003) indicate that the incidence of resin pockets is also high in stands sampled in coastal Bay of Plenty, Bombay and Hawke's Bay.

Three types of resin pockets were described by Somerville (1980). Type 1 resin pockets are radially narrow discontinuities in the wood that are oval in the tangential-radial plane and filled with oleoresin and callus tissue. Type 2 resin pockets are similar to Type 1, but are radially flattened, contain less callus tissue, and open to the external environment at early stages in their development. They later become occluded by cambial overgrowth with the formation of an occlusion scar that may be retained across several subsequent growth rings. Type 3 resin pockets originate as lesions in the cambial zone. Surrounding healthy cambium occludes

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causing an occlusion scar similar to that of Type 2 resin pockets. Generally, no distinction is made between Type 2 and Type 3 resin pockets.

It is important to understand the environmental and silvicultural factors that contribute to the formation of resin pockets, so that their incidence in logs intended for appearance-grade lumber can be reduced. There are differences of opinion in the published literature as to the cause of resin pockets. Frey-Wyssling (1938, 1942) contended that resin pockets are formed by mechanical bending stress due to exposure to strong winds. These stresses result in a tangential rupture of the cambium, which form into resin pockets. Wind exposure was proposed by Clifton (1969) as the cause of the high incidence of resin pockets on the Canterbury plains. A significant amount of anecdotal evidence was present to support this claim. However, Cown (1973) argues that water stress, rather than exposure to strong winds is the main factor associated with the formation of resin pockets. This is based on the observation that resin pockets appear to be associated with false rings, which in turn are an indirect effect of drought on xylem formation.

None of these studies that attempt to identify the cause of resin pockets are based on data from controlled experiments. One known controlled experiment was performed by Temnerud et al. (1999) who applied bending stresses to 5-year-old Scots pine (*Pinus sylvestris* L.) trees during dormancy and/or growth. They found that approximately 30% of the stems that were exposed to bending stresses during growth had xylem wounds, whereas those stems exposed during dormancy and non-exposed controls did not exhibit xylem wounds. Because these wounds were similar to naturally occurring resin pockets, Temnerud et al. (1999) concluded that mechanical bending stress due to wind loading could lead to the formation of resin pockets.

A recent study (Downes et al., 2008) found resin blemishes were almost invariably related to Type 2 resin pockets, resulting from the centripetal transport of resin towards the pith from an event that was sufficient to cause the localised death of cambial initials. This initiated a wound response typified by the production of resin. In contrast, Type 1 pockets were not associated with resin blemishes, presumably because the localised cambial damage that caused them did not destroy the cambial initials. There was a consistent distinction between Type 1 and 2 pockets with the former generally occurring within the first 50% of the growth ring and the latter in the second 50%.

The hypothesis tested in this study was that resin pockets are caused by localised damage to the cambium experienced during wind events. To address this hypothesis, data was analysed from an experiment on a dryland site, where 14-year-old *P. radiata* trees were guyed or left in an untreated unguyed condition from July 2006 to September 2008. Using these data the objectives of this study were to (i) examine how the imposition of guying influenced tree diameter increment and (ii) determine the main and interactive effects of year of formation, height within stem and guying treatment on the incidence of Type 1 and 2 resin pockets.

2. Methods

2.1. Site description and treatments

Measurements were taken from a *P. radiata* plantation located near Christchurch (latitude 43° 28' S, longitude 172° 23' E, elevation 90 m a.s.l.). The soil at this site, which is classified as a Waimakariri very stony sand and very stony sandy loam, is shallow and very free draining (Kear et al., 1967). Very severe seasonal water deficits are characteristic of this soil and are common at this location as the long term annual rainfall is low (624 mm yr⁻¹) and evaporative demand over spring and summer is high. This site also

commonly experiences strong winds from both the northwest and southerly direction.

The plantation was established in 1992 using an improved seedlot with a growth and form rating of 14¹. Boron Ulexite was applied in July 1994 at 60 kg ha⁻¹ and in April 2001 the site was thinned to waste to a stocking of 700 stems ha⁻¹. This site was selected as 80% of trees demonstrated external resin bleeding, which has been found previously to be a good indicator of resin pocket frequency (Cown et al., submitted for publication).

