SCION

New Zealand Journal of Forestry Science

41 (2011) 41-60

www.scionresearch.com/nzjfs

published on-line:
28/01/2011

A review of resin features in radiata pine

Dave J. Cown[1,*], Lloyd A. Donaldson[1] and Geoffrey M. Downes[2]

[1] *Scion, Private Bag 3020, Rotorua 3046, New Zealand*

[2] *CSIRO, GPO Box 252-12, Hobart 7001, Tasmania, Australia*

(Received for publication 19 November 2008; accepted in revised form 28 October 2010)

*corresponding author: dave.cown@scionresearch.com

Abstract

In pine trees, resin is formed in an interconnecting system of tube-like structures known as resin canals. In radiata pine (*Pinus radiata* D.Don) these are most common in the earlywood/latewood transition zone and within the latewood. Within- and between-tree variation in resin canal occurrence has been poorly documented and little is known about factors controlling canal frequency or the relationship between canal distribution and the formation of timber blemishes. The presence of resin canals is often associated with the formation of resinous defects of various kinds which can cause major losses in timber production of particularly appearance-grade wood products.

This review summarises recent studies of radiata pine, which have shown that:

- the formation of resin canals and resinous blemishes on stems and in wood is more frequent in hotter, drier sites subject to water stress. It is also influenced by silvicultural procedures (stocking rate and thinning) and genetic constitution;
- external signs of resin bleeding on stems may indicate the presence of internal resin blemishes that degrade timber products. Some companies now record external resin bleeding in forest inventory systems in order to improve harvest planning. Such data are used to guide pruning intensity and the selection of genotypes in breeding programmes;
- resinous blemishes on log ends can be an indication of internal defects in radiata pine timber. These include resin pockets, resin patches, galls, blemishes and intra-ring checks. Some companies now segregate logs in the log yard by visual inspection of log ends; and
- certain types of resin features are sometimes associated with external lesions and dimpling on the log surface.

Keywords: *Pinus radiata;* resin canals; resin pockets; resinous blemishes; softwoods.

Introduction

Resinous defects are arguably the most important down grading factor in appearance grade timber. When resinous defects are present in high numbers then there is a significant reduction in clearwood grade recovery and a subsequent reduction in value. Timber grading rules often limit their presence in finished products (Standards Association of New Zealand, 1988). Radiata pine (*Pinus radiata* D.Don) wood has some unique resin-related features, such as pruning occlusion scars, resinous intra-ring

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

checks, needle fleck, and resinous heartwood, which are not adequately covered by current timber grade specifications. Although the presence of resin in radiata pine has major financial implications for the New Zealand forest industry (Clifton, 1969; Beauregard et al., 1999; Park & Parker, 1982; McConchie, 2003; McConchie et al., 2007), little is known about factors that control its formation and variability. Research has concentrated on the elimination of resin pockets, which are the most serious form of resinous blemish in clearwood products (Cown, 1973; Somerville, 1980; Donaldson, 1983; Ridoutt et al., 1999; Park, 2004; Woollons et al., 2009). Since 2004, Wood Quality Initiative Ltd. (WQI), an industry consortium based in New Zealand (http://www.wqi.co.nz), has investigated resinous features on stems, logs and timber of radiata pine in an attempt to improve our understanding of these important degrading features. Much of this work is not yet publicly available.[1]

This review summarises existing knowledge about resin canals and resinous blemishes in radiata pine and discusses factors considered to influence their occurrence in radiata pine timber.

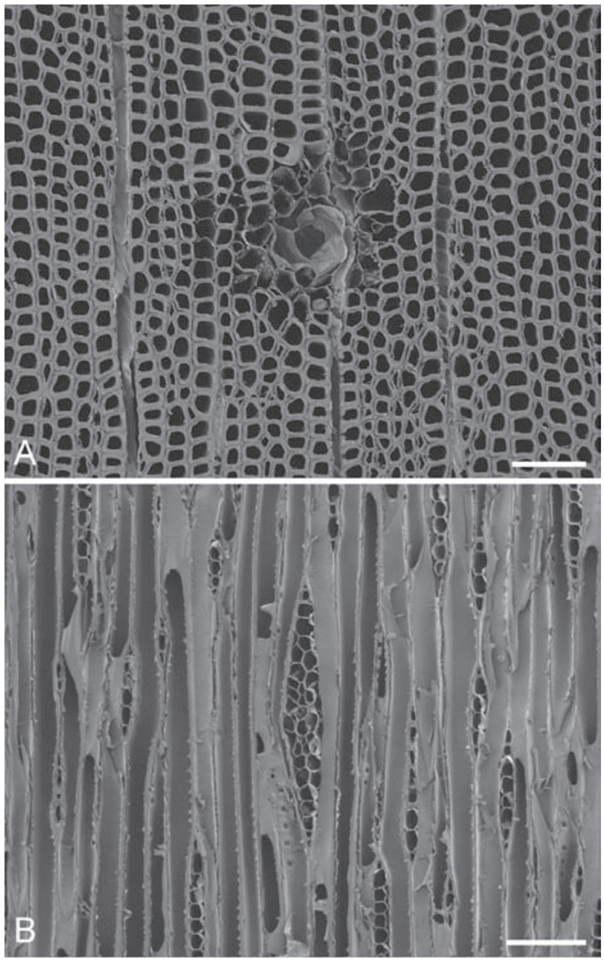

FIGURE 1: Resin canals in radiata pine wood. A: Transverse wood section showing single vertical resin canal. B: Tangential longitudinal wood section showing horizontal canals. Scale bar = 100 μm.

Origin of resin in softwoods

Softwoods are important for modern-day production of solid and reconstituted wood products, pulp, paper, and chemicals. Resin, a solid or semisolid viscous substance insoluble in water, is secreted in the tissues of many softwood tree species. Interconnecting vertical (axial) and horizontal (radial) resin canals are a regular feature of the wood and bark of four timber-producing genera in the family Pinaceae: *Pinus* (pines), *Picea* (spruce), *Larix* (larch) and *Pseudotsuga* (Douglas-fir). Resin canals also develop in the cortex and phloem of the stems and in sparse irregular patterns during normal wood formation (Wu & Hu, 1997). Each horizontal canal is associated with a vertical canal (Werker & Fahn, 1969). The canals are tubular structures composed of long-lived epithelial resin-secreting cells (Harris, 1991; Lin et al., 2001), parenchyma support cells, and strand tracheids (Patel, 1971). The diameter of vertical canals is commonly three or four times greater than that of horizontal canals (Koch, 1972). Resin is formed in the epithelial cells and is transported through the matrix of vertical and horizontal ducts (Figures 1 & 2). In radiata pine, the vertical canals (100 – 200 μm in diameter) usually consist of five or six epithelial cells surrounded by a parenchymatous sheath. The number of sheath cells and the number of canals are highly variable.

The sapwood of radiata pine contains approximately 1.5% dry weight of resin. Heartwood formation (resin impregnation) commences when the stems are approximately 10 years old and progresses outward from the pith, affecting about half of a growth ring each year (Cown et al., 1991). Ingress of resin occurs through the horizontal resin canals (Harris, 1965). In old stems, resin may account for 25 – 35% of the weight of the heartwood, an increase that has also been observed in both *Pinus elliottii* Englm. and *P. taeda* L. (Larson et al., 2001). Lloyd (1978) and Cown et al. (1991) noted that the latewood of growth rings nearest to the pith occasionally contain extensive deposits of resin which increase wood density to unusually high levels. Resin canals in these rings tend to be evenly distributed.

