CORRELATION OF RESISTANCE TO A PULSED CURRENT WITH SEVERAL WOOD PROPERTIES IN LIVING EUCALYPTS

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ABSTRACT

Pulse resistance, basic density, moisture level, heartwood extractives content, pH, and levels of sodium, potassium, calcium, magnesium, and manganese were determined for the inner and outer heartwood and the sapwood from 10 trees of each of six eucalypt species. In most instances pulse resistance was positively and significantly ($p = 0.05$) correlated with basic density ($r^2 = 0.3$–0.8), but was weakly and/or inconsistently associated with the remaining factors. The usefulness of a pulsed current resistance meter in detecting decay in the eucalypts studied is possibly limited because a substantial change in only one or two of the relevant wood properties during decay may not induce a perceptible change in pulse resistance.

INTRODUCTION

The Shigometer, which produces a pulsed electric current and measures resistance to its passage through wood, has been used to detect decay in various living conifers and deciduous hardwoods and in utility poles (Shigo & Shigo 1974; Shigo *et al.* 1977). However, the usefulness of the device as a means of detecting decayed or decaying wood in some species, including eucalypts, has been questioned (Piirto & Wilcox 1978; Wilkes & Heather 1982a; Wilson *et al.* 1982; Wilkes 1983). A major limitation in determining the appropriateness of more widespread use of the Shigometer is the general lack of detailed information on the relative influence of various wood properties on pulse resistance (Shigo *et al.* 1977; Wilson *et al.* 1982). Such information might indicate the "types" of wood in which the meter could be expected to detect decay effectively. For example, if pulse resistance is predominantly dependent on the concentration of cations, which may carry electrical charges in wood (Lin 1967), the Shigometer could well have limited application in detecting decay in eucalypts since in many species the mineral levels and pH do not alter markedly as heartwood tissues discolour and decay (Wilkes 1982, and unpubl. data). In eucalypts decay is usually accompanied by a reduction in both basic density and extractives content (Wilkes & Heather 1982b, 1983), factors which may influence ion movement (Wilkes & Heather 1982a). Thus, if in eucalypts pulse resistance is largely controlled by basic density and extractives content, the Shigometer might be useful in detecting decay, providing natural radial variation in the properties is limited (Wilkes 1983). This study examines the influence of wood properties on pulse resistance in a range of eucalypt species.

MATERIALS AND METHODS

Ten trees of each of six eucalypt species (*Eucalyptus albens* Benth., *E. bancroftii* Maiden, *E. dealbata* A. Cunn. ex Schau., *E. goniocalyx* F. Muell. ex Miq., *E. macrorhyncha* F. Muell. ex Benth., and *E. sideroxylon* A. Cunn. ex Woolls) were selected as representative of a 40-year-old dry sclerophyll forest. The trees, 10 to 40 cm diameter at breast height over bark, were felled and a bolt, some 20 cm axially and showing no visible signs of decay, was cut at breast height, wrapped in polythene, and stored at 4°C.

Within a few days of felling, the bolts were cross-cut 8 cm from each end, leaving a "fresh" disc 4 cm thick. On a randomly selected radius, pulse resistance measurements were made at the inner heartwood (2 cm from the pith), outer heartwood (2 cm from the sapwood-heartwood boundary), and outer sapwood (0.5 cm from the cambium) using a needle probe. The two needles, 8 mm long and 12 mm apart, were inserted, tangentially aligned, to a depth of 6 mm; a 2-mm-thick plastic washer at the base of each needle insulated the receptacles from the wood surface. Readings were also taken at the corresponding points on the opposite (under) face of each disc. The positions encompassed the extremes in pulse resistance – in *Eucalyptus,* resistance readings usually peak in the outer heartwood, and are relatively low in the sapwood and inner heartwood (Wilkes 1983).

The wood at each of the three positions, lying between the points of needle insertion on opposite faces, was then dissected to determine five further wood properties:

- Basic density (kg/m^3), calculated as the ratio of oven-dry weight of a 2-cm^3 block to its swollen displacement volume;
- Moisture level (kg/m^3), derived by recording the pre- and post-dry (105°C) weights of the same block;
- Extractives content (kg/m^3) (for heartwood tissues only), taken as the total weight loss in 1 g of wood, ground through a 1-mm sieve, and extracted in a soxhlet with methanol for 8 hours, then in a small tissue bag in several changes of boiling water for a further 2 hours;
- pH, recorded using an Anax meter, for the filtrate of a solution containing 0.5 g of sawdust (1-mm screen) and 12 ml of distilled water, combined 16 hours prior to measurement (Stamm 1961);
- Concentrations (g/m^3) of the minerals sodium, potassium, calcium, magnesium, and manganese, derived by flame emission or atomic absorption spectrophotometry using 0.3 g of sawdust digested in 5 ml of hydrochloric acid and 15 ml of nitric acid.