Five pairs of trees exhibiting high levels of external resin bleeding were identified and selected for investigation. Pairs were selected, as much as possible, to be growing close to each other and to be of similar size and form. One tree of each pair was selected at random as a control tree and the other guyed to minimise wind-mediated swaying. Selected trees ranged in height from 10 to 15 m during July 2006.

In July 2006, guying treatments were installed. Each guyed tree was stabilised by three metal cables attached to metal stakes driven ~1200 mm into the ground, placed 120° apart at a distance of ~5 m from the tree. A collar was placed around the stem at approximately 60% of tree height immediately above the closest whorl to this height. The height had been selected as the most appropriate to minimise sway by mechanical modelling (pers. comm. John Moore). Each of the three cables was attached to this collar and moderately tensioned with a view to resisting movement away from the vertical position.

Manual dendrometer bands were placed at 1.4 m above ground around each tree in September 2006. Tree diameter increment was measured at intervals of approximately 1 month.

2.2. Tree harvest

In September 2008, guying treatments were removed and all trees were destructively sampled. Each tree was felled and the lower 6 m of the stem was cut into 50 mm thick discs. The upper surface of each disc was cleaned. The disc was then placed on a back board and imaged using a high resolution colour camera. Images taken at 100 mm intervals were used for recording resin pocket occurrence.

2.3. Collecting resin defect

Each image was corrected to a constant scale (Downes et al., 2008) and descriptors for each defect recorded. Resin pockets were classified as Type 1 or Type 2 as described previously. As resin pockets are effectively a defect occurring in the circumferential direction, the co-ordinates of each end was marked and the tangential length of the pocket determined. For resin pockets, the year of occurrence and height were recorded. Following guying, resin pockets were allocated to three growing seasons that included 06/07, 07/08 and 08/09. The period for 08/09 only included 4 months of data prior to the tree felling.

2.4. Data analysis

The resin pocket raw data were screened and summarised prior to analysis. Measurements taken prior to 1998 were not used in the analysis, to ensure that almost all combinations of height and year of occurrence, over the 6 m stem section, were included in the final dataset. Exclusion of these data is unlikely to affect the results as the vast majority of resin pockets occurred after 1998. The resin pockets recorded in each disc (0.05 m) were summed over 0.5 m intervals, by year, for each tree to reduce the stochastic variation

¹ Growth and form rating reflect a seedlots relative genetic worth for growth and stem form.

associated with height above the ground, so that the effect of height on resin pocket incidence could be clearly discerned.

Tree diameter increment analyses use the cumulative diameter increment determined after installation of the dendrometer bands. Also included in analyses was the diameter increment rate determined as the difference in diameter between measurements divided by the measurement interval. Treatment differences in actual diameter were not significantly different at $P = 0.05$ at the start of the guying period.

All analyses were undertaken using SAS (SAS Institute, 2000). A mixed effects model that accounted for the repeated nature of measurements was used to examine the main and interactive effect of treatment and time on cumulative diameter increment and diameter increment rate after September 2006. Separate models were developed for Type 1 and 2 resin pockets. A mixed effects model with a nested structure was used to test the main and interactive effects of guying treatment, year, and height on incidence of resin pockets. In analyses, the term guying treatment tested the effect of guying on resin pocket incidence, after the instigation of guying treatments in July 2006. Residuals for all models were tested for normality and transformed as necessary to meet the underlying assumptions of the models used.

3. Results

3.1. Tree increment patterns

Cumulative increment was significantly affected by time ($P < 0.001$) with both treatments showing increases over the duration of the experiment. The significant interaction between treatment and time ($P < 0.001$) indicated that cumulative diameter increment exhibited different trajectories between treatments (Fig. 1a). Treatment divergence occurred 6 months after guying was applied, and by the end of the experiment cumulative diameter increment of unguyed trees significantly ($P = 0.046$) exceeded that of guyed trees by 34% (19.3 vs. 14.3 mm). Treatment differences in cumulative diameter increment were significant at $P = 0.05$ for three of the four final monthly measurements (Fig. 1a).

