Type 1 and 2 resin pockets in New Zealand radiata pine: how do they differ?

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Abstract

Resin pockets are a significant source of wood-quality degrade in *Pinus radiata* D.Don (radiata pine) logs for many forests around New Zealand. Low rainfall and windy conditions coupled with stony soils and poor soil water-holding capacity have been implicated in their occurrence. Resinous defects have little impact on the structural properties of timber and consequently their occurrence may be underestimated in plantations grown for purposes other than appearance grade timber. It has been common in industry trials to describe resin pockets according to three distinct categories; Types 1, 2 and 3. This paper builds on a series of existing studies directed at understanding the physiological causes of resin pocket occurrence and suggests that current distinctions drawn between different types of resin pockets represent a developmental continuum. Specifically, it argues that a morphological continuum exists between what is generally categorised as Type 1, and Types 2 and 3 resin pockets. It is not intended that the proposed gradation replace the current classification of resin pockets. Rather it is suggested that there is a common physiological cause to better focus research directed at managing their occurrence.

Keywords: drought; radiata pine; resin; resin pocket; wind; wood quality.

Introduction

Resin pockets are a defect found in the xylem of those conifers that have resin ducts, i.e. *Pinus* spp. and *Picea* spp. (Cown, 2011). An increase in the production of resin is a defence mechanism against infection, wounding or damage. A national survey across New Zealand (Cown, 1973) found that resin pockets were present in nearly all exotic forests, often associated with "false rings" – a sign of water stress. They are a major cause of clearwood degrade in New Zealand, representing a significant cost to industry.

Three types of resin pockets have been described (Somerville, 1980). Type 1 pockets are radially narrow discontinuities in the wood which 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 can be open to the external environment at early stages in their development. They become occluded by cambial overgrowth resulting in an occlusion scar. Type 3 resin pockets originate as lesions in the cambial zone. Surrounding healthy cambium occludes causing an occlusion scar similar to that of Type 2 resin pockets. In practice there is considerable difficulty in distinguishing between Types 2 and 3. On the basis that they effectively are the same type, distinctions are not now generally made between them. Resin pockets are considered to be a separate category of defect than resin blemishes, which are the most commonly identified resin-related defect in sawn timber.

At present, the underpinning physiological causes of resin pocket occurrence are debated, and there is little

published work addressing these issues. Whatever the causes, occurrence seems to be linked with fast growing trees that are severely affected by water stress and/or wind events (Cown, 1973; Seifert et al., 2010; Temnerud, 1997; Temnerud et al., 1999.). As economic pressures on production forests increases the demand for faster growth over shorter rotations on more marginal sites, increases in the occurrence of such defects can be expected. Thus classifying defects and understanding their causes will become increasingly important in order to develop appropriate silvicultural practices to moderate their occurrence.

In 2006, the New Zealand Wood Quality Initiative (www.wqi.co.nz), in partnership with Scion and the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO), initiated a series of studies intended to explore the physiological causes of resin pocket occurrence in radiata pine. It is important to understand the characteristics and development of resin pockets, so that the frequency of defects in logs intended for appearance grade lumber can be reduced. One study involved the destructive sampling of six mid-rotation trees severely affected by external resin bleeding at six climatically different sites (five within New Zealand, one in Tasmania, Australia). This study was undertaken to map the within-tree distribution of resin pockets as a function of tree height, year of occurrence and position within the annual ring (% ring width) (Watt et al., 2011; Appendix – Downes et al., 2008). A second study, also involving the destructive sampling of trees, compared the effects of stem guying to minimise the effect of wind sway (Watt et al., 2009). Both these projects involved the visual assessment of resin pockets in thousands of images taken at high longitudinal resolution (25 – 50 mm increments) along tree stems.

These recent studies identified several features that had not previously been noted. Across all sites there was a consistent difference between the time of formation of Type 1 and Type 2 resin pockets. Type 1 resin pockets generally occurred within the first 50% of an annual growth ring (early wood) and Type 2 pockets were more commonly found in late wood at approximately 80 – 90 % of annual ring width (Watt et al., 2011). Type 1 resin pockets were also present in the second half of the ring but less frequently. Conversely, Type 2 resin pockets were rarely found in earlywood.

