INCIDENCE OF BROWN WOOD (INCIPIENT ROT) AND ROT IN REGROWTH KARRI.

COMPARISON OF 12- TO 14-YEAR OLD TREES ON TWO COMMUNITY VEGETATION TYPES

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Abstract

The incidence and extent of discolouration, incipient rot, rot, insect galleries and kino were assessed in 1 m billets from 122 12- to 14-year old regrowth karri trees of similar management history. Selected trees were the most dominant and least dominant trees from each of ten sample points from each of three coupes representing the two commonest community vegetation types in the karri forest.

There were no significant differences in stand parameters, tree parameters and the extent of symptoms between community vegetation types.

Incipient rot and rot occurred in 83 per cent of the dominant and co-dominant trees, but in only 28 per cent of the sub-dominant and suppressed trees. Discolouration and incipient rot were present both above and below crown break. Discolouration was most abundant between 1 m and 9 m above ground level and was mainly in the centre of the billets. Incipient rot and rot were most abundant at ground level. Where entry points could be recognised, incipient rot was most frequently associated with branches, but it was also associated with insect galleries. This association was not constant between coupes. Insect galleries occurred both above and below crown break. They were most abundant at ground level on sub-dominant and suppressed trees, but were most abundant between 2 m and 6 m in the dominant and co-dominant trees. These differences reflected infestation by different species of borer. Kino was most abundant in more recently formed wood and was mainly associated with branches.

Of the most dominant trees with incipient rot, rot and borers, the most severely affected trees are likely to be taller, of larger diameter, with deeper crowns and lower crown break than trees which are not as badly affected.

Introduction

Karri (*Eucalyptus diversicolor* F. Muell) is endemic to the extreme south-west of Western Australia. It occurs in pure stands interspersed with stands of jarrah (*E. marginata* Donn ex Smith), jarrah-marri (*E. calophylla* Lindley) or treeless flats and swamps. Its occurrence, together with a description of past management of the karri forest is given by Bradshaw and Lush (1981).

Harvesting karri stands for timber was initially by clear felling, but this was replaced by selection cutting in about 1938. Selection cutting, however, resulted in difficulties with regeneration burning, fire protection, declining health of residual trees and difficulties in carrying out further harvests. Consequently, selection cutting was replaced by clear felling in 1967 (Bradshaw and Lush 1981). The present forest is therefore a mosaic of virgin karri stands, regenerating, even aged stands resulting from clear felling, and uneven aged stands resulting from selection cutting. Regenerating stands comprise about 46 per cent of the area available for timber production. As these stands mature they will comprise an increasing proportion of the timber resource harvested from WA forests; by 2020 it is estimated that about 40 per cent of the state's sawlog supply will be regrowth karri (CALM 1987).

CALM's timber inspectors have been concerned that the quality of wood from thinnings from regrowth areas is lower than that in logs from mature forest. A sawmill survey of medium sawlogs, mainly sourced from regenerating stands at Treen Brook, showed that about 23 per cent contained rot, whilst a further 47 per cent contained brown wood (Donnelly *et al.* 1994). Experimental work has shown that brown wood (which is not a defect) is incipient rot and can be caused by at least two different fungi (Davison and Tay 1990). When differences in log volume were taken into consideration, Donnelly *et al.* (1994) showed that there was a very highly significant difference between the proportion of sawlogs with no rot or incipient rot from thinnings from regrowth stands compared with first grade sawlogs sourced from mature stands. Medium sawlogs (from regrowth stands) had more rot and brown wood.

Sawlog quality standards are specified by CALM (CALM 1993). Quite apart from standards relating to the physical dimensions of a log, first grade sawlogs must have at least 50 per cent millable wood on the worst face, logs with a larger proportion of rot will be downgraded to second grade, salvage or chiplogs. Sawlogs do not, therefore, represent a random sample of log quality, but a sample of the best logs taken from a coupe. In addition, unless the coupe is clear felled, sawlogs will not necessarily be derived from all dominance classes. Thinnings, for example, will represent the least dominant and slowest growing trees in a stand. Some form of field sampling is needed to assess wood quality in growing trees, and to make comparisons between sites, stands and management practices.

Inions *et al.* (1990) classified the karri forest into 13 community types based on plant species composition, climate and edaphic factors. They showed that karri productivity, assessed as mean age-standardised top height, differed significantly between community types. We have used the two commonest community vegetation types (4 and 10) as the basis for a stratified random survey. In this survey we have:

(i) compared the incidence of brown wood and rot in young regrowth trees

(ii) compared the incidence of insect damage, discolouration and kino in the surveyed trees

(iii) compared the frequency of these symptoms in trees of different dominance class

(iv) compared the incidence of these symptoms at different heights above ground level

(v) described the distribution of these symptoms within the surveyed trees

(vi) used regression analysis to determine which site and tree characteristics are correlated with the incidence of incipient rot and rot, and insect galleries in dominant and co-dominant trees.

The results of this survey are presented in this report.

Method

Site selection

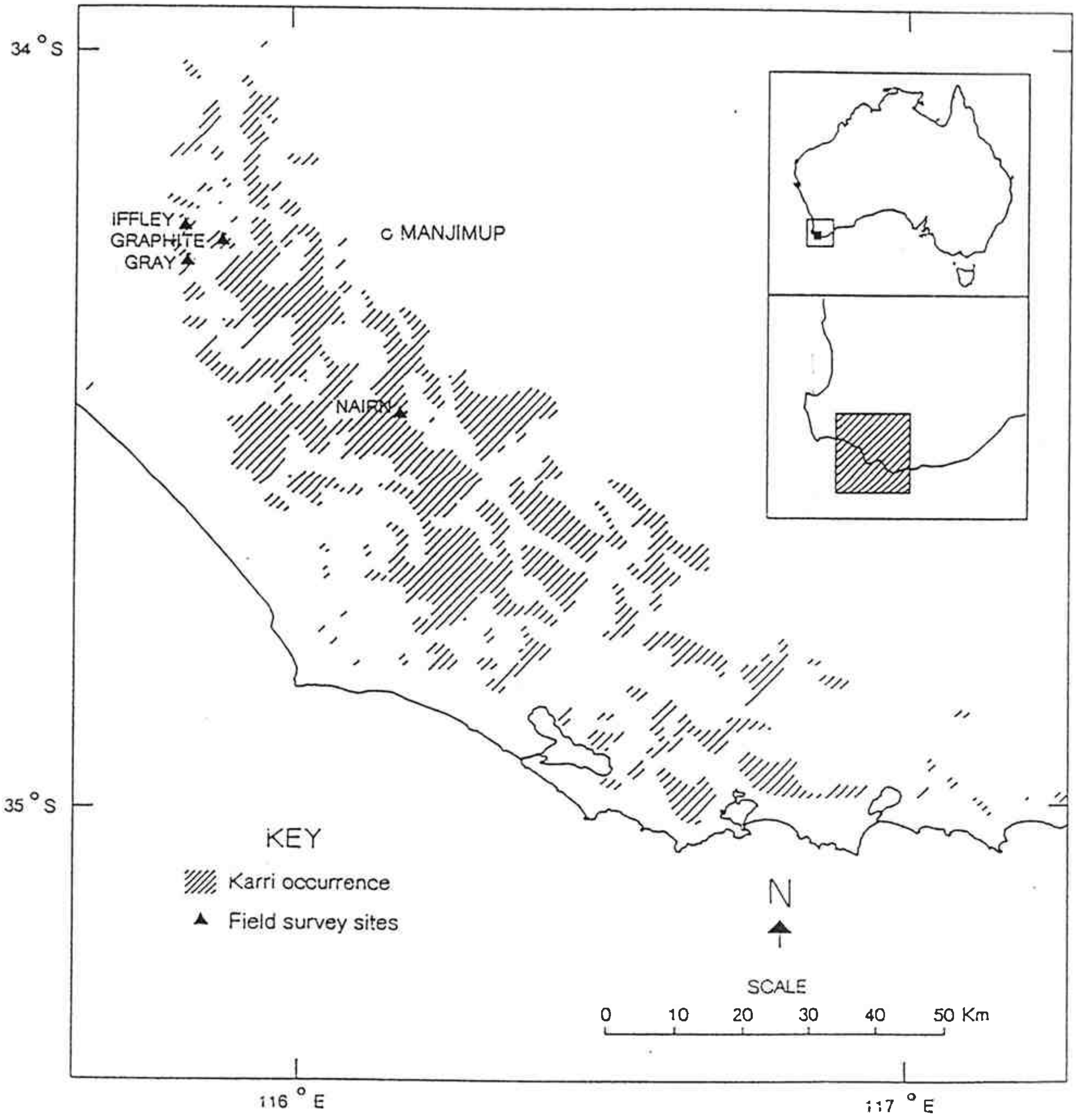
The study was a stratified random survey of the incidence of brown wood and associated symptoms in 12- to 14-year-old regrowth karri coupes. Fourteen coupes of seed tree regenerated karri were visited and community vegetation types determined. Three coupes of each of community vegetation type 4, and community vegetation type 10 were chosen based on uniformity of age and stocking. Community vegetation type 4 sites are moist, either on gravelly duplex soils, or low in the profile. Soils are very alkaline and characteristic vegetation is *Acacia pentadenia* Lindley, *Chorilaena quercifolia* Endl. and *Lepidosperma effusum* Benth. (Inions *et al.* 1990). Three coupes within Nairn forest block were selected (Fig. 1, Table 1).