Correlations between pulse resistance and the other wood properties were assessed by least squares simple or multiple regression employing the statistical computer language GLIM. Linear, quadratic, and cubic models were used. The correlations were computed using data for all positions in each species, and also separately for the sapwood and heartwood of the 10 trees of each species.

RESULTS AND DISCUSSION

The general patterns of radial variation in the wood properties measured (Table 1) agree with those reported elsewhere for various other eucalypts (Hillis 1978; Lambert 1981; Wilkes & Heather 1982a). The degree of correlation between pulse resistance and the other wood properties is shown in Table 2. Results for simple regression using linear models only are presented since the contribution of a wood property in accounting for variability in pulse resistance in the multiple regression models usually reflected its contribution in the simple regression situation, and quadratic and cubic models generally failed to improve correlations substantially. For sapwood and heartwood, basic density is very frequently positively and significantly ($p = 0.05$) correlated with the resistance reading. This relationship is presumably causal since increasing volumes of cell wall substance could be expected to offer increasing obstruction to ion movement from one cell lumen to another (Wilkes & Heather 1982b). However, the relevant r^2 values are often less than 0.5, suggesting that other factors, in total, could influence pulse resistance as much as, or more than, wood density in many situations, e.g., in both the sapwood and heartwood of *E. bancroftii.* In *E. dealbata, E. macrorhyncha,* and *E. sideroxylon,* heartwood extractives may have the effect of physically inhibiting movement of ions through wood substance (Wilkes & Heather 1982a).

Contrary to the findings of Tattar *et al.* (1972), there is no consistent negative association between the concentration of any of the minerals and pulse resistance in heartwood or sapwood (Table 2). This was perhaps to be expected with minerals which typically show low solubility and/or low ionic mobility in wood, e.g., magnesium and manganese (Tattar *et al.* 1972); but even levels of potassium, *c.* 95% of which is soluble in both sapwood and heartwood in the study species (Wilkes unpubl. data), are very often poorly correlated with pulse resistance. Grouping the data for sapwood and heartwood produces a higher coefficient of determination, since the decrease in pulse resistance in the sapwood relative to the heartwood is often well "explained" by a corresponding increase in mineral levels in the former (Table 1).

The results (Table 2) generally support the assertion (Lin 1967; Tattar *et al.* 1972; Shortle 1982) that variations in moisture level well above fibre saturation point have relatively little effect on pulse resistance. Indeed the woods studied were often very nearly saturated (Table 1) suggesting that the availability of water would not normally be the factor limiting mobility of ions, which preferentially move in the lumen water (Lin 1967). The significant ($p = 0.05$) moisture-level/pulse-resistance correlations for heartwood could be largely indirect, reflecting the influence of wood density on electrical conductivity – the increase in resistance from the pith outwards may result primarily from an increase in cell wall thickness, rather than the associated decrease in volumes of free water.

Hydrogen ion concentration may be negatively associated with pulse resistance in *Pseudotsuga menziesii* (Mirb.) Franco (Shortle 1982), the ions possibly acting to conduct current. In contrast, in the study species, sapwood has a higher pH (lower hydrogen ion concentration) and a lower pulse resistance than comparable heartwood (Table 1), and thus acidity and resistance reading are positively correlated when sapwood and heartwood data are grouped (Table 2). It might be postulated that pH could

TABLE 1—Properties of wood at three radial positions in six eucalypts

Species	Position	Wood property									
		Pulse resistance (kΩ)	Basic density (kg/m^3)	Moisture level (kg/m^3; % saturation)	Extractives content (kg/m^3)	pH	Mineral concentrations (g/m^3)				
							Na	K	Ca	Mg	Mn
E. albens											
	Inner heartwood	329* ± 62	860	390/90	140	4.1	24	60	2600	96	12
	Outer heartwood	380 ± 68	910	370/92	153	4.1	25	57	2900	66	6
	Sapwood	96 ± 19	770	350/71	—	4.7	15	820	1200	240	25
E. bancroftii											
	Inner heartwood	30 ± 8	630	570/97	68	3.1	31	110	310	450	12
	Outer heartwood	37 ± 7	670	540/97	110	3.6	25	90	250	500	5
	Sapwood	38 ± 8	580	500/81	—	4.7	16	1000	470	180	41
E. dealbata											
	Inner heartwood	244 ± 52	670	490/88	65	3.7	1	12	94	15	0
	Outer heartwood	396 ± 69	800	460/97	109	3.8	7	10	29	12	0
	Sapwood	101 ± 26	600	410/68	—	4.2	14	840	260	72	26
E. goniocalyx											
	Inner heartwood	124 ± 30	640	570/98	96	3.3	23	93	740	350	9
	Outer heartwood	158 ± 42	700	520/96	134	3.1	15	99	260	380	3
	Sapwood	57 ± 12	610	490/82	—	5.0	11	870	350	210	20
E. macrorhyncha											
	Inner heartwood	287 ± 35	610	530/89	83	3.3	1	17	0	4	0
	Outer heartwood	429 ± 49	690	490/90	111	3.5	1	20	0	4	0
	Sapwood	174 ± 43	570	440/70	—	4.6	31	550	110	73	8
E. sideroxylon											
	Inner heartwood	408 ± 41	790	420/87	78	3.8	26	50	440	7	1
	Outer heartwood	> 500	870	380/89	122	3.9	16	33	100	2	1
	Sapwood	180 ± 32	720	340/65	—	4.5	18	660	400	97	35