This report addresses the issue of categorising resin pockets into Types 1 and 2, and proposes the existence of a developmental gradation between them. Underpinning this gradation is a proposed mechanism of formation. The objective of this paper is to contribute to the understanding of the underlying physiological mechanisms behind the occurrence of resin pockets, rather than to propose a new classification system. If the proposed gradation is correct, then both types of resin pockets can be alleviated by addressing the common cause.

Method

Site description and sampling approach

Six regions, identified as having high levels of resin defects, were selected for sampling (Table 1). In each region an industrial plantation (around age 15 y) was selected and a square plot of 100 trees within the plantation was assessed for external resin features. Stem diameter at 1.4 metres above ground (DBH) was measured on each tree and the height of the 10 largest trees determined. Six trees were selected that exhibited significant levels of external resin features. More detailed growth and soil descriptions for the experimental sites are provided by Downes et al. (Appendix – 2008).

TABLE 1: Details of six sites from which trees were sampled and images collected.

Site	Region, Country	Annual rainfall (mm)	Plantation owner	Planted	Latitude (degrees South)	Longitude (degrees East)	Elevation (m AMSL)
Ashley	South Island, NZ	648	Rayonier	1991	-43.19	172.59	210
Balmoral Forest	South Island, NZ	496	Rayonier	1991	-42.83	172.80	180
McLean's Island	South Island, NZ	574	Christchurch City Council	1991	-43.47	172.39	90
Ohurakura	North Island, NZ	1383	Rayonier	1991	-39.22	176.73	375
Payanna	Northern Tasmania, Aus	883	Timberlands	1993	-41.11	147.72	250
Woodhill	North Island, NZ	1028	Carter Holt Harvey	1988	-36.69	174.35	110

Each tree was photographed from several angles, and the software program *Tree D* (Brownlie et al., 2007) was used to provide a digital record of tree form. Trees were felled and the lower 5 metres of stem cut into 50 mm thick discs. This sampling strategy was based on a more detailed study of four trees at the McLeans Island site sampled at 25 mm intervals (Figure 1, Downes et al. unpublished). That study found the majority of defects occurred in the lower 5 m of the stem and that there was no real tendency for pockets to form in a given radial direction as also noted by Clifton (Clifton, 1969). Thus, sampling at 50 mm was calculated to detect sufficient numbers of resin pockets to allow relationships with annual climate patterns to be investigated. The upper surface of each disc was cleaned and photographed on a back board using a camera capable of capturing images up to six megapixals in size. While this approach did not allow the collection of highly detailed stem disc surfaces (e.g. false ring structures could rarely be clearly seen), image quality was sufficient to allow the detection of resin pockets within annual rings.

Collection of data on resin pockets

Purpose built software was written using IDL (Interactive Data Language, http://www.ittvis.com/index.asp) to allow each image to be rectified to a constant scale and positional descriptors for each defect recorded. Resin defects were classified as either Type 1 or Type 2 resin pockets using criteria detailed by Donaldson (unpublished data (2003) see Appendix), as resin blemishes, or as "other" defects (Cown et al., 2011). Typically a resin blemish occurred as a radial stain while "other defects" were predominantly resinous internal checks. For the purposes of this study the attributes of these defects were not quantified. Consistent with recent industry usage, Type 2 and 3 resin pockets (Somerville, 1980) were considered to be the same in this study as they could not be consistently distinguished from each other. For each defect, the dimensions were recorded as follows:

Resin Pockets: The locations of the ends were marked and the tangential length of the pocket determined, along with distance from pith.

Resin Blemishes: The start and end point was marked such that the radial length was recorded.

Other Defects: the location of 'other' defects was recorded.