Table 1. Survey site details.

Coupe	Vegetation type	Altitude (m)	Regeneration method	Regeneration age (yrs)	Comments
Nairn 3	4	120	Seed tree	14	
Nairn 7	4	140	Seed tree	14	Wildfire regeneration
Nairn 9	4	160	Seed tree	12	
Graphite 8	10	200	Seed tree	12	
Gray 1	10	160	Seed tree	13	
Iffley 3	10	180	Seed tree	12	

Community vegetation type 10 occurs in high rainfall areas in the northern karri forest where temperatures are relatively warm (Fig. 1). Soils are gravelly and high in phosphorus both above and below 10 cm depth. Vegetation which characterises this community type includes *Bossiaea laidlawiana* Tovey & P. Morris, *Chorilaena quercifolia* and *Tremandra stelligera* R. Br ex DC.. Single coupes in each of Graphite, Gray and Iffley forest blocks were selected for sampling (Table 1).

Figure 1.
Location of the survey sites.



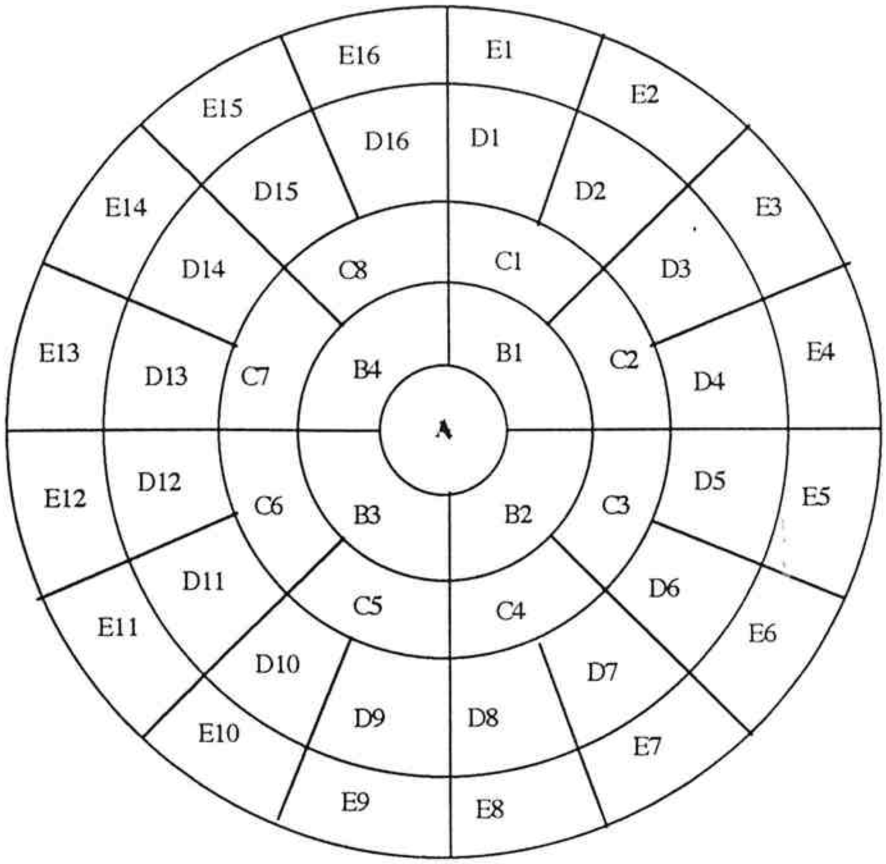
Survey method

Each coupe and point were assessed in separate phases of measurement. The first phase involved recording site and tree information for each point, the second involved assessment of brown wood and associated symptoms after the tree had been felled. Points were located randomly along roads, and at least 30 m in from the edge of the coupe. There were 10 points per coupe (11 at Graphite 8) and 30 points per community type. At each point the top height (the mean height of the two tallest trees in a radius of 16 m around the point) and basal area were measured. Basal area was used as a measure of stand density, stems per ha were not assessed. Site index was calculated from top height measurements (Rayner 1991). The age of the regeneration was recorded. Slope and aspect were measured and fire damage assessed (nil in all coupes).

The largest and smallest tree nearest to the point were selected and the following measurements taken : dominance, crown and bole epicormic development, diameter at breast height over bark (DBHOB), bark thickness, tree form, wood quality and quantity (descriptions in Appendix 1). After all the standing tree measurements were completed, the two trees were felled and total height, crown break height, height to the lowest live and dead limbs, and height to the lowest live and dead limbs greater than 3.5 cm in diameter were measured. The tree was measured into 1 m long billets, extending from ground level into the crown, and marked along its vertical axis in order to realign billets after cutting. Once all height measurements were completed, the billets were cut. Diameter under bark and heartwood diameter were measured with a tape along the long and short axis through the pith of each billet face. Bark thickness was measured in two places.

The type, location and extent of symptoms were recorded using a plastic template overlaid on the upper billet face (Fig. 2, Table 14). Symptoms recorded were discolouration, brown wood, brown cubical rot, white pocket rot, white rot, insect galleries and kino. Association of symptoms with branches or other symptoms was also recorded. The plastic template was aligned with the marked vertical axis on each billet. The location of symptoms were recorded in each 20 cm^2 cell; the extent of symptoms in each cell was recorded as either up to a quarter (< 5 cm^2), between a quarter and a half (5 cm^2 to 10 cm^2), between a half and three quarters (10 cm^2 to 15 cm^2) and over three quarters (>15 cm^2). In this way columns of infection could be identified by comparing the location of symptoms on consecutive billets.

Figure 2.
Template used in assessing billets, each cell is 20 cm².



Statistical analysis

Comparisons of community vegetation type were analysed using SuperANOVA (Abacus Concepts 1989) statistical package. There were three replicates (coupes) nested within each site type, with 10 blocks of two trees in each coupe. As 11 blocks of trees had been assessed at Graphite 8, only the first 10 were used for these analyses. As community vegetation type was not significant, the dataset was re-analysed to compare dominance class using blocks nested within coupes.

The area occupied by different symptoms was estimated from the template data. An extent < 5 cm^2 was estimated as 2.5 cm^2, between 5 cm^2 and 10 cm^2 as 7.5 cm^2, between 10 cm^2 and 15 cm^2 as 12.5 cm^2, and > 15 cm^2 as 17.5 cm^2. Comparisons of the proportion of surface area affected were made on arcsine square root transformed data. Comparisons of location of symptoms on billet faces or in different locations in the surveyed trees were made with StatView (Abacus Concepts 1992) statistical package.

Results

Symptoms

Symptoms of discolouration, brown wood, white rot, white pocket rot, brown rot and insect galleries are described and illustrated in Davison and Tay (1990). Kino was present as pockets or veins.

Comparison of community vegetation types

Site index, basal area, aspect and slope did not differ significantly between community vegetation types (Table 2). There were, however, very highly significant differences between compartments nested within community vegetation types (Table 2). Site index varied from 40.8 at Nairn 9 to 48.2 at Nairn 3, whilst basal area varied from 12.8 m^2ha^{-1} at Iffley to 24.9 m^2ha^{-1} at Gray 1 (Table 2). Aspect varied from 72° to 300° and slope from 3° to 11.5° (Table 2).

Table 2. Comparison of stand parameters between community vegetation types 4 and 10 (n=10).

n.s. not significant; * <0.05; ** <0.01; *** <0.001

	Site index	Basal area	Aspect	Slope
Vegetation type	n.s.	n.s.	n.s.	n.s.
Coupe (vegetation type)	***	***	***	***

Vegetation type	Coupe	Site Index		Basal area (m^2ha^{-1})		Aspect (°)		Slope (°)	
		Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
4	Nairn 3	48.2	0.52	18.3	1.1	300	3.4	7	0.3
4	Nairn 7	47.1	0.24	23.1	1.6	249	5.8	3	0.3
4	Nairn 9	40.8	1.2	23.9	1.6	72	3.4	8.5	0.5
10	Graphite 8	47.3	0.57	23.5	1.5	268	4.4	3	0.7
10	Gray 1	43.8	0.8	24.9	2.4	186	18.8	8	0.2
10	Iffley 3	45.5	0.4	12.8	0.4	232	11.3	11.5	0.4

Total height, crown break and DBHOB did not differ significantly between community vegetation types (Table 3). There were, however, highly significant differences between compartments nested within community vegetation types (Table 3). Total height varied from 15.2 m at Nairn 9 to 17.9 m at Nairn 3, crown break varied from 8.8 m at Graphite 8 to 11.2 m at Nairn 7, whilst DBHOB varied from 13.3 cm at Nairn 9 to 18.0 cm at Nairn 3 (Table 3).

Table 3. Comparison of tree parameters between community vegetation types 4 and 10 (n=20).

n.s. not significant; * <0.05; ** <0.01; *** <0.001

	Total height	Crown break	DBHOB
Vegetation type	n.s.	n.s.	n.s.
Coupe (vegetation type)	**	**	**
Point (coupe, vegetation type)	n.s.	*	n.s.