Heartwood resin is deposited in the lumena of tracheids. At maturity (25 – 30 years), a typical stem contains approximately 25% heartwood, with up to 10% of the resin content in the inner rings (Harris, 1965; Cown & McConchie, 1982; Cown et al., 1991).

[1] *Traditional citation is not possible for the many unpublished WQI reports, but a compilation is given in Appendix 1.*

ISSN 0048 - 0134 (print)
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FIGURE 2: Transverse section of radiata pine wood showing resin canals in the earlywood/latewood transition zone of an annual growth ring.

Variability in normal resin canal occurrence

Few systematic studies have been carried out on the frequency and size of resin canals either within or between stems. A method developed by Yang et al. (2007) has enabled small samples (5 mm breast-height increment cores or wood strips) to be used to document systematic within-stem variability. A recent study in Chile established only weak links between resin canal occurrence and visible external resin bleeding (ERB) on the bark of trees (Ananias et al., 2010).

Occurrence of resin canals within annual growth rings

In radiata pine, vertical resin canals are most common in the earlywood/latewood transition zone and more frequent in latewood than in earlywood, but their occurrence has not been examined systematically. Considerable variability has been reported in other genera and species. For example, resin canals are more common in the transition zone between earlywood and latewood in spruce and larch (Werker & Fahn, 1969; Fahn, 1979), while in some pines they are more common in latewood (Stephan, 1967; Alfieri & Evert, 1968; Zamski, 1972a, b). Resin canals occur throughout the earlywood and latewood of the first 12 growth rings in some southern pines (e.g. *Pinus elliottii* Englm.; *P. taeda* L.), but in mature wood and compression wood they tend to be more prominent in the latewood (Hobert, 1932; Koch, 1972). Reid and Watson (1966) reported that, in lodgepole pine (*Pinus contorta* Douglas), vertical canals are formed during the latter half of the growing season, 88% being found in the last 40% of the annual ring. Wodzicki (1961) and Larson (1964) concluded that external conditions influence within-ring positions of vertical canals. Changes in temperature and photoperiod were found to influence canal formation in Aleppo pine (*P. halepensis* Mill.), with a lag period of several months (Zamski, 1972a). Temperature had a greater effect than photoperiod.

In the most detailed study of resin features to date, Wimmer et al. (1999) examined radial and longitudinal variation in the pattern of vertical resin canals in a single Norway spruce (*Picea abies* (L.) H.Karst) tree. Although canals were present throughout the growth rings, they were most frequent in the transition zone between earlywood and latewood (Figure 3). Canals were evenly distributed in rings nearest the pith, but outside the juvenile core their frequency tended to be related to specific years of wood formation. Earlywood canals were more common in the upper part of the stem. There was significant positive correlation between summer temperature in the current year and resin canal frequency. Seasonal data showed that temperature was the most influential factor.

Blanche et al. (1992) reported that vertical resin canal formation in loblolly pine (*Pinus taeda)* was initiated 12 weeks after cambial reactivation. In their study, canal frequency was found to increase from 3/cm^2 in June (earlywood) to 44/cm^2 in August (latewood) and then to stabilise. Frequency of horizontal canals (35.5/cm^2) did not vary during the growing season. Hodges et al. (1981) had previously failed to find evidence of a relationship between resin flow and horizontal resin canal density.

Pith-to-bark distribution

Wimmer et al. (1999) recorded the number, frequency and within-ring position of canals in a 3.4 mm wide tangential section of each ring within a single stem of *Picea abies*. Frequency decreased rapidly with distance from the pith in the first few rings, then increased slightly (Figure 3). It was higher in particular years (e.g. 1976, a dry year), when continuous bands formed along the stem.

In a study of radiata pine stems sampled from 17 sites, Yang et al. (2007) documented a slight increase in canal frequency and size with distance from the pith. Neither frequency (r^2 = 0.50) nor size (r^2 = 0.36) were closely related to the number of resinous blemishes

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

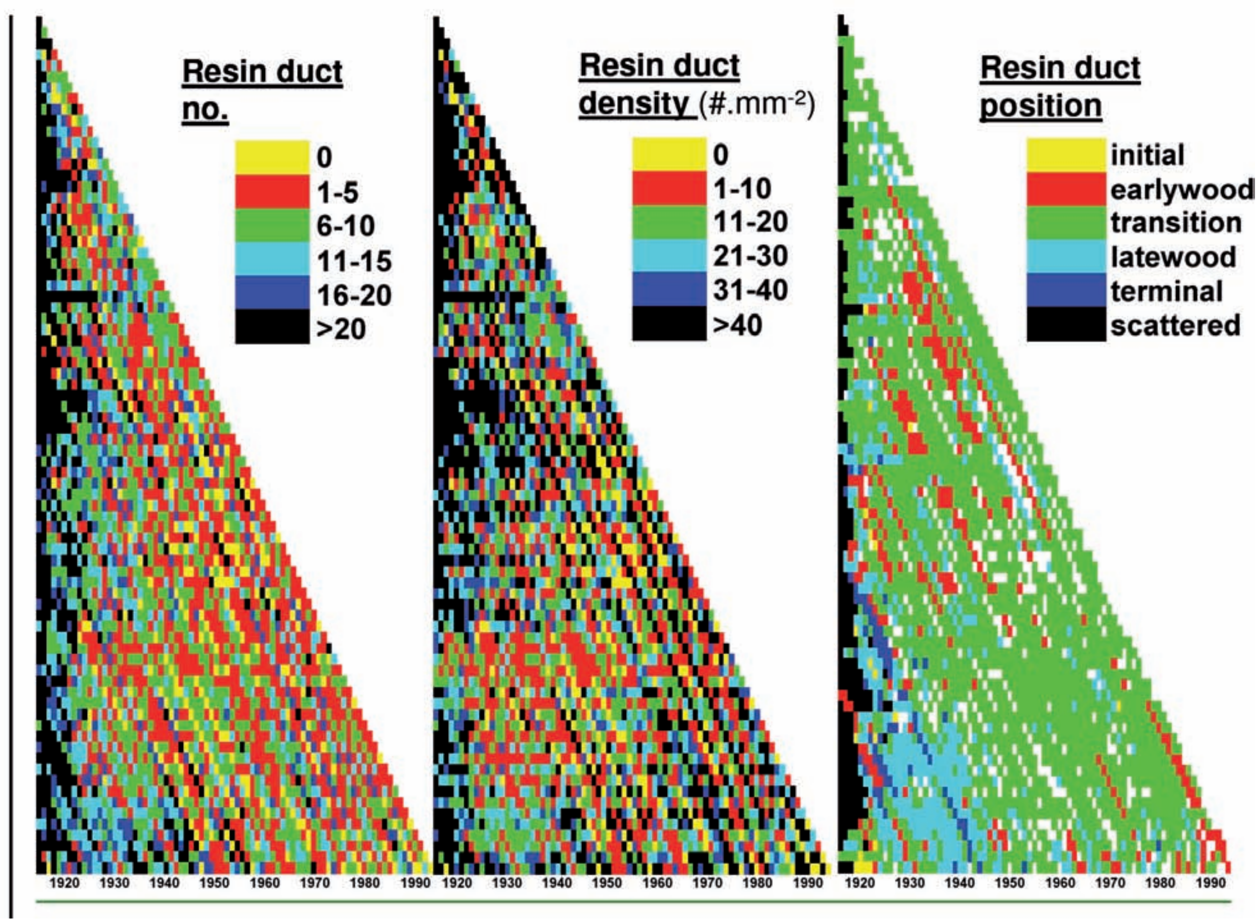

FIGURE 3: Pattern of resin canal occurrence within a single stem of *Picea abies*. (Reproduced with permission of R. Wimmer, Agricultural University of Vienna).

recorded on wood discs. Within-tree (between growth ring) differences accounted for a greater proportion of the total variation than between-tree or between-site differences.