Each image was examined individually using the software, each defect manually classified by the operator, the annual ring in which it occurred identified and the within-ring position of the defect estimated as a percentage. Considerable effort was directed at identifying only a single occurrence of a resin pocket, where pockets extended longitudinally into other images, to avoid double counting.
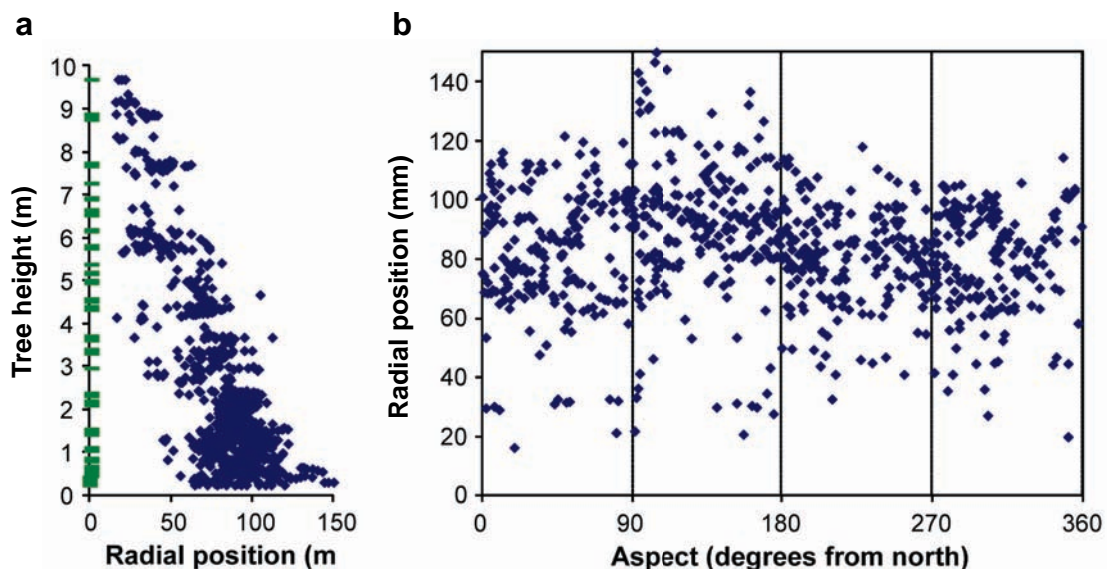

FIGURE 1: Within-tree distribution of resin pockets (Type 1 and 2) in a typical sampled tree exhibiting severe external resin bleeding at McLean's Island, New Zealand: (a) radial by longitudinal variation is shown with each point (♦) representing a single resin pocket. Bars on the y-axis indicate the position of branch whorls. In this presentation, different aspects have been combined. (b) radial by circumferential variation.

Results and Discussion

Recent studies have reported the analysis of the data collected in this study in terms of the within-tree distribution of resin pockets, their relationship with stem guying and the influence of growth rate and rainfall (Watt et al., 2009; Watt et al., 2011). The intention here is not to reanalyse these data, but to describe an apparent continuum in morphology that was observed during data collection. There are very few datasets comprehensive enough to allow such detailed visual exploration of the location and appearance of resin pockets. The high level of sampling across a range of sites and the intensity of data collection along the stem (every 50 mm) allowed several features to be identified that had not, to these authors' knowledge, been previously observed. As noted in Watt et al. (2011), Type 1 resin pockets predominantly occurred in the first 50% of ring width (earlywood) and were not associated with resin blemishes. 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 (Appendix – Downes et al., 2008).

One of the problems with data collection was the decision making required in order to classify a resin pocket as Type 1 or 2. After comparing data collected by different people, it was decided to use a single operator to collect data from each image to minimise errors arising from subjective differences. Regular discussions among staff provided more consistent identification. A similar, more obvious difficulty in distinguishing between Types 2 and 3 has already been noted, with the result that they are now usually regarded as the same feature. However, in general there has typically been a clear distinction between Types 1 and 2, suggesting that they arose from different causes (Graeme Young, Tenon Ltd., personal communication).

The difficulties in categorisation in the current study arose from an apparent morphological continuum between the two types, and hence a common cause. As a result, a progression has been described that generally, but not always, seemed consistent with a hypothesis that Type 1 and 2 pockets represent the ends of a continuum of severity of localised damage/cell death in the developing xylem (cambial zone). A set of representative images is displayed as a continuum between Types 1 and 2 (Figures 2 – 6).

