FACTORS INFLUENCING THE FORMATION OF RESIN POCKETS IN PRUNED RADIATA PINE BUTT LOGS FROM NEW ZEALAND

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ABSTRACT

Resin pocket incidence is an important variable when assessing the potential appearance-grade quality of wood from *Pinus radiata* D. Don in New Zealand. High levels diminish value. Several theories have been proposed to explain the origin of resin pockets; in New Zealand researchers have considered silviculture to be an important factor.

A comprehensive database derived from stand sampling and sawing studies has been used to explore the relationship between butt log resin pocket incidence and twenty nine climatic, physical, soil and silvicultural variables. A total of 1055 sites, distributed over 281 stands in four distinct regions, were analysed. The incidence of butt log resin pockets ranged from 0 to 7.65 RP/m^2.

Multiple linear regression methods were utilised to build a prediction model. Initially, four significant predictors were isolated, vapour pressure deficit, solar radiation, a measure of wind damage and readily available water. Further analysis showed a fifth variable (tree diameter breast height/size of the defect core), also contributed to the model. The R^2 value of the equation was 0.50 and residual analysis showed the model to be generally unbiased over four locations.

Average daily October vapour pressure deficit made the biggest (58%) contribution to the regression and the coefficients were all positive except water availability which was negative, as expected. We interpreted these results to infer that stress (associated with moisture and exposure related issues) in conjunction with other factors, including accelerated growth, is a major cause of resin pocket incidence.

Keywords: resin pocket; butt log; climate, topography; silviculture; regression modelling, radiata pine.

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INTRODUCTION

This paper is concerned with analyses linking the incidence of resin pockets to a set of silvicultural, topographical, soil and climatic variables obtained in *Pinus radiata* forests resident in four central North Island areas of New Zealand (Bay of Plenty, Kaingaroa, Taupo/Turangi and Hawkes Bay).

Resin pockets are a common feature of softwoods with resin canals in the *Pinaceae* family (Clifton, 1969; Cown, 1973; Somerville, 1980; Temnerud, 1997) and are present to some extent in all New Zealand radiata pine stands. They are internal wood defects that cause appearance-grade timber and veneers to be degraded. High levels of resin pockets also reduce log value.

Several theories have been proposed to account for the formation and incidence of resin pockets. Temnerud (1997) defined the following four major groupings:

(1) Stem breakage due to wind;
(2) Internal stress;
(3) Pathological causes; and
(4) Combinations of (1) to (3), i.e. interactive causes.

(1) Cell collapse caused by wind-induced mechanical bending can lead to stem breakage. This is certainly supported by evidence for the New Zealand Canterbury plains. Higher incidence of resin pockets have also been observed on exposed ridges of Ashley forest (Clifton, 1969).

(2) Internal stress is considered a function of high water tension and poor cell strength (possibly caused by nutrient deficiencies). By linking resin pocket occurrence with false rings, Cown (1973) demonstrated that water stress, rather than strong winds, may be the primary factor in pocket formation. Nutrient deficiency may also be implicated.

(3) Pathological theories for resin pocket formation relate to injuries in tree phloem and xylem layers caused by insects and/ or micro-organisms (Temnerud, 1997). However, the current evidence for these theories is not strong in New Zealand. For example, Hood and Gardener (2002) eliminated *Armillaria* infection as a major cause of resin pocket formation.

In this paper we attempt to relate resin pocket incidence in *P. radiata* butt logs to a comprehensive set of silvicultural, topographic, soil and climatic variables.

MATERIALS AND METHODS

Data

Resin Pocket Data

The data analysed here were a subset of the database constructed by Interface Forest & Mill Ltd. from routine sampling of stands for pruned butt log quality between 1999 and 2007. Stems were sampled in sets of six spanning the stipulated diameter range and drawn from 3-5 sites within any stand, depending on size. Qualitative descriptions of topography, aspect, moisture and exposure were recorded for each site. Logs were extracted and transported to a small sawmill where they were flat sawn 'around the clock' to 25 mm boards until all of the defect core[1] was exposed. The mill setworks were used as a measuring instrument to acquire the internal variables required to facilitate calculation of Pruned Log Index and Clear Veneer Potential (Park, 2005) for individual logs but resin pocket incidence was recorded at the site level only.