Vertical distribution

LaPasha and Wheeler (1990) studied spatial relationships between vertical and horizontal canals in loblolly pine and confirmed the existence of an infrequently interconnecting system. Individual canal length ranged between 20 and 510 mm, and increased with age. Vertical and horizontal canals were often in close proximity, sharing epithelial cells, but direct openings between them were rare in non-injured tissue.

Wimmer et al. (1999) showed that, in a single Norway spruce tree, the vertical pattern of resin canal distribution had cylindrical symmetry, except in some years where frequency and position within the ring were affected by an environmental event (e.g. high temperature). Kilpeläinen et al. (2007) found a similar effect in Scots pine (*Pinus sylvestris* L.).

A study of radiata pine in New Zealand has shown that resin canal frequency is greater at breast height (1.4 m above ground level) than further up the stem, and that canal diameter increases with height (Yang et al., 2007).

Variability associated with environmental effects

There is clear evidence that both frequency and size of resin canals found in softwoods can be influenced by external conditions e.g. climate, fertiliser application, insect attack (Frey-Wyssling, 1938; Schumacher et al., 1997; Temnerud, 1997; Tombleson & Inglis, 1986; Tomlin et al., 1998; Wimmer et al., 1999). Environmental conditions influence the production of resin canals in a number of species. Resin canal frequency in a single Norway spruce tree was positively and significantly correlated with summer temperature (Wimmer et al., 1999). Smith et al. (1977) reported, that in black pine (*Pinus nigra* J.F.Arnold), resin canal radial diameter responded strongly and positively to spring rainfall whereas tangential canal diameter responded negatively to autumn temperature. In contrast, Levanic (1999) could find no evidence of a relationship between

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ISSN 1179-5395 (on-line)

climate and resin canal number or density in black pine, but canal number was positively correlated with growth ring width.

In radiata pine, resin canals have been associated with “false latewood” formed in response to water stress (Cown, 1973). The study of Yang et al. (2007) revealed that canal frequency is positively associated with mean annual temperature in this species. Wood from warmer sites at low elevation tended to contain more resin canals. Other factors such as soil fertility and rainfall were shown to have little impact on resin canal frequency.

Genetic variability

Wilkinson (1983) noted that genetic variability in the resistance of eastern white pine (*Pinus strobus* L.) to attack by weevils was associated with a propensity for forming traumatic resin canals. Large between-stem and between-provenance variability has also been noted in the response of Norway spruce to real and simulated insect attack (O’Neill et al., 2002). A study of 19-year-old trees revealed moderate heritability for both size and number of resin canals (h^2 = approximately 0.4: Hannrup et al., 2004).

Variability due to physical damage

In several species, particularly spruces and pines, resin has an important role in tree response to physical damage (O’Neill et al., 2002; Tomlin et al., 1998). Resin production in the stems of softwood trees is a defence mechanism that helps to prevent infection of wounds to the cambium, protects the stem against decay, and limits the effects of insect and fungal attack. Some species in which resin canals are not normally present (e.g. *Chamaecyparis obtusa* (Siebold & Zucc.) Endl.; Yamanaka, 1989), produce them under stress. Such “traumatic” resin canals may develop as a physiological response to physical damage, such as insect or fungal attack, (as well as severe climatic conditions). Although anatomically identical to “normal” canals, traumatic canals are more likely to be closely-spaced (often in “rings”) and are easier to see with the naked eye.

Traumatic canals are found in many species of the Pinaceae, including radiata pine. Clifton (1969) noted the appearance of traumatic resin canals in response to attack by the wood wasp *Sirex noctilio* F., and Cown (1973) drew attention to their association with drought. Softwoods that do not normally contain resin canals in their wood but may develop traumatic resin canals in response to stress are: *Abies spp. (firs); Cedrus spp.* (cedars); *Tsuga spp.* (hemlocks); *Taxodium spp.* (cypressess); and *Sequoia* spp. (redwoods). In other conifers, resin is produced in unspecialised axial and ray parenchyma cells (Phillips, 1948; Jane, 1970; Leney & Moore, 1977; Visscher & Jagels, 2003).

Resin defects in radiata pine wood

A number of defects are associated with resin in radiata pine wood (Clifton, 1969; Cown, 1973, Donaldson, 1983; McConchie et al., 2007). Losses of up to 58% of the value of clearwood have been attributed to the occurrence of resin “blemishes” consisting of patches, pockets, streaks, and shakes (WQI, unpublished data). Their presence on the surface of clear boards or veneer reduces the value of timber, especially where appearance is important. Studies over many years have not produced a reliable method for determining their presence or absence in a log, or for predicting their occurrence. The development of new technologies, such as internal log scanning (Tombleson, 2007), offers new approaches to this issue.

Resin pockets

Resin pockets occur sporadically within the wood of many resinous softwoods (Figure 4). In Europe they have been attributed to climatic influences (Frey-Wyssling, 1938). In Sweden they are regarded as an endemic feature of Norway spruce (Temnerud, 1997) but detailed studies have failed to identify the main contributory causes.

In radiata pine, resin pockets are universally present at a low frequency level, and occasionally cause serious defects in clear timber and veneer (Kininmonth & Whitehouse, 1991). An average incidence of 0.6 pockets/m^2 has been estimated from sawing studies, but individual stand means of up to 2.7/m^2 have been observed. Incidence in individual logs can range between 0 and 5 pockets/m^2, with forest averages of up to 2/m^2 (Park, 2004; 2005). In some New Zealand forests, notably on the Canterbury

FIGURE 4: Resin pockets and blemishes in a radiata pine log.

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

plains, the occurrence of resin pockets can reach very high levels (Cown, 1973). Pruning was discontinued at low elevation exposed sites in the region for this reason (Clifton, 1969).

Several resin-pocket variants have been noted in studies of radiata pine, based on size, shape and occlusion characteristics and have been labelled Type 1, Type 2 and Type 3 (Somerville, 1980, Donaldson 1983). Somerville (1980) recorded a range of dimensions for each (Table 1). Details of each type are as follows:

- *Type 1* (Figure 5A). This is the most common form, seen as an occasional defect in timber from all forests. It occurs as a tangentially-orientated "lens-shaped" cavity filled with callus and liquid resin and is completely enclosed within a growth ring. No apparent change in meristematic activity of the cambium is apparent after pocket formation and it is assumed that the cavity forms when new cells are differentiated at the inner surface of the cambium.