The images in Figures 2 – 6 were selected from those across the five New Zealand sites (Table 1) to illustrate the observed gradation between Type 1 and Type 2 resin pockets. We hypothesise that the gradation is driven by varying degrees of tissue damage in the developing xylem, triggered primarily by water stress, interacting with environmental/mechanical factors that magnify the effect of the stress, resulting in the localised damage to dividing and enlarging cells. This essentially builds on the hypothesis by Cown (1973), who associated resin pocket occurrence with false ring structures. To a considerable extent this was evident in the images collected here (see Figure 2), with all of the sites exhibiting false ring structures to varying degrees. Other analyses (unpublished data) indicate the occurrence of both types of resin pockets to be associated with summer weather conditions affecting plant water stress. The sequence between Figures 3 and 5 may be variable, but the basis of the gradation is that Type 1 and Type 2 pockets can arise from a common cause that damages developing xylem in the cambial region (Figure 7). Type 1 pockets occur when either the causal conditions are less severe (e.g. low available soil water with moderate temperatures), or the tree is physiologically better able to cope with stress compared to more susceptible trees (e.g. better developed root system with greater soil water access, together with a smaller canopy, with lower requirement to access soil water resources).
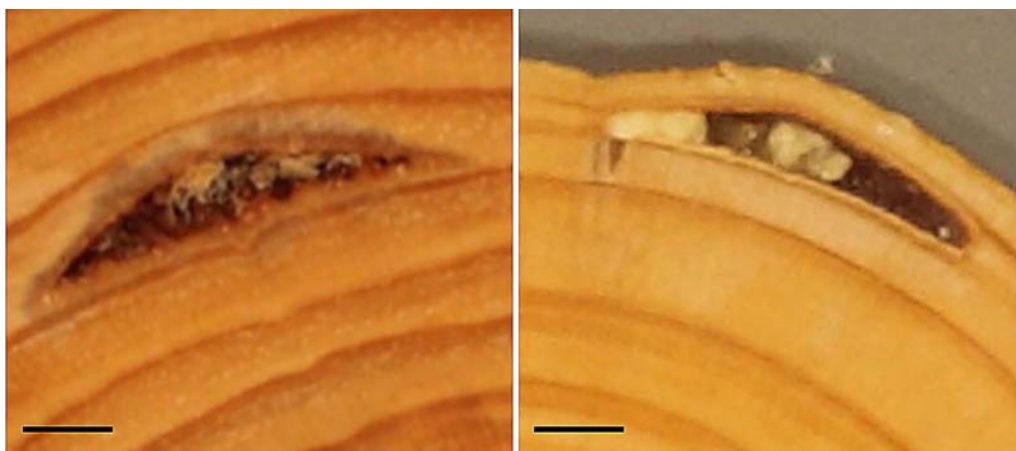

FIGURE 2: Classic Type 1 resin pocket formed in low density earlywood (left) or immediately after a false ring (right). There is no evidence of growth occlusion as subsequent growth rings are continuous. There is some evidence of swelling and deformation of the growth ring outward. No evidence of resin blemishes associated with the pocket (Bar = 10 mm).
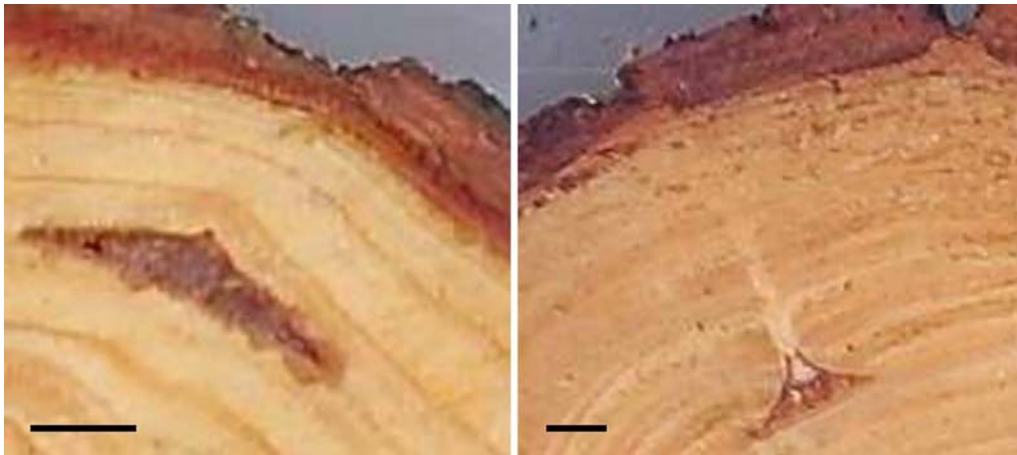
FIGURE 3: Two examples of Type 1 pockets developing a "volcano" shape, with a small point of tissue damage extending toward the bark side (Bar = 10 mm).