Vegetation type	Coupe	Total height (m)		Crown break (m)		DBHOB (cm)	
		Mean	s.e.	Mean	s.e.	Mean	s.e.
4	Nairn 3	17.9	1.4	9.7	0.4	18.0	2.3
4	Nairn 7	17.3	1.1	11.2	0.5	15.9	2.0
4	Nairn 9	15.2	1.4	9.4	0.3	13.3	1.3
10	Graphite 8	15.4	1.1	8.8	0.4	15.8	1.9
10	Gray 1	16.5	0.9	10.3	0.4	14.6	1.5
10	Iffley 3	15.6	1.4	9.0	0.4	16.0	1.9

The billet surface area examined, heartwood surface area and sapwood width did not differ significantly between community vegetation types (Table 4). There were, however, significant differences between compartments nested within community vegetation types (Table 4). Billet surface area varied from 952 cm^2 at Nairn 9 to 2 349 cm^2 at Nairn 3, heartwood surface area varied from 214 cm^2 at Nairn 3 to 842 cm^2 at Nairn 9, and sapwood width varied from 2.6 cm at Nairn 7 to 3.0 cm at Graphite 8 (Table 4).

Table 4. Comparison of billet surface parameters between community vegetation types 4 and 10 (n=20).

n.s. not significant; * <0.05; ** <0.01; *** <0.001

	Billet surface area	Heartwood surface area	Sapwood width
Vegetation type	n.s.	n.s.	n.s.
Coupe (vegetation type)	***	**	*
Point (coupe, vegetation type)	n.s.	n.s.	n.s.

Vegetation type	Coupe	Billet surface (cm^2)		Heartwood surface area (cm^2)		Sapwood width (cm)	
		Mean	s.e.	Mean	s.e.	Mean	s.e.
4	Nairn 3	2 349	575	842	188	3.2	0.33
4	Nairn 7	1 813	409	619	159	2.6	0.25
4	Nairn 9	952	193	214	55	2.8	0.24
10	Graphite 8	1 593	389	481	138	3.0	0.25
10	Gray 1	1 314	288	340	83	2.8	0.25
10	Iffley 3	1 606	351	490	119	2.9	0.28

The proportion of billet surface area affected by either discolouration, or brown wood, or rot, or insect galleries, or kino did not differ significantly between community vegetation types (Table 5). There were, however, significant differences in the proportion of billet area affected by discolouration or kino between compartments nested within community vegetation types (Table 5). The proportion of billet surface area affected by discolouration ranged from 0.18 per cent at Grey 1 to 1.41 per cent at Nairn 7, while the proportion of surface area affected by kino varied from 0.37 per cent to Grey 1 to 1.78 per cent at Graphite 8 (Table 5).

Table 5. Comparison of the proportion of billet surface area affected by discolouration, brown wood, rot, insect galleries or kino from trees on two community vegetation types (n=20). Key: D = discolouration, BW = brown wood, R = rot, IG = insect galleries, K = kino.

n.s. not significant; * <0.05; ** <0.01; *** <0.001

	D#	BW#	R#	IG#	K#
Vegetation type	n.s.	n.s.	n.s.	n.s.	n.s.
Coupe (vegetation type)	*	n.s.	n.s.	n.s.	**
Point (coupe, vegetation type)	n.s.	n.s.	n.s.	n.s.	n.s.

arc sine square root transformed data

Vegetation type	Coupe	D (%)		BW (%)		R (%)	
		Mean	s.e.	Mean	s.e.	Mean	s.e.
4	Nairn 3	0.64	0.40-0.94	0.06	0.02-0.14	0.003	0-0.01
4	Nairn 7	1.41	1.02-1.87	1.34	0.65-2.26	0.118	0.07-0.34
4	Nairn 9	1.10	0.74-1.53	0.28	0.12-0.50	0.00	0.00
10	Graphite 8	0.88	0.58-1.25	0.05	0.01-0.12	0.02	0.002-0.06
10	Grey 1	0.18	0.09-0.29	0.18	0.08-0.31	0.02	0.002-0.06
10	Iffley 3	1.39	1.06-1.76	0.43	0.13-0.92	0.19	0.03-0.50

Vegetation type	Coupe	IG (%)		K (%)	
		Mean	s.e.	Mean	s.e.
4	Nairn 3	0.01	0.002-0.04	0.61	0.45-0.79
4	Nairn 7	0.09	0.02-0.20	0.69	0.48-0.94
4	Nairn 9	0.04	0.01-0.10	0.72	0.53-0.94
10	Graphite 8	0.06	0.01-0.17	1.78	1.32-2.32
10	Grey 1	0.25	0.11-0.45	0.37	0.24-0.53
10	Iffley 3	0.12	0.04-0.24	0.90	0.58-1.29

The proportion of billet end surface area affected by the symptoms of discolouration, brown wood, rot, insect galleries and kino, when combined together, did not differ significantly between community vegetation types (Table 6). There were, however, significant differences in the proportion of billet surface area affected by brown wood and rot, discolouration, brown wood, rot and insect galleries, and discolouration, brown wood, rot, insect galleries and kino, between compartments nested with community vegetation types (Table 6). The proportion of billet surface area affected by brown wood and rot varied from 0.09 per cent at Nairn 3 to 1.95 per cent at Nairn 7, the proportion of billet surface area affected by discolouration, brown wood, rot and insect galleries varied from 1.23 per cent at Nairn 3 to 4.72 per cent at Nairn 7, whilst the proportion of billet surface area affected by all symptoms varied from 1.97 per cent at Grey 1 to 5.84 per cent at Nairn 7 (Table 6).

Table 6. Comparison of the proportion of billet surface area affected by symptoms in combination on two community vegetation types (n=20).
Key: D = discolouration, BW = brown wood, R = rot, IG = insect galleries, K = kino.

n.s. not significant; * <0.05; ** <0.01; *** <0.001

	BW+R#	BW+R+IG#	D+BW+R+IG#	D+BW+R+IG+K#
Vegetation type	n.s.	n.s.	n.s.	n.s.
Coupe (vegetation type)	*	n.s.	**	**
Point (coupe, vegetation type)	n.s.	n.s.	n.s.	n.s.

arc sine square root transformed data

Vegetation type	Coupe	BW+R (%)		BW+R+IG (%)		D+BW+R+IG (%)		D+BW+R+IG+K (%)	
		Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
4	Nairn 3	0.09	0.03-0.18	0.18	0.08-0.31	1.23	0.84-1.68	2.32	1.87-2.83
4	Nairn 7	1.95	1.10-3.03	2.48	1.48-3.72	4.72	3.38-6.27	5.84	4.39-7.48
4	Nairn 9	0.28	0.12-0.50	0.56	0.31-0.88	2.20	1.60-2.90	3.31	2.60-4.10
10	Graphite 8	0.10	0.02-0.22	0.25	0.08-0.50	1.46	0.92-2.12	4.39	3.64-5.20
10	Gray 1	0.29	0.14-0.49	0.84	0.53-1.23	1.41	1.04-1.84	1.97	1.51-2.51
10	Iffley 3	0.88	0.29-1.78	1.18	0.46-2.23	4.14	2.86-5.65	5.56	4.03-7.32

Comparison of dominance class

There were very highly significant differences in total height, DBHOB and crown break between the most dominant and least dominant trees at each sample point (Table 7). There were no significant differences in the height to the lowest green limb between the most dominant and least dominant trees, but there were highly significant differences in the height of the lowest dry limb (Table 7).

Table 7. Comparison of the parameters between the most-dominant and least dominant trees (n=60).

n.s. not significant; * <0.05; ** <0.01; *** <0.001

	Total height	DBHOB	Crown break	Lowest green limb	Lowest dry limb
Coupe	**	**	**	**	*
Point (coupe)	n.s.	n.s.	n.s.	*	n.s.
Dominance	***	***	***	n.s.	**

Dominance	Total height (m)		Crown break (m)		DBHOB (cm)		Lowest green limb (m)		Lowest dry limb (m)	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e	Mean	s.e
Dominant or co-dominant	20.8	0.3	10.4	0.2	23.0	0.6	8.7	0.3	5.9	0.4
Sub-dominant or suppressed	11.8	0.3	9.1	0.2	8.2	0.2	8.4	0.3	4.6	0.3

Comparison of dominance class, proportion of surface area examined. There were very highly significant differences in the billet surface area, heartwood surface area and sapwood width between the most dominant and least dominant trees at each sample point (Table 8).

Table 8. Comparison of billet surface parameters between the most dominant and least dominant trees (n=60).

n.s. not significant; * <0.05; ** <0.01; *** <0.001

	Billet surface area	Heartwood surface area	Sapwood width
Coupe	***	**	*
Point (coupe)	n.s.	n.s.	n.s.
Dominance	***	***	***

Dominance	Billet surface area (cm^2)		Heartwood surface area (cm^2)		Sapwood width (cm)	
	Mean	s.e.	Mean	s.e.	Mean	s.e.
Dominant or co-dominant	1500	193.5	901	76.6	3.9	0.08
Sub-dominant or suppressed	100	13.0	39	5.1	1.8	0.04

The proportion of billet surface area affected by discolouration, brown wood or kino did not differ significantly between the most dominant and least dominant trees at each sample point (Table 9). There was, however, a significant difference between the proportion of billet surface area affected by rot and insect galleries between the most dominant and least dominant trees (Table 9).