* All values the mean for 10 trees; confidence interval ($p = 0.05$) given for pulse resistance

> 500 pulse resistance beyond the range measured by the Shigometer

TABLE 2—Coefficients of determination (r^2) for regressions between pulse resistance and other wood properties

Tissues	Species	Wood property								
		Basic density	Moisture level	Extractives content	pH	Mineral concentration				
						Na	K	Ca	Mg	Mn
Sapwood and heartwood*	**E. albens**	0.78+	0.06+		0.20—	0.09—	0.72—	0.30+	0.26—	0.21—
	E. bancroftii	0.01—	0.34—		0.45—	0.07+	0.00	0.04—	0.04—	0.21+
	E. dealbata	0.72+	0.09—		0.45—	0.14—	0.58—	0.38—	0.47—	0.54—
	E. goniocalyx	0.51+	0.00		0.39—	0.01—	0.45—	0.01—	0.12+	0.36—
	E. macrorhyncha	0.73+	0.06+		0.24—	0.21—	0.52—	0.21—	0.33—	0.29—
	E. sideroxylon	0.61+	0.79+		0.29—	0.02+	0.82—	0.18+	0.74—	0.65—
Sapwood†	**E. albens**	0.49+	0.01+		0.06—	0.08+	0.02+	0.01+	0.04—	0.20—
	E. bancroftii	0.08+	0.70+		0.08+	0.00	0.40—	0.32—	0.09+	0.61+
	E. dealbata	0.43+	0.14—		0.10—	0.02—	0.63—	0.04—	0.29—	0.00
	E. goniocalyx	0.51+	0.26—		0.10—	0.00	0.20—	0.15—	0.10+	0.09—
	E. macrorhyncha	0.35+	0.01—		0.01—	0.00	0.05+	0.73+	0.38+	0.66+
	E. sideroxylon	0.33+	0.02—		0.00	0.07—	0.03—	0.17+	0.40—	0.01—
Heartwood‡	**E. albens**	0.48+	0.17—	0.09—	0.05—	0.03—	0.03+	0.39+	0.00	0.01+
	E. bancroftii	0.08+	0.24—	0.06+	0.13+	0.22+	0.33—	0.45—	0.04—	0.20—
	E. dealbata	0.63+	0.47—	0.47+	0.16—	0.02—	0.07—	0.04—	0.01—	0.00
	E. goniocalyx	0.40+	0.36—	0.02—	0.04—	0.08+	0.00	0.06+	0.12—	0.21—
	E. macrorhyncha	0.60+	0.43—	0.31+	0.03—	0.00	0.00	0.00	0.05+	0.00
	E. sideroxylon	0.49+	0.31—	0.49+	0.08+	0.05—	0.01—	0.46+	0.30+	0.09—

+ — Wood property positively or negatively correlated with pulse resistance.

* Correlation coefficient significant ($p = 0.05$) for r^2 values > 0.13 (0.19 for **E. sideroxylon** since outer heartwood data could not be used - see Table 1).

† Correlation coefficient significant for r^2 values > 0.40.

‡ Correlation coefficient significant for r^2 values > 0.19 (0.40 for **E. sideroxylon**).

influence pulse resistance indirectly through its effects on the ionisation of minerals, but when sapwood and heartwood are considered separately, effects of acidity on pulse resistance are minimal.

The electrical properties of the wood of *E. bancroftii* are quite different from those of the other woods. Despite moderate radial variation in specific gravity, extractives content, and mineral levels (Table 1), pulse resistance is consistently low within and between trees of this species. The wood is unusually brittle, and shows an exceptional propensity to shrink on drying (Hall *et al.* 1970; Wilkes unpubl. data), possibly resulting from unusual cell wall organisation which may affect pulse resistance.

These results indicate that a complex combination of factors determine a single resistance reading, as has been suggested for *E. microcorys* F. Muell. (Wilkes & Heather 1982b). This complexity probably has the net effect of limiting the usefulness of the Shigometer in detecting heart rot in many species, since a substantial change in only one or two of the relevant wood properties during decay may not induce a perceptible change in pulse resistance. Certainly the Shigometer technique proved to be rather unreliable in predicting the occurrence of decay in the species under study (Wilkes 1983). Hence the suitability of the device for each possible intended use (e.g., detecting decay, or determining sapwood width, tree vigour, or radial variation in wood density within trees) must be established for individual eucalypt species and possibly for other genera.

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