- *Type 2* (Figure 5B). This originates as a Type 1 pocket but erupts through the cambium to produce visible external resin bleeding. The original cavity flattens and activity in the adjacent cambium is reduced. An occlusion scar that may contain resin, callus, and bark is formed. Type 2 resin pockets result in radial indentation of the cambium and subsequent annual rings, and this may persist for many years.

- *Type 3* (Figure 5C). This is a small defect that appears to originate in a cambial lesion. It may cause external resin bleeding. The occlusion process is similar to that observed in Type 2 pockets. The defect is a narrow, longitudinally-oriented cavity in the wood filled with dry resin, parenchymatous tissue and bark cells.

Cown (1973) observed that Type 1 resin pockets usually originate at either "false latewood" boundaries or along bands of closely-spaced vertical resin canals – both indicators of stress. High winds and drought have both been suggested as causative factors (Clifton, 1969; Cown, 1973, Watt et al., 2010). Recent findings on the seasonal periodicity of resin pocket formation (Type 2 appearing predominantly in the late season when water is often more limiting) has suggested that the different appearance of at least Types 1 and 2 may be a cambial reaction to specific environmental factors which remain unclear, although both water stress and

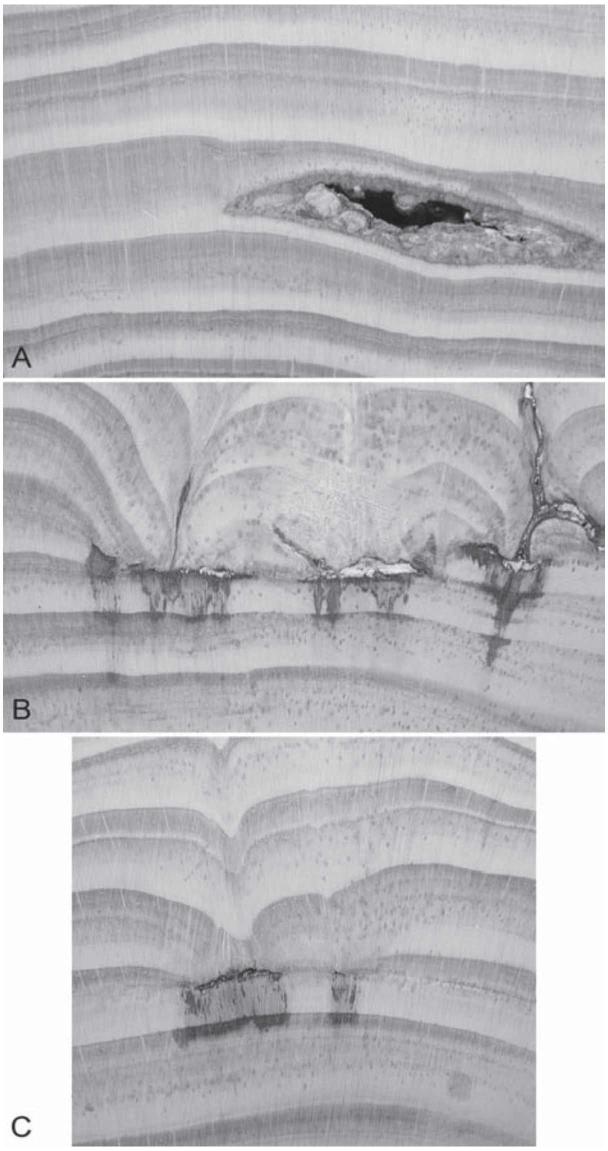

FIGURE 5: Cross sections of radiata pine wood. A:Type 1 resin pocket; B: Type 2 resin pocket; C: Type 3 resin pocket.

wind factors appear to be implicated (Appendix – Bruce et al., 2008; Jones, et al., 2009).

Both Fenton (1977) and Somerville (1980) looked for possible links between the occurrence of resin on log bark and the incidence of resin pockets in the corresponding timber products. Variability between sample logs was high, and no conclusive evidence of a relationship was found. In a later study of clonal material

TABLE 1. Radiata pine resin pocket dimensions (mm). (After Somerville, 1980).

Orientation of measurement	Type 1	Type 2	Type 3
Tangential	20 - 50	10 - 40	3 - 10
Radial	3 - 6	15 - 35	3 - 10
Longitudinal	40-100	40 - 120	25 - 70

ISSN 0048 - 0134 (print)
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(McConchie, 1997), the incidence of resin pockets and blemishes on log ends and in processed timber was recorded. Results demonstrated significant clonal differences in the occurrence of both resin pockets and resinous blemishes. The most severely affected clone was identified throughout an experimental forest by the presence of extensive resin bleeding on the bark. A second study was carried out in which resinous characteristics on log ends were assessed, as was the lumber from the pruned butt logs. These two studies provided a combined sample of more than 120 logs from two New Zealand locations (Central North Island and Hawkes Bay). Computer modelling showed that prediction of the incidence of resin pockets in processed timber was improved when the presence of resinous blemishes in the log end were included in the assessments, (Ridoutt et al., 1999).

Other resinous blemishes

A number of other features (broadly classified as "resinous blemishes") also have a negative effect on timber value (Amos, 1954; Larson, 1994; Lo 1987). These range from small radial streaks associated with stem needle retention and galls, to random patches of resin saturation and abnormal heartwood. Some blemishes are caused by insect attack (e.g. *Sirex noctilio*) and physical damage to the cambium. Most tend to be small and randomly-distributed.

Normal heartwood

Heartwood is resinous by nature. Radiata pine has a low proportion of heartwood in the stem and is considered to be a "sapwood" species, especially when harvested less than 30 years after planting. A typical 25-year-old stem contains 7.5 rings of heartwood at breast height. Heartwood formation is a process in which cell death is associated with an increase in resin content (from 1.5% dry weight to as much as 20% near the pith); a decrease in moisture content (from "saturated" to approximately 45% dry weight); and an increase in wood density. These changes start to occur at breast height when trees are about 10 years old and extend outwards at a rate of about half a growth ring each year. The average number of heartwood rings can be predicted if tree age is known. These changes increase the natural durability of the wood and decrease its permeability. Heartwood formation and resin content both vary from tree to tree. The degree of resin infiltration is related to tree age (Harris, 1965; Cown et al. 1991). Latewood of heartwood is often saturated with resin and is easily seen (Figure 6).

Occasionally, resin bleeding from dry timber is blamed for loss of value in finished products (Figure 7). Resin bleeding can occur if heartwood is exposed to heat (particularly when combined with direct sunlight) or has been treated with preservatives incorporating a solvent carrier. It may also occur where resin pockets or resinous latewood are located close to the surface of the timber.

FIGURE 6: Normal radiata pine heartwood (Note resinous latewood).

FIGURE 7: Resin bleeding of primed radiata pine timber.

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Resinous heartwood

Occasionally stems produce abnormally resinous heartwood in which round or star-shaped resin patches may extend for varying distances from the pith (Figure 8). The cause of this condition is unknown. Affected wood has a characteristic smell, but is not always resin-soaked. It often occupies a greater proportion of the annual ring than the normal heartwood.