Logs were sawn in their sets of six and the number of resin pockets (and other random defects) on the upper face of potentially "Clear and Shop Grade" boards for each set were counted manually as they were pulled from the green chain. Lumber from inside the pruned defect core was excluded.

Somerville (1980) defined three types of resin pocket. Although methods of recording the number and type of resin pockets (RP) varied and evolved over the eight year period of data collection, it was still possible to differentiate combined Type 1 and Type 2 pockets and the smaller, Type 3, pockets, which were classified separately. This paper considers only the total count of all resin pockets. The incidence of resin pockets (RP/m^2) has been defined as 'the average number observed per square metre of sawn surface area in timber from the clear and intermediate (clear-cuttings) zones of pruned logs (Park, 2004).

Resin pocket measurements were obtained for butt logs from sites within pruned stands resident in Bay of Plenty, Hawkes Bay, Kaingaroa and Taupo/Turangi. The distribution, numbers of samples and range of RP/m^2 are summarised in Table 1.

Physical and Topographical, Silvicultural, Climatic and Soil Data

Each site was allocated a NZ Map Grid Northing and Easting. In turn, these co-ordinates were addressed to the software Land Environment New Zealand (LENZ) (Leathwick et al., 2002) from which a variety of topographic, climatic and soil variables were generated. These are summarised in Table 2. Full definitions of these are given by Leathwick et al., 2002 and 2003.

[1] Defect core is the cylinder containing pith, branch stubs and occlusion scars. It includes any widening effects due to stem sinuosity at the time of pruning (Park, 1989).

Silvicultural data included the frequency, timing, intensity and mode (waste or production) of thinning as well as diameter of the defect core and diameter breast height (DBH).

October values for vapour pressure deficit (VPD) and wind were used because this is the month when strong and hot westerly winds are most prevalent across New Zealand (Leathwick et. al., 2003).

TABLE 1: Distribution of sites surveyed and the number of resin pockets found in them.

Region	Stands	Sites within each stand	Resin Pockets (RP)/m^2			
			Mean	S.D.	Min.	Max
Bay of Plenty	55	194	0.47	0.50	0	2.96
Hawkes Bay	39	113	1.01	0.91	0.03	7.65
Kaingaroa	86	380	0.37	0.36	0	2.50
Taupo/Turangi	101	368	0.31	0.33	0	3.10
TOTAL	281	1055				

Analyses

The resin pocket incidence data were averaged by stands, giving a sample size of 281, Table 1. The distribution of average stand resin pocket incidence was strongly left-skewed so a square-root transform was applied to each datum. This markedly normalised the distribution.

Preliminary analyses included searches for gross outliers in the data through principal component analysis (Manly, 2005), together with a series of correlation and graphical plots between the potential predictor variables and resin pocket intensity. These also served to improve the identification of the potential predictor variables associated with the response variable.

Multiple linear regression analyses were undertaken using a functional form:

$$RP^{0.5} = \beta_0 + \beta_1 X_1 + \ldots + \beta_n X_n \qquad [1]$$

where in [1]

RP = average stand resin pockets/m^2
X_i = any predictor variable
β_i = regression coefficient

TABLE 2: Thirty predictor variables that potentially affect resin pocket incidence.