Diameter increment rate was significantly affected by time ($P < 0.001$), and the interaction between treatment and time ($P < 0.001$). Diameter increment rates were most marked during the growing season (September to May) with diameter increment rate in unguyed trees exceeding that of guyed trees by an average of 48% during these periods (Fig. 1b). Significant differences in diameter increment rate were noted during four of the monthly measurement intervals. These significant differences occurred in December 2006, May, October and December 2007, during which time increment rate in unguyed trees exceeded that of guyed trees by 118, 82, 65, and 184%, respectively (Fig. 1b).

When increment rate data for the winter period were excluded the analysis showed that diameter increment rate exhibited a significant ($P < 0.001$), positive relationship with mean daily rainfall over the measurement period (Fig. 2). Linear lines fitted separately to each treatment show that treatment differences were more marked at low mean daily rainfall rates, diverging to a common value at high mean daily rainfall (Fig. 2). Source of rainfall data?

3.2. Resin pocket incidence

The analysis of variance (Table 1) showed that Type 1 resin pockets were most significantly affected by year ($P < 0.001$), and height above the ground ($P < 0.001$). Averaged across all trees, the incidence of resin pockets showed a peaked relationship with tree height reaching a maximum number of 0.62 resin pockets year⁻¹ m⁻¹ at 2.25 m (Fig. 3a). Resin pocket frequency increased

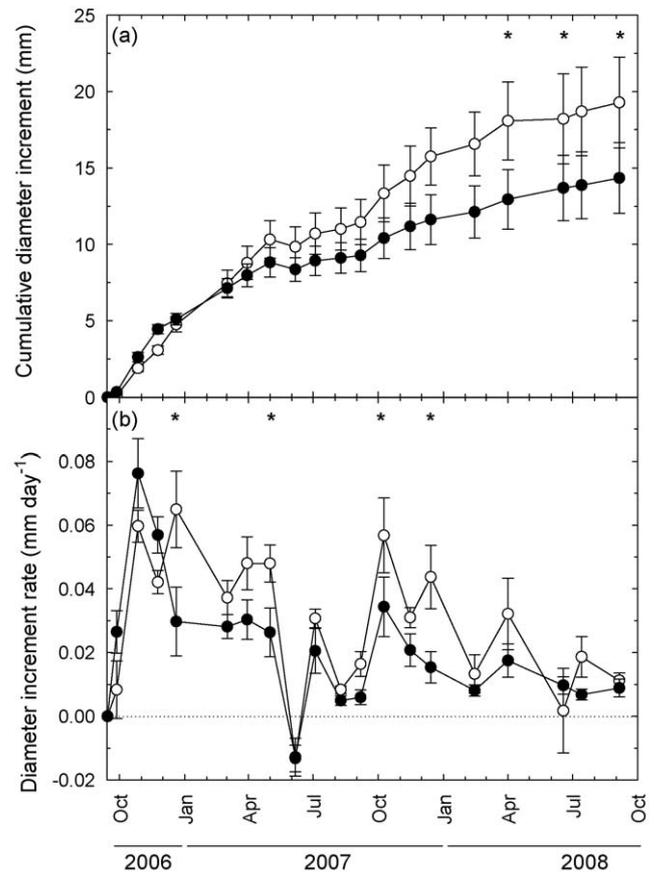


Fig. 1. Changes in (a) cumulative diameter increment and (b) diameter increment rate after guying was imposed for guyed (closed circles) and unguyed (open circles) trees. For both figures each value shows the mean \pm the standard error, from five trees. Asterisks at the top of each graph denote significant treatment differences at $P = 0.05$.

from 0 in 1998/99 to a maximum of 0.77 resin pockets year⁻¹ m⁻¹ in 04/05, before declining (Fig. 3b).