Classic Type 1.0 resin pockets (Figure 2) probably result from the localised damage or death of cells in the zone of primary walled enlarging cells (Figure 7), most likely in the region between cells that are transitioning between meristematic and enlarging stages. There is no damage to cambial initials and consequently the continuity of the cambial surface is not disrupted and there is no deformation of the annual ring structure. As the severity of the stress, or sensitivity to it, increases, the damage to differentiating cells extends toward the meristematic region and cambial initials (Figure 3), producing a more "volcano" appearance. Greater severity results in the death of some cambial initials (Figure 4). At that point, some occlusion of growth is required to seal the wound and the growth ring boundary becomes deformed, (characteristic of a Type 2 pocket) but there is still a Type 1 base to

the defect, possibly limiting the flow of resin into the already formed wood. If the damage to the cambial initials is significant, resin production occurs as a wound response and blemishes appear as a streak of resin orientated centripetally towards the pith. This blemish is what is typically called "resin streak" in sawn board studies. In our wider study, a resin pocket was classified as a Type 2 pocket if there was evidence of resin blemish and/or growth ring disturbance (Figures 4 – 6).

The continuum between Type 1 and Type 2 pockets is probably confounded by other characteristics or tissue damage, and hence not one-dimensional. The anatomical abnormality preventing the restoration of the cambial surface may not be a consistent feature of the gradation, but a different type of damage, resulting

FIGURE 4: Increasing cambial damage and disruption of subsequent growth ring continuity are occlusion features normally associated with Type 2 pockets. These features are becoming evident in these two examples. Often there is a narrow, radial defect extending from the resin pocket to the bark. No evidence of resin blemishes (Bar = 10 mm).
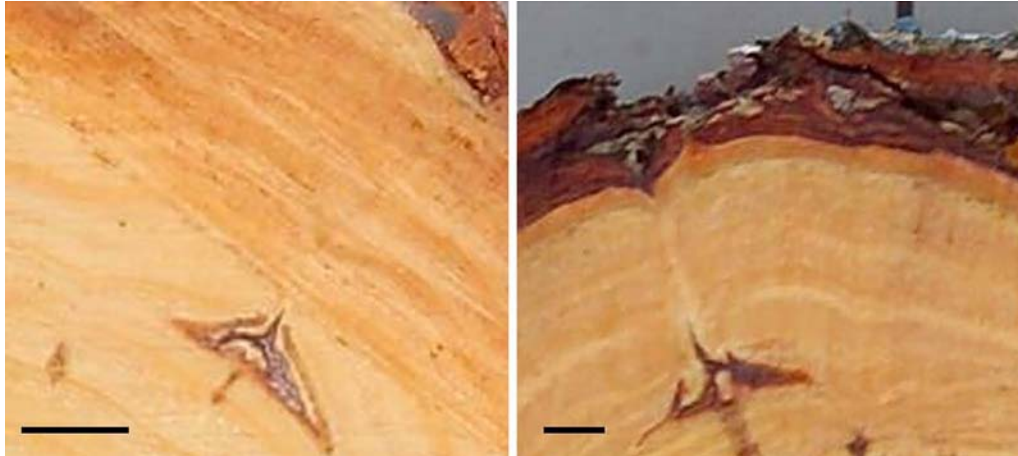
FIGURE 5: In these two examples, damage severity increases to generate a resinous wound response, resulting the radial smears of resin appearing that extend centripetally toward the pith. (Bar = 10 mm)

in a "volcano-like" appearance caused by a trace of unusual tissue extending to the bark. This suggests some form of damage linking the phloem with the xylem. The presence of galls (Appendix – McConchie et al., 2007) on these sites may be related to these features and explain the trace extending to the bark. As the severity of the damage to the cambial initials increases, a wide occlusion scar results, characteristic of a typical Type-2 pocket (Figure 6).