Table 9. Comparison of the proportion of billet surface area affected by discolouration, brown wood, rot, insect galleries or kino in the most dominant and least dominant trees (n=60). Key: D = discolouration, BW = brown wood, R = rot, IG = insect galleries, K = kino.

n.s. not significant; * <0.05; ** <0.01; *** <0.001

	D#	BW#	R#	IG#	K#
Coupe	*	n.s.	n.s.	n.s.	**
Point (coupe)	n.s.	n.s.	n.s.	n.s.	n.s.
Dominance	n.s.	n.s.	*	*	n.s.

arc sine square root transformed data

Dominance	D (%)		BW (%)		R (%)	
	Mean	s.e.	Mean	s.e.	Mean	s.e.
Dominant or co-dominant	1.08	0.92-1.25	0.26	0.18-0.36	0.01	0.002-0.01
Sub-dominant or suppressed	0.65	0.48-0.86	0.32	0.17-0.53	0.10	0.04-0.18

	IG (%)		K (%)	
	Mean	s.e.	Mean	s.e.
Dominant or co-dominant	0.02	0.01-0.04	0.81	0.72-0.90
Sub-dominant or suppressed	0.18	0.10-0.27	0.79	0.62-0.90

The proportion of billet surface area affected by brown wood, rot and insect galleries in combination, differed significantly between the most dominant and least dominant trees (Table 10). When symptoms were combined in other combinations, however, there were no significant differences between the most dominant and least dominant trees (Table 10).

Table 10. Comparison of the proportion of billet surface area affected by symptoms in combination in the most dominant and least dominant trees (n=60). Key: D = discolouration, BW = brown wood, R = rot, IG = insect galleries, K = kino.

n.s. not significant; * <0.05; ** <0.01; *** <0.001

	BW+R#	BW+R+IG#	D+BW+R+IG#	D+BW+R+IG+K#
Coupe	*	n.s.	*	**
Point (coupe)	n.s.	n.s.	n.s.	n.s.
Dominance	n.s.	*	n.s.	n.s.

arc sine square root transformed data

	BW+R (%)		BW+R+IG (%)	
	Mean	s.e.	Mean	s.e.
Dominant or co-dominant	0.32	0.22-0.45	0.43	0.31-0.58
Sub-dominant or suppressed	0.59	0.34-0.92	1.18	0.79-1.65

	D+BW+R+IG (%)		D+BW+R+IG+K (%)	
	Mean	s.e.	Mean	s.e.
Dominant or co-dominant	2.12	1.89-2.35	3.14	2.86-3.42
Sub-dominant or suppressed	2.57	1.95-3.28	4.39	3.60-5.24

Comparison of dominance class, proportion of trees affected. Although making comparisons of the proportion of surface area affected by various symptoms is useful when differences between the total areas examined are not too great (Table 4), the differences between trees of different dominance class are large. The mean billet surface area of dominant or co-dominant trees was 15 times the area of sub-dominant or suppressed trees (Table 8). As some symptoms, eg insect galleries, will be of similar size, irrespective of the dominance class of the tree, a more valid comparison is between the proportion of trees of different dominance class affected by different symptoms. When these comparisons are made there is both more discolouration and brown wood in the most dominant trees than in the least dominant trees, and this difference is very highly significant (Table 11). There are, however, no significant differences in the proportion of trees with rot, insect galleries or kino between the most dominant or least dominant trees (Table 11).

Table 11. Comparisons of the proportion of most dominant and least dominant trees affected by discolouration, brown wood, rot, insect galleries or kino (n=6). Key: D = discolouration, BW = brown wood, R = rot, IG = insect galleries, K = kino.

n.s. not significant; * <0.05; ** <0.01; *** <0.001

	D#	BW#	R#	IG#	K#
Coupe	n.s.	n.s.	n.s.	n.s.	n.s.
Dominance	***	***	n.s.	n.s.	n.s.

arc sine square root transformed data

	D (%)		BW (%)		R (%)	
	Mean	s.e.	Mean	s.e.	Mean	s.e.
Dominant or co-dominant	98.8	97.0 - 99.8	73.3	68.2 - 78.1	20.1	14.8 - 26.0
Sub-dominant or suppressed	50.8	42.6 - 58.9	19.1	10.6 - 29.3	9.4	3.6 - 17.7

	IG (%)		K (%)	
	Mean	s.e.	Mean	s.e.
Dominant or co-dominant	49.7	40.5 - 58.8	95.7	83.6 - 100.0
Sub-dominant or suppressed	24.1	20.8 - 27.5	61.4	52.2 - 70.2

When symptoms are combined, more of the most dominant trees than least dominant trees are affected, and these differences are either highly significant or very highly significant (Table 12).

Table 12. Comparison of the proportion of most dominant and least dominant trees affected by discolouration, brown wood, rot, insect galleries and kino in various combinations. Key: D = discolouration, BW = brown wood, R = rot, IG = insect galleries, K = kino.

n.s. not significant; * <0.05; ** <0.01; *** <0.001

	BW+R#	BW+R+IG#	D+BW+R+IG#	D+BW+R+IG+K#
Coupe	n.s.	n.s.	n.s.	n.s.
Dominance	***	***	***	**

arc sine square root transformed data

	BW+R (%)		BW+R+IG (%)		D+BW+R+IG (%)		D+BW+R+IG+K (%)	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
Dominant or co-dominant	82.9	74.6-89.9	90.5	83.3-95.8	100	0	100	0
Sub-dominant or suppressed	27.8	18.8-37.7	46.0	37.0-55.1	66.9	59.5-73.4	87.5	82.2-92.1

Comparison of the incidence of symptoms at different heights above ground level
Because billets were always cut at fixed distances above ground level, the data can be examined to determine whether the different symptoms are random, or show a specific pattern with height. The number of billets assessed at each height are shown in Table 13. Results are shown as the proportion of billets affected by a specific symptom.

Mean crown break for all trees was 9.7 m, for dominant and co-dominant trees 10.4 m, and for sub-dominant and suppressed trees 9.1 m.

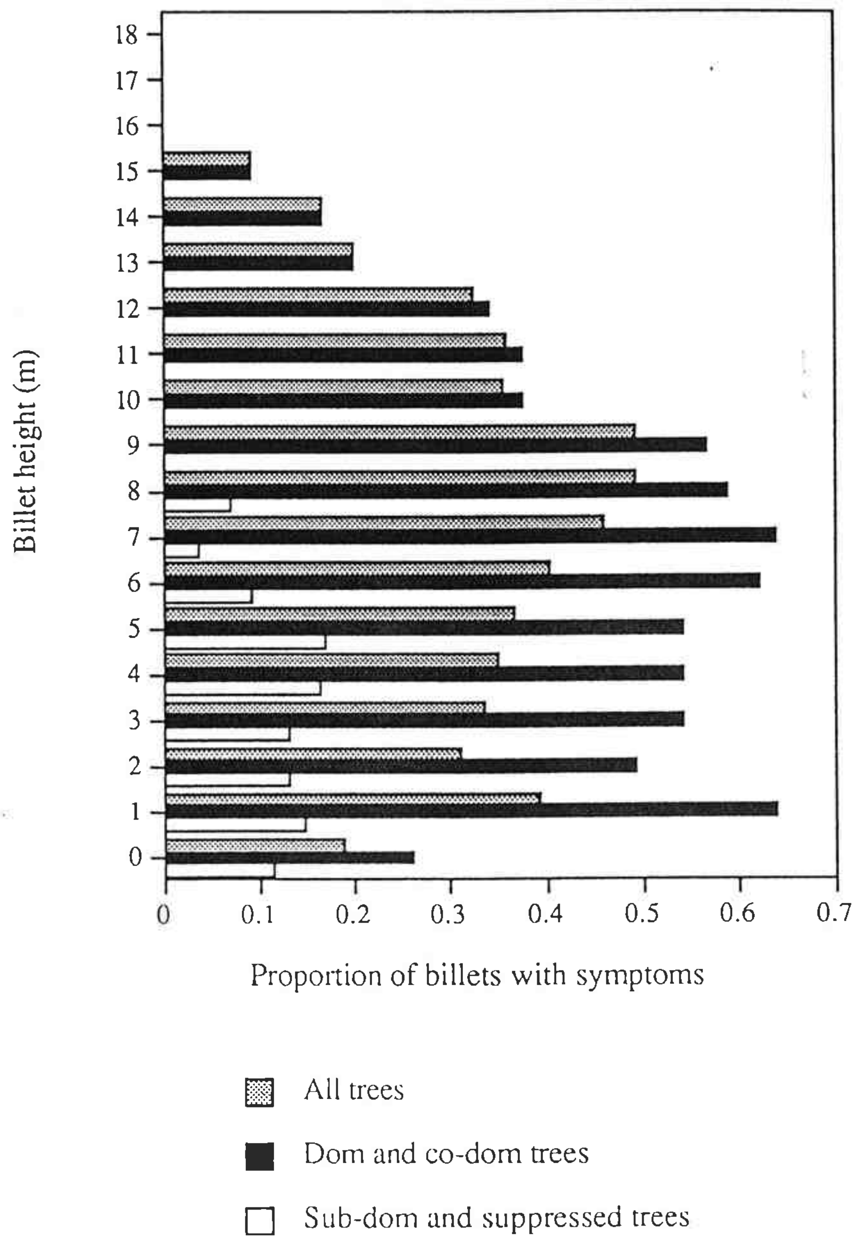
Table 13.
Number of billets assessed at different heights above ground level.