The imposition of guying had a significant ($P = 0.049$) influence on the incidence of Type 1 resin pockets (Table 1; Fig. 4a). Over the last three growing seasons guying reduced the incidence of resin pockets by on average 54% (Table 2). Although the interaction between treatment and year was not significant, resin pocket

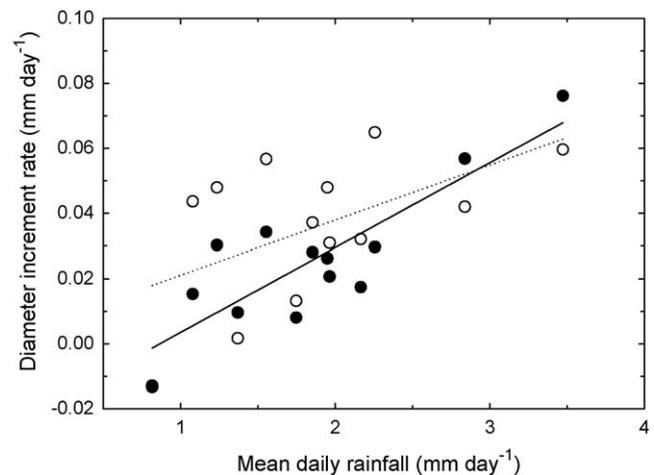


Fig. 2. Relationship between mean daily rainfall and diameter increment rate for guyed (closed circles) and unguyed (open circles) trees. Linear lines of best fit are also shown for guyed (solid line) and unguyed (dotted line) trees.

Table 1

Analysis of variance showing the significance of the main and interactive effects of treatment, year and height on resin pocket incidence for Type 1 and 2 resin pockets. All values shown are *P*-values.

Source of variation	Resin pockets	
	Type 1	Type 2
Treatment	0.049	0.28
Year	<0.001	<0.001
Height	<0.001	<0.001
Treatment × year	0.85	0.69
Treatment × height	0.54	0.15

incidence was relatively unaffected by guying during 07/08 (Fig. 4a) but substantially reduced during 06/07 and 08/09, by respectively 68% and 100%. Similarly, although there was no significant interaction between treatment and height, treatment effects were more marked at lower heights (Fig. 5). Resin pocket incidence in guyed trees was on average 19% of values in unguyed trees below 2 m, but on average 58% of values for unguyed trees above this height (Fig. 5).

The incidence of Type 2 resin pockets was significantly affected by both year and tree height ($P < 0.001$). Resin pocket incidence significantly declined with tree height from 1.40 to 0.22 resin pockets year⁻¹ m⁻¹ at respective heights of 0.75 and 5.25 m (Fig. 3a). The relationship between resin pocket incidence and year

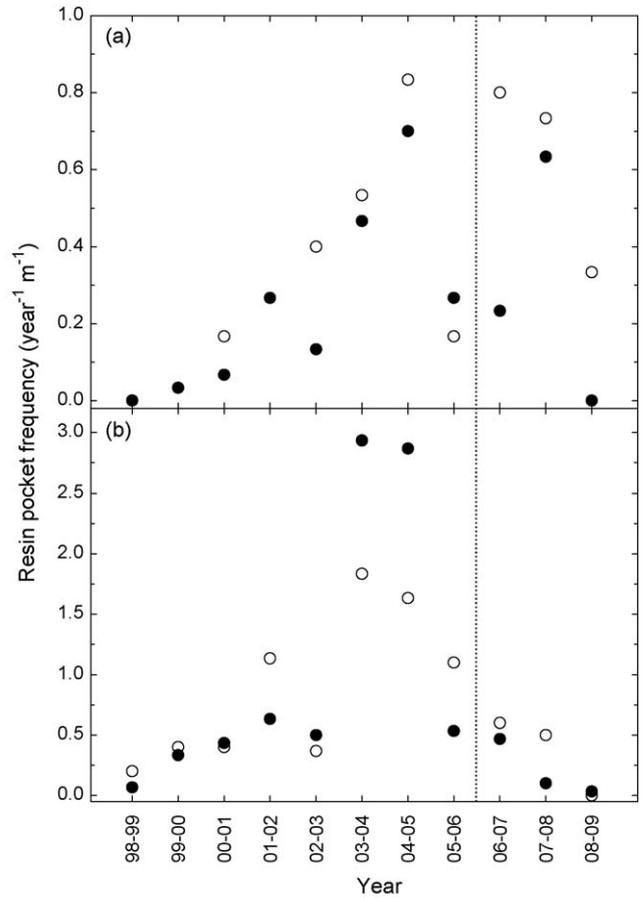


Fig. 4. Annual variation in (a) Type 1 and (b) Type 2 resin pocket formation for unguyed (open circles) and guyed (closed circles) trees. The dotted line represents the time of guying.

was strongly peaked, with a maxima of 2.38 resin pockets year⁻¹ m⁻¹ occurring during 03/04 (Fig. 3b).