Variable Type	Variable	Units
Physical and Topographical[a]	Northing	m
	Altitude	m
	Stem top-outs	%
	Exposure	Scale of 1 – 5
	Windthrow	%
Silvicultural	Age following first thinning	years
	Age following final thinning	years
	Residual Stocking following first thinning	Stems ha^{-1}
	Residual Stocking following final thinning	Stems ha^{-1}
	Thinning Type (waste or production)	-
	Average defect core diameter	mm
	diameter breast height (DBH)	mm
Climatic	Mean daily October Wind speed[c]	km/h
	Mean annual temperature	°C
	Minimum winter temperature	°C
	Monthly water balance	mm
	Mean annual rainfall	mm
	Annual solar radiation	MJ m^{-2} day^{-1}
	Winter solar radiation	MJ m^{-2} day^{-1}
	Monthly Ratio of rainfall to evaporation	-
	Average daily October vapour pressure deficit	kPa
	Number of Growing degree days[b]	-
Soil	Drainage	Scale of 1 - 5
	Acid soluble Phosphorus	Scale of 1 - 5
	Exchangeable Calcium	Scale of 1 - 4
	Particle size	Scale of 1 - 5
	Potential rooting depth[c]	Scale of 1 - 5
	Depth to a slowly permeable horizon[c]	Scale of 1 - 5
	Profile of readily available water[c] (expressed as discrete minimum values: 0, 25, 50, 75, 100 or 150)	mm
Calculated	STRES (average DBH / average defect core diameter)	-

[a] Easting was also available but was not considered because of difficulties in interpretation.
[b] see Leathwick et al., 2003 for definition
[c] from the Landcare Fundamental Soil layers (Newsome et al., 2000)

To avoid an excessive number of predictor variables, analyses were initially confined to the climate, soil and topographic variables. Even so, with the number of variables available, it was clear that considerable care would be needed to avoid the generation of unstable or incorrect models. A correlation matrix showed that the degree of correlation among the potential predictor variables was not high so the danger of multi-collinearity (Draper & Smith, 1998) occurring was slight. (With high correlations the consequent regression coefficients can be inaccurate).

The 'Best Subset' regression method (Draper & Smith, 1998: p. 329) was utilised using the SAS procedure REG to calculate all possible regressions, using in turn 1, 2,...up to 22 variables. For each equation, the diagnostic statistics Mallow's C_p (Daniel & Wood, 1971) and the Akaike Information Criterion (AIC) (Akaike, 1974) were obtained. Plots were constructed of these goodness-of-fit statistics against the number of parameters in the regressions (p). The two plots were virtually identical, both having clear minimal values around 4-5 parameters. This suggested at least seventeen of the predictor variables were ineffective or not required.

The five potential predictor variables identified were:

Climate:	Vapour pressure deficit;
Climate:	Annual solar radiation;
Physical:	Stem top-outs;
Physical:	Exposure; and
Soil:	Profile of readily available water.

Further regressions were constructed based only on these variables. The multiple regression construction options 'Backwards', 'Forwards' and 'Stepwise' (Draper & Smith, 1998) were all utilised using a probability $p = 0.01$ as the criterion for the addition or deletion of variables. All three methods led to a provisional model with four predictor variables, the exposure index not being required. As a final precaution, a stepwise regression was run with all twenty-two variables, which gave the same result.

The provisional model strongly suggested that various expressions of stress were influencing resin pocket intensity. Therefore, when considering which silvicultural variables might also contribute to the model, we tried to choose those that could be construed as expressions of stress-related conditions. Apart from the age and residual stocking, of trees following first and final thinnings, we created a ratio 'STRES' defined as the average breast height diameter divided by average defect core diameter. We also defined a simple dummy variable to distinguish between waste and production (later age) thinning. Stepwise regression analysis showed that the STRES ratio significantly improved the model, but no other important silvicultural variable emerged.

Finally, we checked whether alternative functional forms or first order interactions of any two variables improved the model. No interactions emerged but the stem top-out variable was improved by applying a square-root transform.