Billet height (m)	Sample size		
	All trees	Dominant and co-dominant	Sub-dominant and suppressed
0	122	61	61
1	122	61	61
2	122	61	61
3	122	61	61
4	122	61	61
5	114	61	53
6	104	61	43
7	87	61	27
8	75	61	13
9	69	60	9
10	59	56	3
11	50	48	2
12	46	44	2
13	35	35	
14	24	24	
15	11	11	
16	6	6	
17	3	3	
18	1	1	

Discolouration Discolouration was most abundant between 1 m and 9 m, and was more abundant in dominant and co-dominant trees than in sub-dominant and suppressed trees (Fig. 3).

Figure 3

Proportion of billets with discolouration



Brown wood Brown wood is most abundant at ground level, and in this data set, decreases above 6 m (Fig. 4). It is more abundant in dominant and co-dominant trees than in sub-dominant and suppressed trees.

Rot In this data set, rot is most abundant at ground level (Fig. 5).

Figure 4
Proportion of billets with brown wood

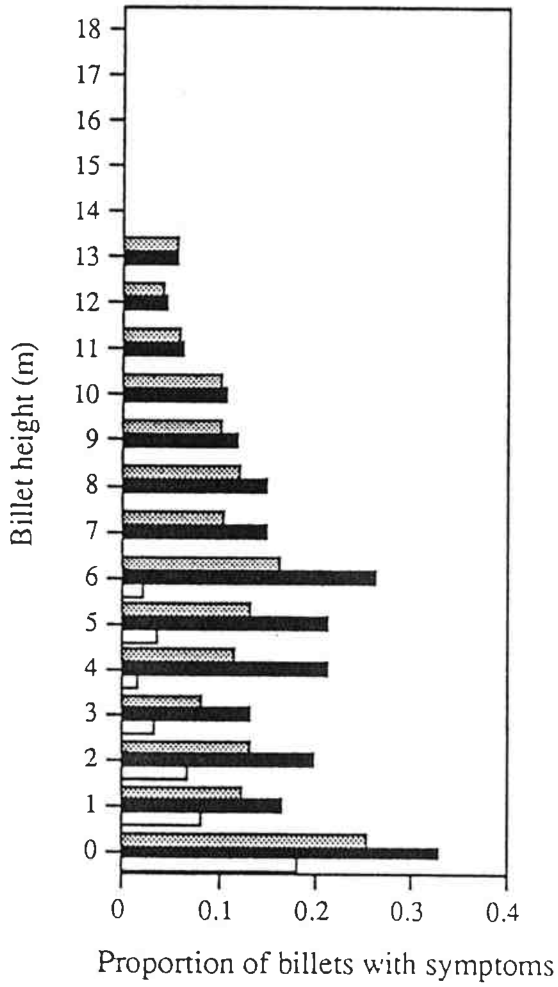
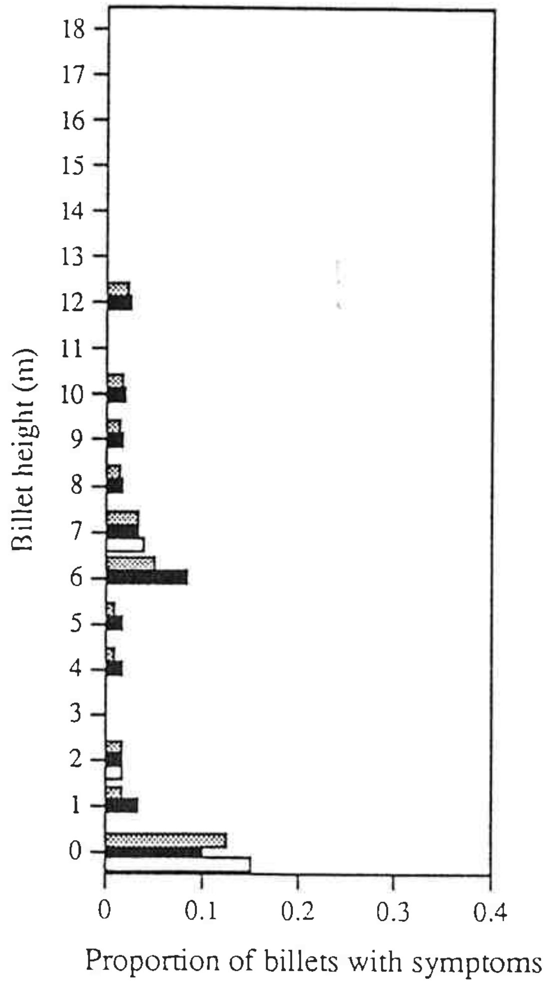


Figure 5
Proportion of billets with rot



All trees

Dom and co-dom trees

Sub-dom and suppressed trees

Insect Galleries. Insect galleries in sub-dominant and suppressed trees are most abundant at ground level, whilst in dominant and co-dominant trees they are most abundant between 2 m and 6 m above the ground (Fig. 6).

Kino Kino was more abundant in dominant and co-dominant trees than in sub-dominant and suppressed trees (Fig. 7). When all trees were considered, it appeared to be fairly uniformly distributed between 0 m and 15 m (Fig. 7).

Figure 6
Proportion of billets with insect galleries

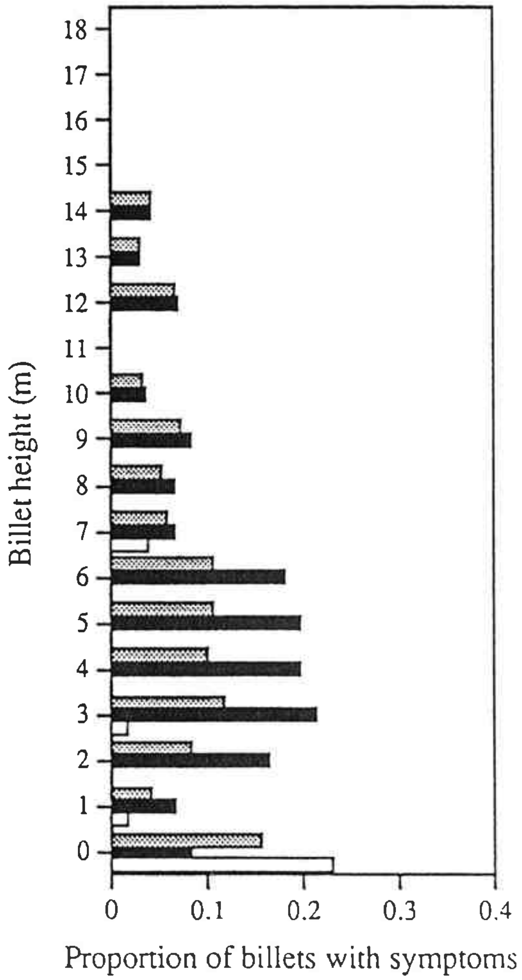
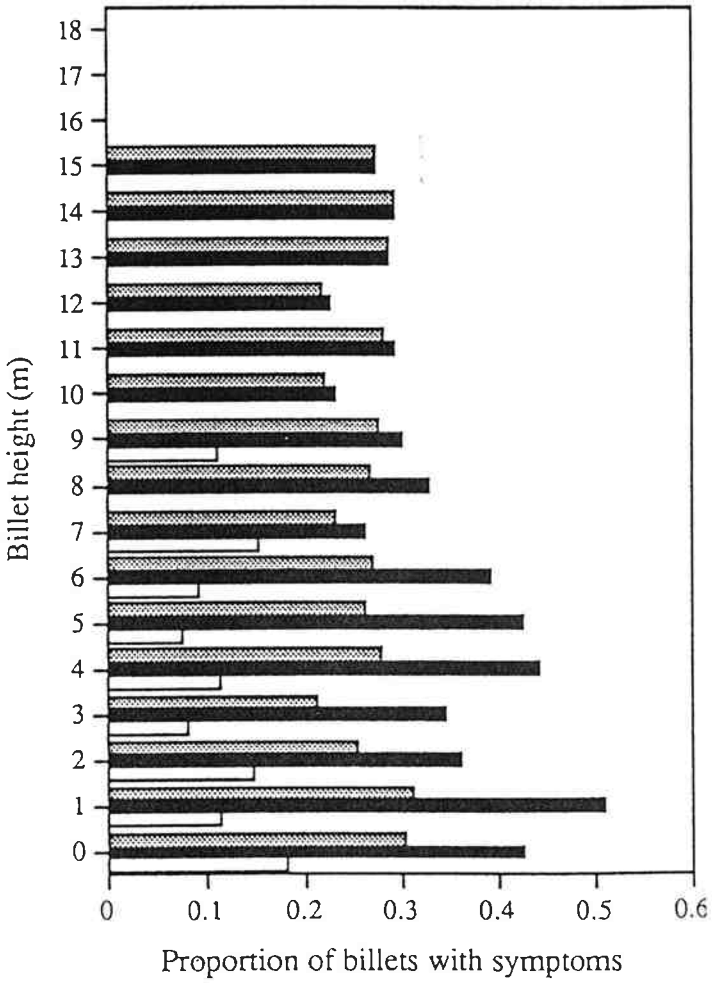


Figure 7
Proportion of billets with kino



All trees

Dom and co-dom trees

Sub-dom and suppressed trees

Distribution of symptoms within the trees
The template which was used to estimate the surface area affected by different symptoms also allows the position of symptoms to be recorded. The template describes the billet surface as a series of concentric rings, indicated by a letter of the alphabet (Table 14), with each ring subdivided into 20 cm^2 portions, indicated by a number (Fig. 2). As the template was always orientated in the same way on each billet of the surveyed trees, a symptom extending axially for more than 1 m to 2 m would have the same template location on adjacent billets. The template, therefore, allows comparison to be made of the incidence of symptoms at different distances from the centre of the tree, and allows an estimate of whether these symptoms occur as columns or pockets. The surface area occupied by each concentric ring, and the number of billets assessed for each ring, are given in Table 14.