FIGURE 8: Resinous heartwood in a radiata pine log

A resinous heartwood condition known as “red heart” (Figure 9) is sometimes encountered in Southland, New Zealand, where affected logs are routinely segregated (D. McConchie, personal communication). The name “red heart” is apt as this condition produces a characteristic red ring at the sapwood/heartwood margin.

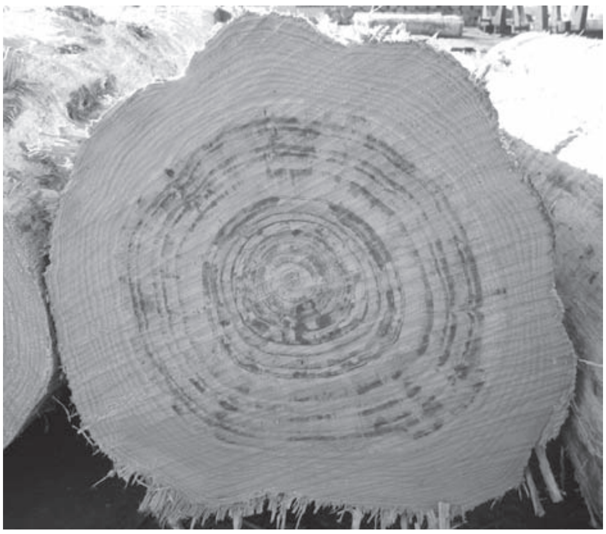

FIGURE 9: “Red heart” radiata pine wood.

In radiata pine, resinous heartwood does not lead to the serious problem of “heart shakes” which occurs in some other species e.g. *Pinus elliottii* (slash pine) in South Africa and Australia (Darrow, 1992; Malan, 1998; Harding et al., 2006).

Resin streaks

Resin from internal knots and streaks may be invisible in new wooden products but can bleed through to the surface during use. Treatment with specially-formulated primer/sealers can restrict this bleed-through. Even if the resin does not “bleed” to the surface, it can affect the quality of surface coatings by a process refereed to as “show-through”. Resin streaks are common in several softwoods where causes may include wind, latewood resin saturation, stem splitting, pruning damage, fungal or insect attack, and wood overgrowth around branches (Dietrichson et al., 1985; Donaldson, 1983; Larson, 1994; Lo 1987). Slash pine is notorious for the development of severe resin streaking associated with stem cracks (Huffman, 1955; Harding et al., 2006). Streaking is not a major issue in radiata pine although small resin streaks occur frequently in both the sapwood and heartwood (Figure 10).

FIGURE 10: Resin streaking in radiata pine wood.

Intra-ring checking

Cavities within individual growth rings may contain both resin and callus, and are sometimes regarded as resin features. Intra-ring internal checking is often encountered during the drying of certain hardwoods but is infrequent in softwoods. In New Zealand, it was first observed in Douglas-fir (Reid & Mitchell, 1951). More recently, it has been recognised as a defect in radiata pine clearwood, especially in wood derived from young trees (Booker, 1994; Haslett & McConchie, 1986; Miller & Simpson, 1992; Simpson et al., 2002).

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ISSN 1179-5395 (on-line)

It was once a matter of concern in the forest industry because the large investment in pruning was based on the assumption that clearwood is defect-free. At present, it seems to be accepted as an occasional low-level problem.

Two types of intra-ring checks are recognised in radiata pine. “Wet checks”, which form infrequently in the living stem, are not considered to be a major problem. They become filled with callus tissue and liquid resin (Figure 11) and are eventually incorporated in the heartwood.

FIGURE 11: Cross section of radiata pine stem showing resinous checking (wet checks) within growth rings.

“Dry checks” form in sapwood during timber drying. No callus tissue or resin appears in the cracks (Amos, 1954) (Figure 12). Dry checks are much more common than wet checks and can be a major source of degrade in clearwood products. The work of Pang et al. (1999) with radiata pine indicates that tangential shrinkage and collapse are greater in wood that is prone to checking.

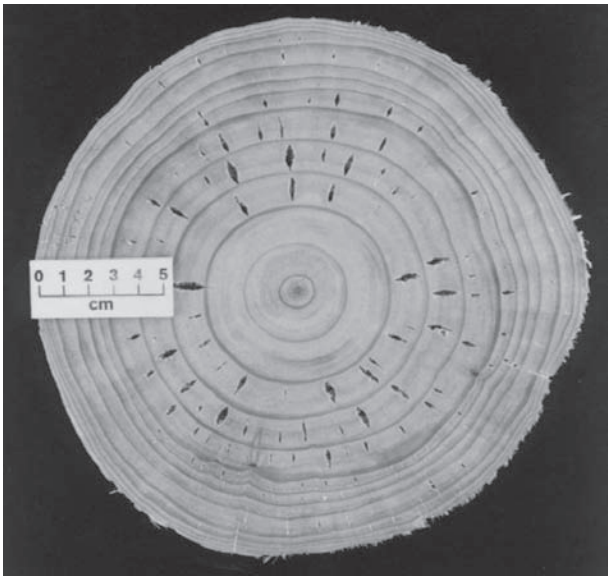

FIGURE 12: Dry checking within growth rings of radiata pine.

Bird’s eye and needle fleck

“Bird’s eye” and “needle fleck” (Figure 13) are the names given to two types of wood defect (Appendix – Donaldson, 2003b). Both are sometimes classified as resin defects in clearwood products although they do not contain resin. Needle fleck results from the persistence of stem needle traces which form small (1 – 2 mm) knot-like structures. It is usually confined to the first few annual rings, where it presents no problems. Occasionally needle trace persists throughout the wood structure, particularly in the lower stem, resulting in the presence not only of distinct radial defects (Figure 13A, C) but also dimpling of the wood surface beneath the bark (Harris & Singh, 1987). In some cases the defects are large and contain a bark inclusion, in which case they are referred to as “bird’s eye”. Their presence is normally only visible either after removal of the bark or in timber products (Figure 13B, D). High-resolution scanning may offer the opportunity for segregation from other pruned logs (Tombleson, 2007). On the tangential surface of the wood they appear as small circular grain disturbances, and can cause severe degrade (Figure 13D). They are occasionally considered to be a problem in radiata pine in New Zealand. Resin defects such as Type 2 resin pockets are often associated with needle traces (Figure 14). The presence of stem needles and a tendency to form epicormic shoots has been shown to be most prevalent on the northern (sunny) side of stems grown in the open. Fertiliser treatment may also have an effect by increasing the incidence of epicormic shoots (Mead & Will, 1976). Crowe (1976) observed persistence of adventitious shoots on more than 25% of pruned stems where less than 50% of the live crown had been retained. He recommended removal of epicormic shoots (but not stem needles) from the pruned part of the stem during the last pruning operation. This was considered to be a cost-effective alternative to delay in thinning and pruning operations, which would increase the size of the defect core.

Galls

Galls often form on the stems of radiata pine, and are sometimes associated with resin bleeding as shown in Figure 15 (Appendix – Donaldson, (2003b); McConchie, (2003); McConchie et al., (2007); Ramsfield & Donaldson, (2003)). They consist of tissue which develops as the stem grows, leaving a small track of distorted grain. Galls are included with lesions during external stem assessments (McConchie, 2003) although actual association with resin features is not clear. The causes of gall formation are not yet known.