A three dimensional study of these features was not the objective of these investigations. However, on numerous occasions Type 2 pockets were observed to extend over multiple discs (25 or 50 mm intervals), and not uncommonly extended for greater than 200 – 250 mm (Figure 4). This was well in excess of the range observed by Somerville (1980). The severity of the resin defect also varied longitudinally and could be less severe between adjacent discs of greater severity. In contrast Type 1 pockets were rarely observed to extend more than 50 – 100 mm longitudinally.

There is little descriptive data on resin pocket morphology in the broader scientific literature (Cown et al., 2011; Somerville, 1980; Appendix – McConchie et al., 2007), and distinctions between different morphological types appears restricted to studies from New Zealand. The majority of studies have been undertaken in New Zealand where the commercial implications of resin pockets have a significant impact on a well-developed appearance grade manufacturing sector.
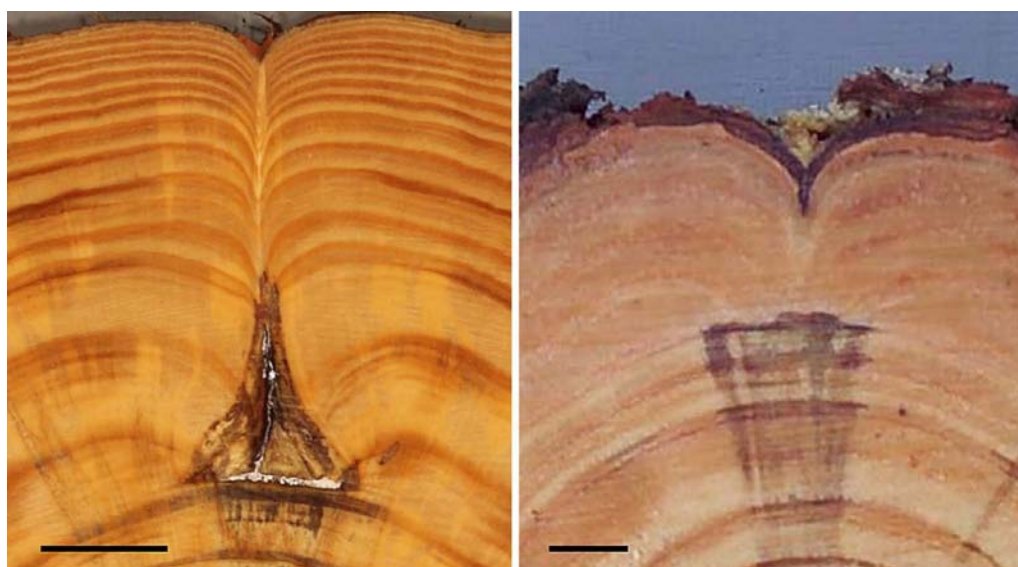

FIGURE 6: The classical features of a Type 2 pocket are developing from a pocket with the Type 1 base (left). A fully occluded classical Type 2 (right) with extensive centripetal resin bleeding, arising from the severe cambial damage at the time of formation (Bar = 10 mm).
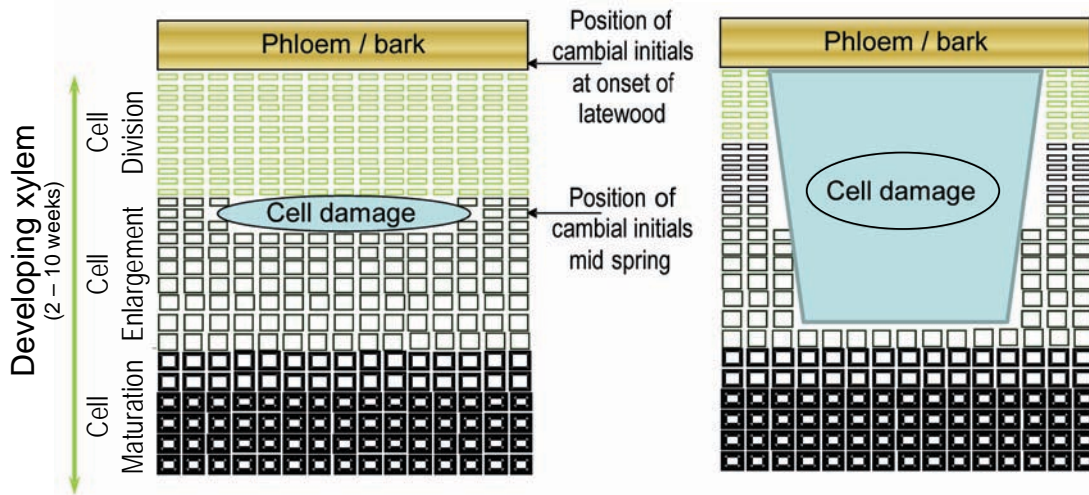
FIGURE 7: Schematic illustration of the nature of damage to developing xylem in the cause of Type 1 (left) and Type 2 (right) resin pockets. It is hypothesised that a gradation of damage severity underpins the morphology of resin pockets currently categorised into the two types.