RESULTS AND DISCUSSION

The equation that gave the best regression was

$$RP^{0.5} = \beta_0 + \beta_1 VPD + \beta_2 STRES + \beta_3 TO^{0.5} + \beta_4 TSR + \beta_5 PRAW \qquad [2]$$

where in [2]

VPD = vapour pressure deficit (kPa)
STRES = average DBH / average defect core diameter
TO = stem topouts (%)
TSR = total solar radiation (MJ m^{-2} d^{-1})
PRAW = profile of readily available water (mm)

The multiple correlation, $R^2 = 0.50$ and the residual mean square = 0.03405. The parameter estimates and standard errors are given in Table 3:

TABLE 3: Regression coefficients and standard errors for Equation [2].

Variable	Regression Coefficient	Standard Error
Intercept	-4.86300	-
VPD	0.01239	0.00266
STRES	0.23450	0.04941
TO	0.08617	0.01424
TSR	0.03012	0.00578
PRAW	-0.00127	0.00046

The PRAW regression coefficient was significant, $p = 0.0079$. All other regression coefficients were also significant, $p < 0.0001$.

Residual plots confirmed that Equation [2] was virtually unbiased over the four regions. Figure 1 shows a histogram of the residual values separated by the regions.

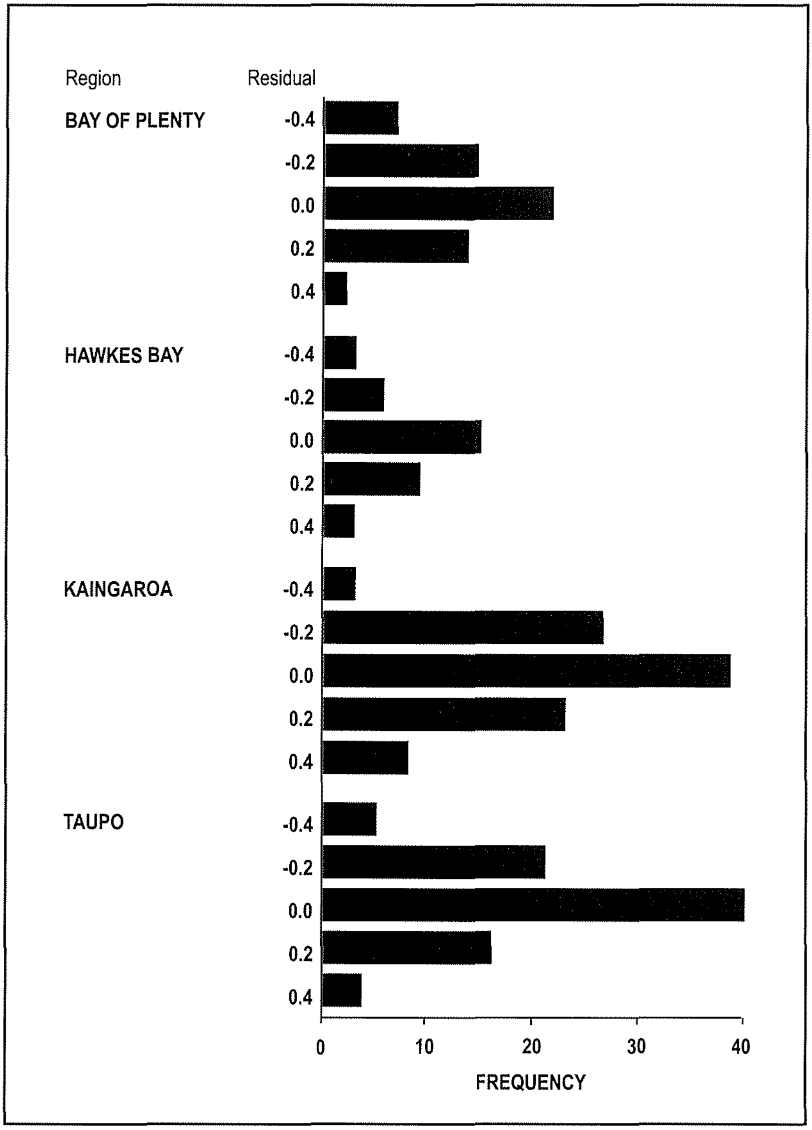

FIGURE 1: Histogram of residuals from Equation [2] by region.