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

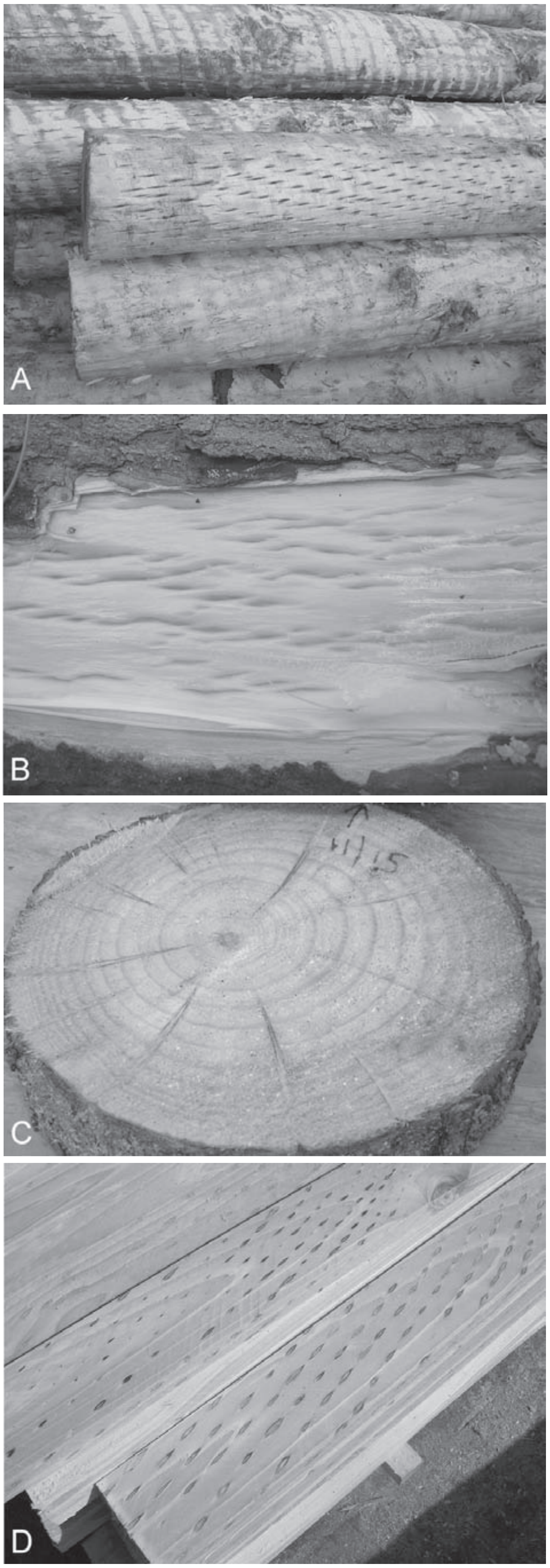

FIGURE 13: Radiata pine timber defects. A, B: Dimples under the bark. C: Resinous blemishes in a mature stem. D: Bird's eye in sawn timber.

FIGURE 14: Resin pockets, blemishes and persistent needle traces in radiata pine wood.

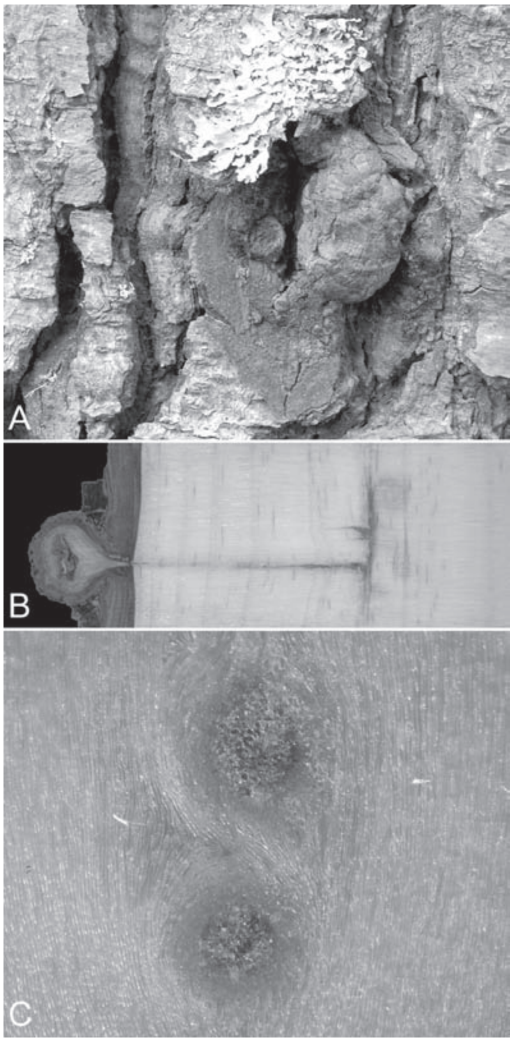

FIGURE 15: Radiata pine. A: Galls on the surface of the bark B: Longitudinal section showing a gall associated with a defect in the wood. C: showing resinous blemishes in the wood, associated with galls. (Courtesy WQI Ltd).

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

Links between external log characteristics and resin defects in wood

Resin features visible on the growing stem (bleeding, lesions, galls – collectively known in New Zealand as external resin bleeding or ERB) are common in radiata pine. They are most often associated with physical damage caused by pruning, thinning, hail, deer, possums, insects or disease (Donaldson, 1983; McConchie & Horvath, 1998).

Resin blisters arise from cortical resin canals and are common on young bark (Figure 16A) but do not affect the underlying wood. Physical damage or rupture of the bark may expose horizontal resin canals contained in fusiform rays and result in resin bleeding or the formation of bark resin pockets and lesions (Figure 16 B, C, D). This is most likely to happen when the bark is young, thin and easily damaged, and often remains as a surface feature.

Early investigations by Clifton (1969), Cown (1973), Fenton (1977) and Somerville (1980) failed to produce conclusive evidence of a link between external signs of resin on bark and the occurrence of resinous blemishes in processed timber. A study of trees in an experimental forest in the central North Island (McConchie, 1997) provided the first record of resin pockets and blemishes on log ends that could be related to incidence of resin features in the timber. A similar study carried out on trees from Hawke's Bay established a tentative relationship between visible resinous blemishes on log ends and sawn timber (Ridoutt et al., 1999). Prediction of timber quality from log-end assessments was found to be improved if observations included resinous blemishes as well as resin pockets.