Table 14. The billet area occupied by the concentric rings described by the template, together with the number of billets assessed at each location.

Location	Billet area (cm^2)	Billet radius (cm)	Number of billets assessed
A	0-20	0-2.52	1 294
B	20-100	2.52-5.64	1 113
C	100-260	5.64-9.10	684
D*	260-580	9.10-13.59	228
E*	580-900	13.59-16.93	27

*Locations D and E were combined for χ^2 analysis because expected values were less than 5.

Discolouration There was significantly more discolouration in billets taken from below crown break (37.0 per cent) than above crown break (23.0 per cent) (DF=1, χ^2=12.9, P=0.0003). Discolouration was not randomly distributed on the billet face(Table 15), it was usually present in the centre of billets (location A, Fig. 8).

Discolouration occurred in both pockets (in a single billet) and columns (in the same location in more than one adjacent billets). There was significantly more discolouration in columns in the most dominant trees (35.0 per cent) than in the least dominant trees (18.4 per cent) (DF=1, χ^2=4.1, P=0.04). The longest column of discolouration extended over 14 adjacent billets.

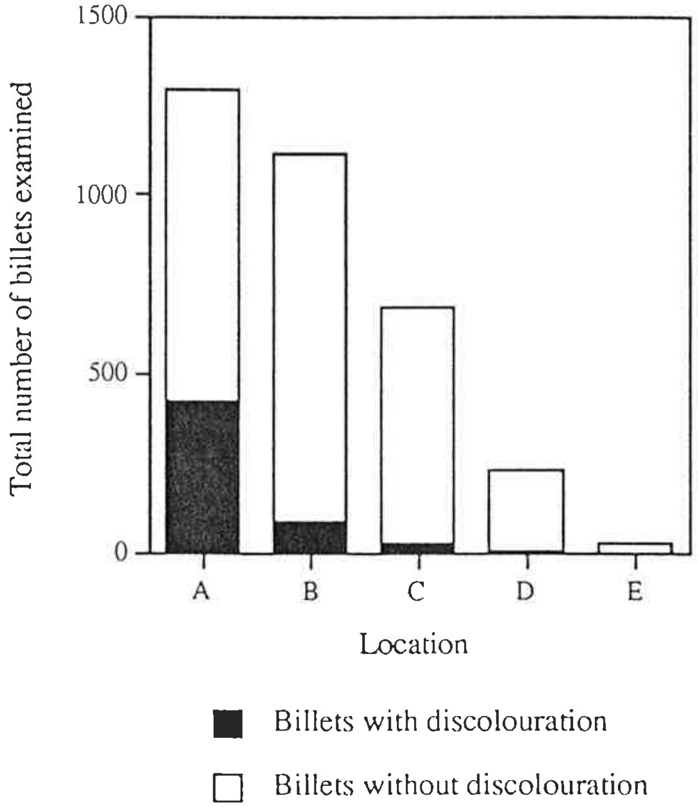
Table 15. The incidence of discolouration at different locations on the billet face.

Location	Discolouration		No discolouration		Total
	Observed	Expected	Observed	Expected	
A	422	210	872	1 084	1 294
B	84	181	1 029	932	1 113
C	30	111	654	573	684
D + E	7	41	248	214	255
Totals	543		2 803		3 346

DF=3, χ^2=421.9, P<0.0001

Figure 8

Location of discolouration on billets



Brown wood There was significantly more brown wood in billets taken below crown break (13.2 per cent) than above crown break (4.6 per cent) (DF=1, χ^2=10.5, P=0.0012). Brown wood was not randomly distributed on the billet face (Table 16, Fig. 9), it was more abundant in location B, and less abundant in locations C, D and E than would have been expected (Table 16).

Table 16. The incidence of brown wood at different locations on the billet face.

Location	Brown wood		No brown wood		Total
	Observed	Expected	Observed	Expected	
A	91	91	1 203	1 203	1 294
B	95	78	1 018	1 034	1 113
C	40	48	644	636	684
D + E	9	18	246	237	255
Totals	235		3 111		3 346

DF=3, χ^2=10.1, P=0.018

Figure 9

Location of brown wood on billets

In 90.7 per cent of cases brown wood occurred as pockets. This proportion was similar in both the most and least dominant trees (90.8 per cent and 90.0 per cent respectively). The longest column extended over six adjacent billets.

Associations between brown wood and possible entry points were recorded whenever they were seen. It was associated with both insect galleries and branches. Branches included live and dead branches, and branch stubs; no attempt was made to distinguish between them. This association was not random at the sampled coupes, at Iffley 3 brown wood was more frequently associated with insect attack than at other coupes, whilst at Nairn 3 it was more frequently associated with branches (Table 17). There was no difference in the association of brown wood with insect galleries and branches in the most dominant and least dominant trees (DF=1, χ^2=0.02, P=0.89).

Brown wood was associated with rot in 14 billets, in 10 cases it was associated with white rot, in three cases with white pocket rot and in one case with brown rot.

Table 17. The association of brown wood with insect galleries and branches at the different sample sites.

Coupe	Association with insect galleries		Association with branches		Total
	Observed	Expected	Observed	Expected	
Nairn 3	3	7.3	13	8.7	16
Nairn 7	7	5.0	4	6.0	11
Nairn 9	2	5.4	10	6.6	12
Graphite 8	5	4.5	5	6.5	10
Gray 1	4	4.1	5	4.9	9
Iffley 3	13	7.7	4	9.3	17
Totals	34		41		75

DF=3, χ^2=16.8, P=0.005

Rot Three types of rot occurred in the billets: brown rot, white rot and white pocket rot. All three rots occurred only in billets taken from below crown break. Rots were infrequent, brown rot was recorded from three billets, white rot from 23 billets, and white pocket rot from eight billets. All observations of rots were combined for analysis. They were randomly distributed on the billet face (Table 18, Fig. 10).

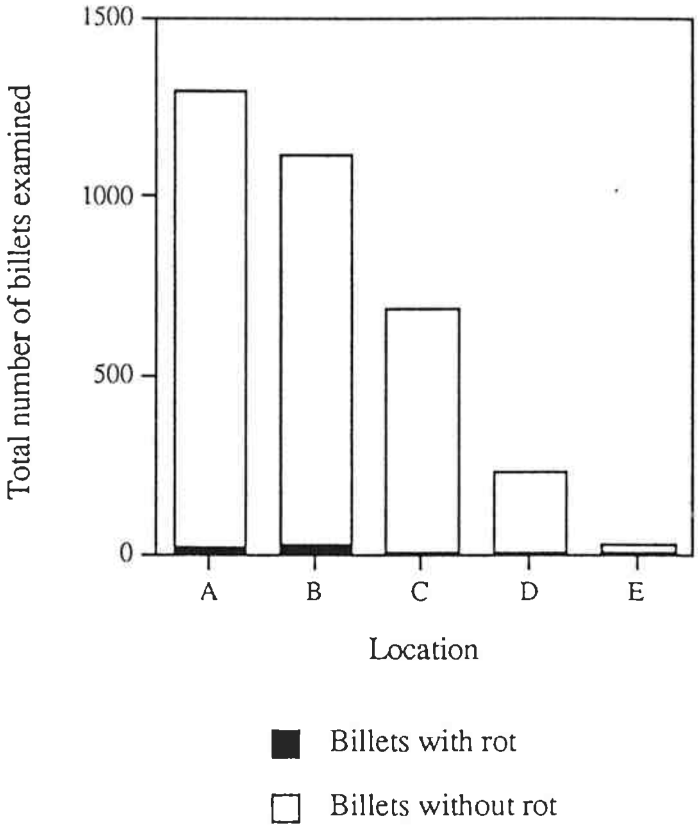
Rot occurred as pockets in all but one case. The column was 3 m long.

Table 18. The incidence of all rot at different locations on the billet face.

Location	Rot		No rot		Total
	Observed	Expected	Observed	Expected	
A	20	21	1 274	1 272	1 294
B	23	18	1 090	1 094	1 113
C	7	11	677	672	684
D + E	5	4	250	251	255
Totals	55		3 291		3 346
	DF=3, χ^2=3.1, P=0.38				

Figure 10

Location of rot on billets



Insect galleries Insect galleries occurred both in billets from above and below crown break. There were, however, significantly more billets with insect galleries below crown break (8.75 per cent) than in the crown (3.45 per cent) (DF=1, χ^2=5.7, P=0.017). Insect galleries were not randomly distributed on the billet face (Table 18, Fig. 11), they were less abundant in location A and more abundant in location C, D and E than would have been expected (Table 19).