This study is, to the best of the authors' knowledge, the first attempt to suggest a continuum between various manifestations of resin pocket morphology. While it is undoubtedly an over-simplification of a complex, multi-dimensional interaction, it provides a guide to others attempting to classify resin pockets. This gradation is not being proposed as a new system for classification in future studies. Rather the continuum is presented as an aid to better understand the physiological basis for these defects. If correct, the ratios between the currently classified Type 1 and 2 pockets on a given site could be indicative of the degree of stress experienced by trees and/or their ability to withstand it. This might help inform forest managers of the degree to which thinning might be needed to alleviate water stress effects, if appearance grade products are the intended market.

Conclusion

Development from a Type 1 to Type 2 resin pocket occurs when a late Type 1 (i.e. occurring in less dense wood after a false ring) transitions into a Type 2 due to a greater level of stress experienced at that point, or a developing xylem less able to contain cell damage. Type 1 pockets have a very consistent morphology in early wood, which is possibly related to the damage occurring in a more vigorous cambium that is better able to absorb or respond to damage, at a time of year when water stresses are less likely to be severe. Type 2 pockets are rarely found in early wood, lending support to the concept that they share a common physiological cause with Type 1 pockets but are a more severe manifestation. The sequence described could be consistent with a gradation in the severity of
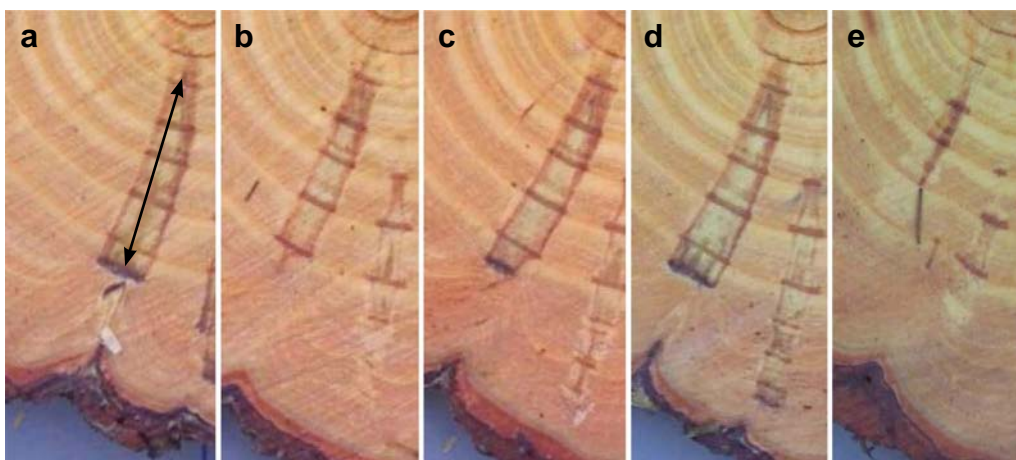

FIGURE 8: This sequence (from left to right) shows the longitudinal variation in a Type 2 resin pocket at, in this case, 25 mm intervals. The severity at (a) decreases to (b), increases through (c) and (d) before decreasing in (e). The associated centripetal resin blemish is evident indicated by the arrow in (a).

cambial damage, not necessarily tangential size or width but extent or depth of cambial cell damage. It is not our intention that the proposed gradation replace the current classification of resin pockets. Rather we seek to suggest a common cause to better focus research directed at managing their occurrence.

Acknowledgements

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