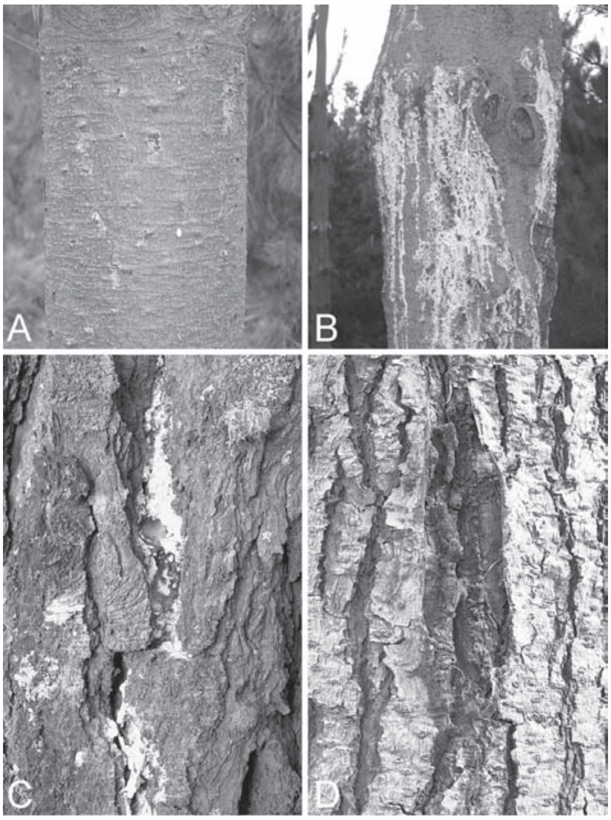

FIGURE 16: Resin bleeding on the surface of radiata pine tree stems. A: Bleeding from bark blisters (cortical resin canals) not associated with wood defects. B: Heavy resin bleeding on the stem of a young tree. C: Fresh resin bleeding on an old stem. D: Evidence of past (black) resin bleeding.

The exact causes of bleeding lesions are often not known, but they may be associated with fast radial growth, wind sway (exposure), damage by animals (e.g. deer, possums), hail or lightning, or mechanical damage from forestry operations. Lesions develop when damage to the cambium results in traumatic resin exudation into the wood and to the outside of the stem. They often leave indentations on the stem, and can result in "bird's eye" and resin defects in timber.

Wood Quality Initiative Ltd studies have confirmed that presence of lesions on mature bark may be a good indication of internal abnormalities in the wood structure and timber value (Appendix – Cown et al., 2006; Holden et al., 2006; Jones et al., 2009; McConchie 2003, 2004a,b, 2005a,b,c; McConchie et al., 2003, 2007; Park and Woollons, 2004; Rawley 2007; Rawley and Park 2006; Yang et al., 2007). Fresh resin is easy to observe on dry bark, but turns dark with age and may be difficult to distinguish from bark, especially on wet stems. Some study results from a national survey are shown in Figure 17 (Appendix – Cown et al., 2005).

Useful field guides have been developed recently by McConchie (2003) and McConchie et al. (2007) that have incorporated current knowledge on external resin characteristics and their implications for New Zealand grown radiata pine. Not all researchers are convinced of the practical application of external signs, however. For example, Park (2005) maintained that since only certain types of resin pockets cause lesions on the bark, their usefulness was limited due to the poor correlation with other types of defect. This conclusion was based on his analysis of data collected in the course of destructive sampling of pruned butt logs. A similar study by Rawley (2007 – Appendix) pointed out that visual assessments are subject to large sampling errors and are useful for qualitative rather than quantitative comparisons.

McConchie (2001) examined logs from two sites in the North Island of New Zealand: (i) Northland; and (ii) East Coast, respectively. In the first study, three batches of logs were selected. Batch 1 represented trees with no resin on the bark; Batch 2 trees with low incidence of visible resin; and Batch 3 trees with moderate incidence

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

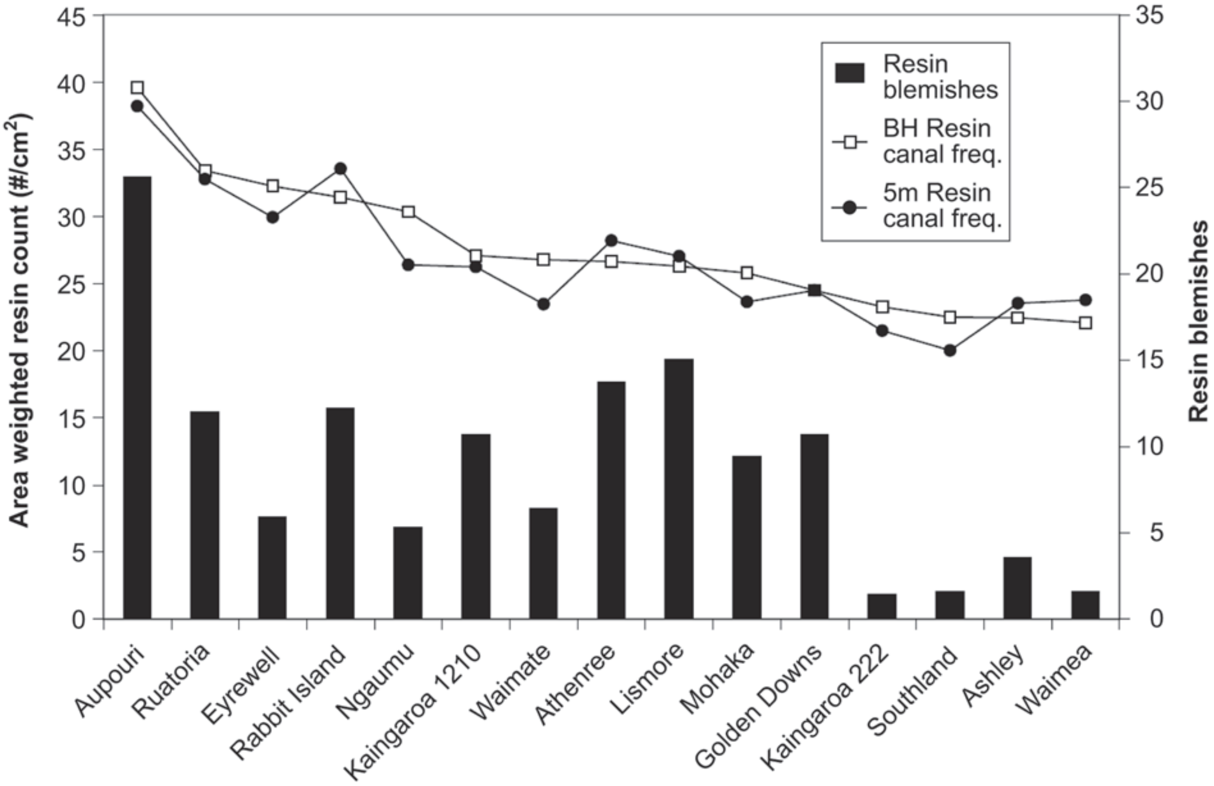

FIGURE 17: Resin pocket incidence in 16-year-old radiata pine (105 stems; 4 discs/stem) by year and stocking density. (Appendix – Cown et al. (2005)).

of resin. Signs of resin on the small ends of logs in each batch were recorded before the timber was processed. The frequency of resin pockets and blemishes in sawn timber was also recorded and was found to be related to the amount of resin apparent on the bark. The yield of “Clear” plus “Moulding Grade” timber was 57% in Batch 1, 47% in Batch 2 and 33% in Batch 3. Log value to the mill was reduced by 8% in Batch 2 and by 12% in Batch 3. In the second study, 77 sawlogs and 72 peeler bolts were examined. No resin features were apparent in the log ends of 16% of the sample and timber from these logs had an average of 0.33 resin pockets/m^2. Log ends of 14% of the sample showed 10 or more resin features, and 3.09 resin pockets/m^2 were observed in the timber. Butt logs with no resin on the bark yielded timber with 0.34 resin pockets/m^2. Timber from the only log with abundant resin on the bark contained 3.8 resin pockets/m^2. The relationship between log resin features (bark resin; resin pockets; blemishes) and resin features in sawn timber was highly significant (p = 0.99; r^2 = 0.7 – 0.9). Subsequent WQI studies confirmed these results (Appendix – McConchie 2004a,b; 2005a,b,c). A summary of recent studies confirmed that the best indicator of resin features in pruned logs is the presence of ERB (Jones et al*.,* 2009 – Appendix).