Table 19. The incidence of insect galleries at different locations on the billet face.

Location	Insect galleries		No insect galleries		Total
	Observed	Expected	Observed	Expected	
A	16	51	1 278	1 242	1 294
B	41	44	1 072	1 069	1 113
C	59	27	625	659	684
D + E	17	10	238	245	255
Totals	235		3 111		3 346

DF=3, χ^2=69.3, P<0.0001

Figure 11

Location of insect galleries on billets

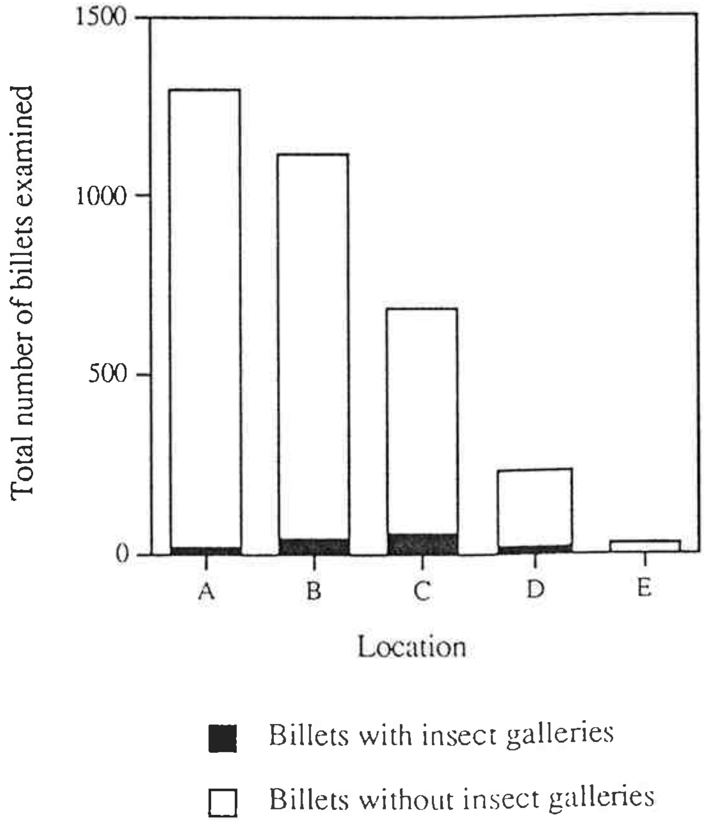


Figure 7 shows that in sub-dominant and suppressed trees, insect galleries were most abundant in the butt, whilst in dominant and co-dominant trees galleries were most abundant between 2 m and 6 m above ground level. These differences are highly significant (Table 20).

Table 20. Comparison of the proportion of trees of two dominance classes affected by insect galleries (n=6).

n.s. not significant; * <0.05; ** <0.01; *** <0.001

	In the butt #	In the stem #
Compartments	n.s.	n.s.
Dominance	**	**

arc sine square root transformed data

	In the butt (%)		In the stem (%)	
	Mean	s.e.	Mean	s.e.
Dominant or co-dominant	5.51	2.51-9.6	43.48	32.16-55.15
Sub-dominant or suppressed	22.15	18.07-26.52	1.14	0.16-3.0

During their life cycle borers which attack stems remain within the tree, thus the minimum number of stem infestations can be estimated from the billet data. In the sub-dominant or suppressed trees there were only single infestations, whilst four of the dominant or co-dominant trees had three infestations and one tree had four (Table 21). Nairn 7 had the highest level of attack by stem borers.

The axial extent of each infestation can be estimated from the number of adjacent billets with insect galleries. Data for both butt and stem infestations are presented in Table 22. The site where galleries had the greatest axial spread was Iffley 3.

Table 21. The minimum number of stem borer infestations per tree in trees from different coupes.

Coupe	Dominance	Minimum number of infestations per tree				
		0	1	2	3	4
Nairn 3	Domminant or co-domminant	7	1	2	0	0
	Sub-domminant or suppressed	9	1	0	0	0
Nairn 7	Domminant or co-domminant	2	5	1	1	1
	Sub-domminant or suppressed	10	0	0	0	0
Nairn 9	Domminant or co-domminant	9	1	0	0	0
	Sub-domminant or suppressed	10	0	0	0	0
Graphite 8	Domminant or co-domminant	7	1	0	3	0
	Sub-domminant or suppressed	11	0	0	0	0
Gray 1	Domminant or co-domminant	6	3	1	0	0
	Sub-domminant or suppressed	9	1	0	0	0
Iffley 3	Domminant or co-domminant	5	2	3	0	0
	Sub-domminant or suppressed	10	0	0	0	0

Table 22. The number of adjacent billets with borer galleries.

Coupe	Dominance	Number of adjacent billets with borer galleries					
		1	2	3	4	5	6
Nairn 3	Domminant or co-domminant	3	1	0	0	0	0
	Sub-domminant or suppressed	2	0	0	0	0	0
Nairn 7	Domminant or co-domminant	9	4	2	0	0	0
	Sub-domminant or suppressed	2	0	0	0	0	0
Nairn 9	Domminant or co-domminant	2	1	0	0	0	0
	Sub-domminant or suppressed	3	0	0	0	0	0
Graphite 8	Domminant or co-domminant	4	3	1	1	0	0
	Sub-domminant or suppressed	2	0	0	0	0	0
Gray 1	Domminant or co-domminant	3	1	1	1	0	0
	Sub-domminant or suppressed	4	1	0	0	0	0
Iffley 3	Domminant or co-domminant	3	2	2	1	0	1
	Sub-domminant or suppressed	3	0	0	0	0	0

Kino There was a similar proportion of billets with kino from both above (26.4 per cent) and below (26.25 per cent) crown break (DF=1, χ^2=0.003, P=0.96). Kino was not randomly distributed on the billet face (Table 23). It was less abundant in location A and more abundant in locations C, D and E than would have been expected (Table 23, Fig. 12).

Kino occurred in pockets in 96.6 per cent of cases. It was more frequently associated with branches (87.6 per cent of observations) than with insect galleries.

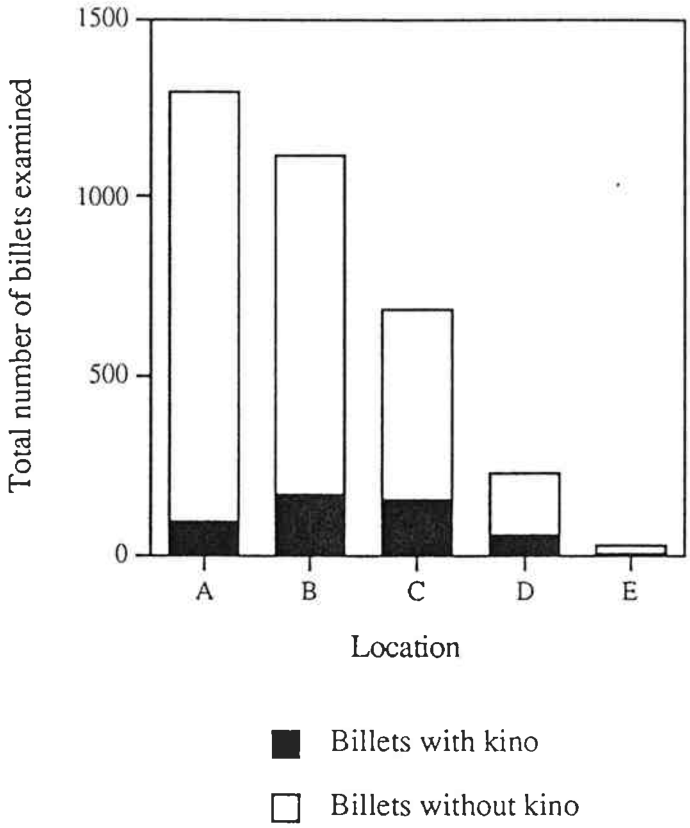
Table 23. The incidence of kino at different locations on the billet face.

Location	Kino		No kino		Total
	Observed	Expected	Observed	Expected	
A	91	183	1 203	1 111	1 294
B	168	158	945	955	1 113
C	154	97	530	587	684
D + E	61	36	194	219	255
Totals	474		2 872		3 346

DF=3, χ^2=114.1, P<0.0001

Figure 12

Location of kino on billets



Association of the presence of brown wood and rot or insect infestation with stand and trees parameters
Tables 5 and 6 show that there are no significant differences in the incidence of symptoms, either singly or in combination between community vegetation types. There are, however, differences between coupes. Table 17 shows that brown wood is associated with branches and insect galleries, and branching will be affected by both stocking and basal area. Basal area and height to crown break differ between coupes (Tables 2 and 3). Ranking coupes in increasing order of basal area, however, does not show any clear trends with the incidence of symptoms (Table 24). Iffley 3, for example, has a low crown break, the lowest basal area, and high brown wood, rot, and insect galleries, but Graphite 8 with the lowest crown break also has the lowest brown wood ranking.

Table 24. The incidence of symptoms in coupes ranked in increasing order of crown break. Key: D = discolouration, BW = brown wood, R = rot, IG = insect galleries, K = kino.