Although the incidence of Type 2 resin pockets was reduced by on average 45% by guying (Table 2), neither treatment ($P = 0.28$) nor either of the interactions of treatment with year (Fig. 4b) or height (data not shown) significantly affected the incidence of Type 2 resin pockets.

4. Discussion

The findings from this study strongly suggest that resin pocket formation is at least partially influenced by tree sway. Although the incidence of both types of resin pockets was lower for guyed trees, these reductions were most marked and only significant for Type 1 resin pockets. As these results are from a controlled experiment they extend previous anecdotal research that has implicated wind as a contributing factor to resin pocket formation. The results also concur with Temnerud et al. (1999) who found bent Scots pine trees (*Pinus sylvestris* L.) had a higher incidence of xylem wounds, compared to unbent controls.

The substantial reductions in tree diameter increment induced by guying are consistent with previous research (Burton and Smith, 1972; Jacobs, 1954; Holbrook and Putz, 1989). These reductions were particularly marked during periods of low rainfall, during which time diameter increments in the guyed treatment were substantially lower than in the unguyed treatment. It is possible that this dampened increment response could result from a lower allocation of carbon to fine roots, stimulated by the reduced stem movement in guyed trees. Stokes et al. (1995) compared young

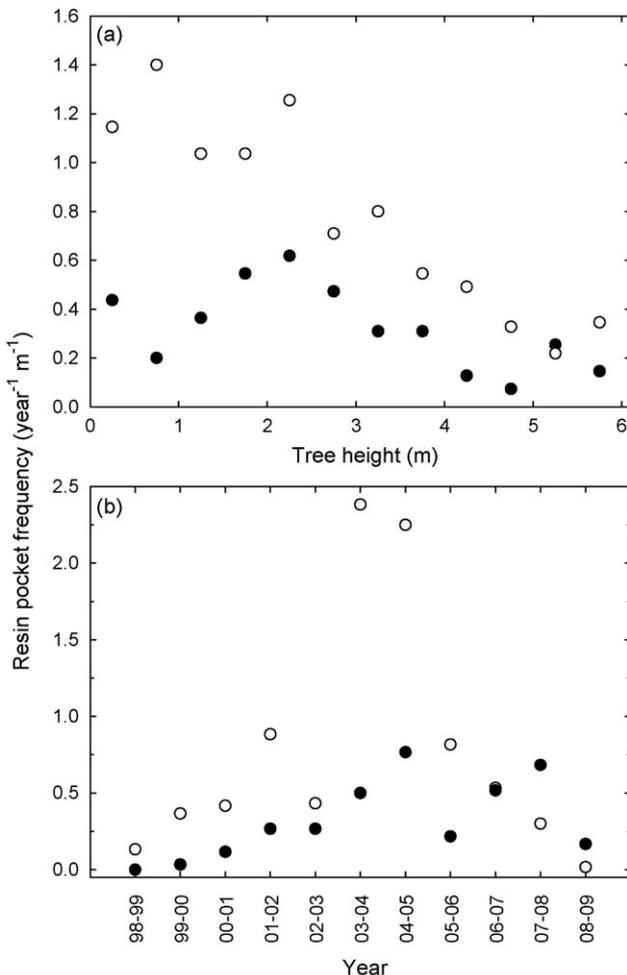


Fig. 3. Variation in resin pocket frequency with (a) tree height and (b) year for Type 1 (filled circles) and Type 2 (open circles) resin pockets.