In the absence of accepted national standards for the assessment of external resin features in stems or logs, individual companies are beginning to develop their own criteria. Some include observations of resin bleeding in stand assessments, and there is an increase in awareness during selection for pruning and thinning. Harvesting of severely affected stands is controlled and quality is monitored. If resin problems are confirmed through feedback of information from sawmills, consideration is given to the adoption of framing regimes for subsequent rotations.

Factors influencing the occurrence of resin defects in pine

There is clear evidence that both frequency and size of resin canals can be influenced by external conditions e.g. climate, fertiliser application, insect attack (Frey-Wyssling, 1938; Schumacher et al. 1997; Temnerud, 1997; Tombleson & Inglis, 1986; Tomlin et al*.,* 1998; Wimmer et al., 1999). There is also now solid evidence of links between resin canal size and frequency and stem resinous defects (Yang et al., 2007) and wood defects of various types (McConchie et al., 2007).

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

Within-tree position

The frequency of resin pockets has been shown to increase with log height class, but no strong association between other blemishes and height is apparent (McConchie, 1997). Gazo et al. (2000a, b) found that frequency of resin defects was greater in pruned butt logs, but did not suggest a connection with pruning operations. Bruce et al. (2008– Appendix) noted that resin pockets were not associated with any particular cardinal direction, but were randomly scattered within the stem cross section. They also noted the frequencies tended to increase with height over time in the lower 5 m off the stem, and there was a strong association between type-2 pockets and resin blemishes

Site and climate

Although existing data are often confounded due to variability in seedlot and/or silviculture, all studies indicate that exposure increases the occurrence of resin defects. In forests on the South Island Canterbury Plains, high winds and drought may be causative factors (Clifton, 1969; Cown, 1973). Observations showing that few resin pockets develop during early tree growth, and that their frequency is greater in wood above the butt log, support this suggestion. The incidence of resin pockets on individual sites has led to the conclusion that specific environmental factors, most likely those associated with water stress, contribute to observed variability (Cown, 1973; Woollons et al., 2009). A recent analysis by Watt et al (2010) infers that wind action is also a contributing factor.

Silviculture

There is also evidence that silvicultural treatment (particularly thinning) is likely to increase the incidence of both resin pockets and blemishes. Studies of trees, logs and sawn timber in spacing trials up to 30 years of age (McConchie, 1997, 2003; R. McKinley, personal communication, 2009) have shown that the incidence of resinous blemishes increases when stocking rates are lower (Table 2).

Genetic variation

A number of resin characteristics in softwoods seem to be genetically controlled (Malan, 1998; Roberds et al., 2003). McConchie (1997) and Kumar (2004) have identified clonal differences in the resin features of radiata pine. McConchie (1997) demonstrated differences in the occurrence of both resin pockets and resinous blemishes in log ends and in processed timber. The most severely affected clone in an experimental forest could be identified by the presence of extensive resin bleeding on the bark. Kumar et al. (2008) examined the effects of site and genotype on the occurrence of external resin bleeding in two trials of radiata pine clones and seedlings. Trees were scored on a scale of 1 (= no sign of stem resin bleeding) to 4 (= severe resin bleeding). A broad range of scores was observed, but differences between sites were small. The proportions of unaffected trees were: Esk, 7%; Woodhill, 8%; Kaingaroa Cpt 1286, 10%; Kaingaroa Cpt 1276, 16%. In a high wood-density trial, the proportions of unaffected trees were Tarawera, 10%; Kaingaroa Cpt 1334, 13%; Glenledi (Clutha, South Island), 18%. Average values were higher in a 1993 female-tester trial. Control seedlots with different Growth and Form rankings levels (Radiata Pine Breeding Company, 2002) showed little difference among themselves and little difference from select progeny material. Weak positive correlations between stem diameter and the incidence of external resin bleeding was observed within trials. Significant within-site family differences in external resin bleeding were demonstrated. Estimated within-site heritabilities were similar, ranging between 0.22 and 0.35. Rankings of families across sites were also similar. Estimated genetic correlations between sites generally exceeded 0.6, an exception being a near-zero correlation between Glenledi and two North Island sites, based on only 25 families. Indications are that selection for reduced external resin bleeding could result in genetic gains at a number of North Island sites.

Conclusions

Under certain circumstances financial losses due to the presence of resin features in radiata pine can be severe. While it is acknowledged that resin canals are

TABLE 2: Occurrence of resin pockets in logs from a radiata pine stocking rates trial (R. McKinley, personal communication, 2009.)

Stems/ha	No. of logs examined	Mean large end diameter (mm)	Mean small end diameter (mm)	Total surface area (m^2)	No. of resin pockets/m^2	Proportion of logs with resin pockets (%)
50	49	830	696	45.7	0.59	61
100	77	714	627	55.7	0.32	32
200	89	627	537	48.7	0.32	38
400	53	585	493	25.0	0.11	23
Total	*268*					*38*

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

the source of all resinous blemishes, there has been little systematic examination of the frequency and size of resin canals within or between tree stems, or of the link between incidence of resin canals and degrade due to resinous blemishes.

Resin canal size and frequency has been shown to be influenced by climatic, silvicultural, biological and genetic variables. Thinning seems to exacerbate the problem but the effects of pruning are less consistent. There is evidence for moderate heritability of resin canal size and frequency. Climatic conditions have an important effect on the occurrence of resin canals and blemishes of all kinds. Hot, dry regions have a reputation for producing timber with resin pockets and intra-ring checking. There is strong evidence that genetic constitution has a significant effect, and that exposure to strong winds increases the frequency of resin defects. Some commercial forestry companies have identified sites where pruning is avoided because of the increased risk of resin defects in pruned timber. The causes of a number of resinous blemish types (needle traces, fleck, bird's eye, galls) are not well understood.

Several forestry companies in New Zealand now routinely document the occurrence of external resin features in conjunction with stand inventory assessments. Sawmillers specialising in clearwood production are developing log grade criteria to reduce the likelihood of degrade due to resin features. It is expected that genetic improvement in external resin bleeding will achieve substantial reductions in the incidence of resin pockets in solid wood products.

Acknowledgements

The authors are indebted to Wood Quality Initiative Ltd for their support of recent work on resinous blemishes in radiata pine timber. We are also grateful to Don McConchie (Wood Quality Focus) for permission to use some of his photographs and to Russell McKinley (Scion) for assistance with preparing some of the figures.

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ISSN 0048 - 0134 (print)
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[2] *Please note that these reports remain confidential to Wood Quality Initiative shareholders. Further information can be obtained from Wood Quality Initiative, Ltd, PO Box 1127, Rotorua 3040, New Zealand.*

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

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ISSN 1179-5395 (on-line)

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ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)