Table 4 shows the predictor variables listed in order of importance to the model with their partial R-square values and the percentage contribution to the overall multiple correlation coefficient.

TABLE 4: Contribution of individual variables to the equation goodness-of-fit.

Predictor	Partial R^2	Contribution (%)
VPD	0.297	58
TO	0.091	18
TSR	0.065	13
STRES	0.038	8
PRAW	0.014	3

The most important of the predictor variables tested was the average October VPD. This variable is the capacity of air to take up water vapour and is dependent on temperature and humidity. If VPD is thought of as 'the potential sucking power of air' then it is easy to visualise that high values of VPD can be detrimental to a tree through moisture loss. In Equation [2], the coefficient associated with VPD is positive giving evidence that resin pocket formation may be linked to induced stress. Contour maps of VPD throughout New Zealand (Leathwick et al., 2003) show parts of coastal Hawkes Bay and Canterbury to be especially prone to high levels of VPD. These two regions are widely known for high levels of resin pockets as confirmed by scoring the highest mean incidence in twelve regions sampled (Park, 2004).

A positive regression coefficient for the percentage of trees with stem top-outs is clearly another implicit measure of stress. Wind *per se* did not emerge as a significant predictor. We attribute this to the point that stem top-outs represent an implicit, but highly localised, measure of maximum wind gusts whereas wind speeds based on historic weather records represent interpolated averages with inevitably high errors.

The regression coefficient for annual solar radiation is positive. Annual solar radiation is possibly a surprising variable to be related to resin pocket intensity. The fact that the association is positive suggests that resin pocket occurrence may also be associated with faster growth. This might be seen to be at variance with a region like Canterbury where only moderate levels of solar radiation are received (Leathwick et al., 2003: p. 28). However, Canterbury also has very high VPD levels, wind exposure and periodic droughts so the model would be compensated to predict large resin pocket intensities.

The coefficient associated with the ratio STRES is also positive. A small defect core followed by subsequent fast tree growth (large DBH) tends to result in a high incidence of resin pockets. Such an outcome may be created inadvertently by hard pruning accompanied by early heavy thinning which induces a transient stress situation (for example, greater exposure).

The profile of readily available water (PRAW) is *not* a measure of depth to a water-table but is an absolute measure of water availability. Here, the regression coefficient is negative indicating more resin pockets are formed in the presence of inadequate water supply.

Cown (1973) showed a clear link between the formation of false growth rings and resin pocket incidence in Canterbury forests, and strongly suggested water stress as a contributing factor.

Equation [2] suggests that resin pocket formation is largely a consequence of stress caused by five statistically non-interacting factors with the two largest contributions relating to moisture and exposure issues (Table 3). Also, resin pocket formation may be exacerbated by accelerated tree growth.

From Table 1, it is clear that the occurrence of resin pockets within each region is highly variable, with standard deviations being virtually equivalent to mean values. This is reflected in the precision and fit of the model not being especially strong with a multiple correlation coefficient (R^2) of 0.50 but we chose to interpret this in a positive way. It is to be expected that prediction errors associated with the explanatory variables are unavoidably high. For example, although there were 287 weather stations available to derive VPD statistics at nominated locations throughout New Zealand, the estimated coefficient of variation (CV) of the LENZ layers is 36%.

For solar radiation there are 98 weather stations and the CV is 20 % (Leathwick et al., 2002). There again, measurement of resin pocket intensity *per se* was associated with a large sampling error.

Although we have identified five factors that predict resin pocket intensity it would be simplistic to assume there are no others. For example, McConchie (1997) considered that genetics play a significant role in the formation of resin pockets. We have only limited data on the genetic origin of the trees sampled in this study. A (large) sub-set of our data, 93% can be identified as GF7 (Carson et al., 1999), where the seed was collected from selected trees. The remaining 7% was open pollinated. Examination of the model residuals shows no sign of bias with respect to these genetic origins, but this comparison is very coarse and needs refining with much more detailed data.

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