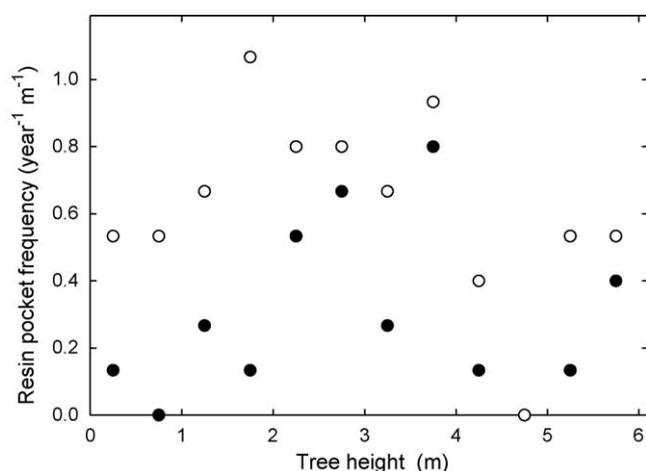


Fig. 5. Variation in Type 1 resin pocket frequency with height for, the post guying period, for guyed (closed circles) and unguyed trees (open circles). Values shown are the mean from the three growing seasons, during the post-guying period.

Table 2

Variation in the total number of resin pockets formed per year, over the lower 6 m of the tree, between control and guyed treatments, before and after guying.

Time	Treatment	Resin pockets	
		Type 1	Type 2
Before guying	Control	1.80	5.30
	Guyed	1.45	6.23
After guying	Control	3.73	2.20
	Guyed	1.73	1.20

trees exposed to wind with control trees and found wind exposure increased the number of coarse roots. Similarly, Downes and Turvey (1990), comparing guyed and unguyed seedlings, found guying treatments significantly reduced root collar diameter. Root mass in the guyed treatments was also lower but the difference was not statistically significant.

There are a number of possible mechanisms by which tree guying may reduce the incidence of resin pockets. It has been suggested that increased mechanical stress induced through stem bending in strong winds results in a tangential rupture of the cambium that forms resin pockets (Frey-Wyssling, 1942). Although this is a plausible explanation, more complex causes involving interactions between water stress and tree sway are also likely.

Variation in the incidence of resin pockets was also attributable to year of formation, tree height, and position within the ring. Type 1 resin pockets were similarly affected by height (range = 0.55 resin pockets year⁻¹ m⁻¹) and year (range = 0.77 resin pockets year⁻¹ m⁻¹). However, for Type 2 resin pockets, variation between years (range = 2.23 resin pockets year⁻¹ m⁻¹) exceeded height variation (range = 1.19 resin pockets year⁻¹ m⁻¹) by two-fold. As has been found previously (Downes et al., 2008), Type 1 resin pockets occurred primarily during the first 50% of the ring width (mean = 38%), whereas most Type 2 resin pockets occurred during the second half of the ring width (mean = 80%).

Although a treatment by year interaction was not noted in this study, reductions attributable to guying varied by year for both resin pocket types. For Type 1 resin pockets reductions were most marked during 06/07 and 08/09, and least marked during 07/08. In contrast, reductions in Type 2 resin pockets induced by guying were more marked during 07/08 than the other post treatment years. This variation does not necessarily indicate that different stimuli influence resin pocket formation for the two types. However, given the differential time of formation between Type

1 and Type 2 resin pockets, it is likely that if the same environmental cues influence formation of resin pockets, these occur during different times of the year.

The strong influence of year highlights the importance of determining how environment influences resin pocket formation. It is likely that a large part of this yearly variation reflects changes in tree age, and ring area. However, the wide fluctuations in Type 1 resin pockets, after 04/05, suggests that annual environmental variation is at least partially responsible for these inter-annual changes in resin pocket incidence.

In conclusion, this study clearly showed the significant effect of tree guying on both diameter increment and resin pocket formation. Although the effect of guying was most marked on the incidence of Type 1 resin pockets, the treatment also resulted in substantial reductions in Type 2 resin pockets. Further research should focus on determining possible mechanisms that can explain the reduced incidence of resin pockets in guyed trees. Given the wide variation in resin pockets between years, more research is also required to identify environmental determinants of this inter-annual variation. Use of this type of information could facilitate development of models that describe resin pocket formation. These models could potentially be used to identify sites prone to resin pockets and develop silvicultural strategies to reduce the incidence of resin pockets within sites.

Acknowledgements

We would like to acknowledge the support and help we received from a number of industry partners, in particular Graeme Young (Tenon) and Keith Mackie (WQI). There were many others not included in this list. From Scion we would like to thank Dave Henley, Jianming Xue and Jenny Grace.

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