Coupe	Crown break	Basal area	Proportion of billet surface area affected by symptoms*						
			D	BW	R	IG	K	BW+R	BW+R+IG
Graphite 8	1	4	3	1	4	3	6	2	2
Iffley 3	2	1	5	5	6	5	5	5	5
Nairn 9	3	5	4	4	1	2	4	3	3
Nairn 3	4	2	2	2	2	2	2	1	1
Gray 1	5	6	1	3	4	6	1	4	4
Nairn 7	6	3	6	6	5	4	3	6	6

* In increasing order.

Correlation of stand and tree parameters in dominant and co-dominant trees Instead of further analysing the data on a coupe basis, the data sets were combined and examined for stand or tree characters which were associated with the presence of brown wood and rot, or insect infestation. As the least dominant trees will be suppressed and die as the stand ages (Schuster 1978) only the most dominant trees were used in the following analyses.

Many stand and tree characters are correlated (Table 25). Correlation coefficients greater than 0.7 occurred between:

- DBHOB with total height, and crown depth
- height to lowest green branch with crown break
- crown break with the ratio of crown depth to total height and height to lowest green branch
- total height with DBHOB and crown depth
- crown depth with DBHOB, total height and the ratio of crown depth to total height
- ratio of crown depth to total height with crown break and crown depth

None of these correlations are unexpected.

Not all of these trees are infested with insects, and not all of the trees have symptoms of incipient rot and rot. The 61 dominant and co-dominant trees can be split into those with incipient rot and rot but no insect damage (n=22), and those with borers (n=30) to determine whether there are any obvious differences in stand and tree parameters. In those trees with incipient rot and rot but no insect attack (Table 26) there were correlations greater than 0.7 between:

- site index with total height
- DBHOB with total height, crown depth and average sapwood width
- height to the lowest green branch with crown break
- total height with site index, DBHOB and crown depth
- crown depth with DBHOB, total height, average sapwood width and the ratio of crown depth to total height
- average sapwood width with DBHOB, crown depth and the ratio of crown depth to total height
- ratio of crown depth to total height with crown depth and average sapwood width

In trees with insect galleries (Table 27) there were correlations greater than 0.7 between:

- height to the lowest green branch with crown break and the ratio of crown depth to total height
- crown break with height to lowest green branch and the ratio of crown depth to total height
- crown depth with the ratio of crown depth to total height
- ratio of crown depth to total height with height to lowest green branch, crown break and crown depth

Table 25. Correlation matrix of stand and tree parameters for all dominant and co-dominant trees (n=61). Correlations greater than 0.7 are shown in bold.

	Site index	Basal area	DBHOB	Height to lowest green branch	Height to lowest dead branch	Crown break	Total height	Crown depth	Crown depth/total height	Bark thickness	Sapwood width
Site index	1.00										
Basal area	0.09	1.00									
DBHOB	0.50	-0.27	1.00								
Height to lowest green branch	0.27	0.37	-0.13	1.00							
Height to lowest dead branch	0.03	0.18	-0.10	0.32	1.00						
Crown break	0.30	0.32	0.02	**0.79**	0.21	1.00					
Total height	0.62	-0.07	**0.72**	0.28	0.05	0.49	1.00				
Crown depth	0.44	-0.34	**0.79**	-0.32	-0.11	-0.26	**0.72**	1.00			
Crown depth/total height	0.17	-0.42	0.56	-0.65	-0.20	**-0.72**	0.24	**0.84**	1.00		
Bark thickness	0.14	-0.14	0.65	-0.07	0.11	-0.02	0.46	0.53	0.38	1.00	
Sapwood width	0.24	-0.27	0.64	-0.28	-0.005	-0.25	0.35	0.59	0.57	0.44	1.00

Table 26. Correlation matrix of stand and tree parameters for all dominant and co-dominant trees with incipient rot and rot, but no insect infestation (n=22). Correlations greater than 0.7 are shown in bold.

	Site index	Basal area	DBHOB	Height to lowest green branch	Height to lowest dead branch	Crown break	Total height	Crown depth	Crown depth/total height	Bark thickness	Sapwood width
Site index	1.00										
Basal area	0.004	1.00									
DBHOB	0.66	-0.34	1.00								
Height to lowest green branch	0.30	0.33	-0.11	1.00							
Height to lowest dead branch	0.10	0.16	-0.08	0.50	1.00						
Crown break	0.41	0.44	0.07	**0.81**	0.37	1.00					
Total height	**0.70**	-0.13	**0.77**	0.26	0.01	0.52	1.00				
Crown depth	0.53	-0.47	**0.85**	-0.28	-0.26	-0.11	**-0.79**	1.00			
Crown depth/total height	0.23	-0.61	0.63	-0.66	-0.43	-0.63	0.32	**0.83**	1.00		
Bark thickness	0.24	-0.29	0.67	0.001	0.13	0.01	0.50	0.58	0.39	1.00	
Sapwood width	0.44	-0.45	**0.86**	-0.25	-0.19	-0.18	0.59	**0.81**	**0.73**	0.64	1.00

Table 27. Correlation matrix of stand and tree parameters for all dominant and co-dominant trees with insect infestation (n=30). Correlations greater than 0.7 are shown in bold.

	Site index	Basal area	DBHOB	Height to lowest green branch	Height to lowest dead branch	Crown break	Total height	Crown depth	Crown depth/total height	Bark thickness	Sapwood width
Site index	1.00										
Basal area	0.05	1.00									
DBHOB	0.36	-0.32	1.00								
Height to lowest green branch	0.25	0.59	-0.20	1.00							
Height to lowest dead branch	-0.08	0.26	-0.16	0.26	1.00						
Crown break	0.23	0.42	-0.10	**0.82**	0.12	1.00					
Total height	0.55	0.007	0.59	0.32	0.06	0.45	1.00				
Crown depth	0.33	-0.38	0.68	-0.44	-0.05	-0.47	0.57	1.00			
Crown depth/total height	-0.11	-0.49	0.50	**-0.71**	-0.11	**-0.83**	0.12	**0.88**	1.00		
Bark thickness	0.05	0.02	0.64	-0.19	0.12	-0.11	0.40	0.50	0.38	1.00	
Sapwood width	0.02	-0.25	0.48	-0.29	0.02	-0.32	0.05	0.34	0.41	0.26	1.00

These correlations were used as the basis of multiple regressions using ln of the proportion of surface area affected by either symptoms of incipient rot and rot combined, or insect galleries, as the dependant variable. The best regressions, derived empirically are given in Tables 28 and 29.

Table 28. Regression coefficients for multiple regression of ln proportion of the billet surface area of dominant and co-dominant trees affected by brown wood and rot ($R=0.69$, $R^2=0.47$, $n=22$).

	Coefficient	s.e.	P
Intercept	21.4	10.2	0.052
Total height (m)	0.86	0.47	0.086
Crown depth/total height	-45.2	20.3	0.041
Height to lowest green branch (m)	0.37	0.17	0.038
Crown break (m)	-2.57	0.96	0.016
DBHOB (cm)	0.11	0.09	0.21

Table 29. Regression coefficients for multiple regression of ln proportion of the billet surface area of dominant and co-dominant trees affected by insect galleries ($R=0.68$, $R^2=0.46$, $n=30$).

	Coefficient	s.e.	P
Intercept	14.1	10.7	0.20
Crown break (m)	-1.67	0.99	0.10
Crown depth/total height	-32.7	21.9	0.15
DBHOB (cm)	0.11	0.05	0.034
Mean bark thickness (cm)	-1.84	0.64	0.008
Total height (m)	0.70	0.50	0.18

There are no single stand or tree parameters which can be used as predictors of either high levels of insect infestation or high incidence of brown wood and rot.

Discussion

Site parameters

Inions *et al.* (1990) classified the karri forest into community vegetation types based on climate, soil characteristics and the distribution of plant species. When this system was proposed it was believed to be a useful predictor for karri productivity, assessed as mean age-standardised top height, but Rayner (1992) has shown that there is no correlation between community vegetation type and site index. Community vegetation type, however, is a useful way of discriminating between sites where karri grows and is a valid basis for making comparisons between different stands, and we have used this as the basis of our billet survey.

We have compared the incidence of different symptoms in similar aged trees (12- to 14-year old) with similar management histories (seed tree regeneration, exclusion of fire), on the two commonest community vegetation types (4 and 10), in a small sample of the most dominant and least dominant trees. Our survey has confirmed Rayner's (Rayner 1991a, 1992) observation that community vegetation type is not a good predictor of site index (Table 2). It has also shown that the proportion of billet surface area affected by symptoms, either singly or in combination, does not differ between these vegetation types (Tables 4 and 5). Our results, however, show that the coupes we surveyed differed significantly in the stand parameters site index and basal area (Table 2), and the tree parameters total height, crown break, DBHOB, billet surface area, heartwood surface area and sapwood width (Tables 2 and 3). Some of these parameters are likely to affect the incidence of symptoms such as brown wood (incipient rot) and rot because the fungi which cause these symptoms can only infect the wood through wounds. Common entry points in many trees include fire scars, mechanical damage, roots, branches, insect galleries and animal damage (Rayner and Boddy 1988).

The importance of branching and other crown characteristics In regrowth karri Davison and Tay (1990) and Donnelly *et al.* (1994) have shown that incipient rot and rot are most commonly associated with branches, but are also associated with insect galleries and fire/*Armillaria* scars. The association of incipient rot and rot with branch stubs and occluding branches has been recorded in many plantation-grown and regrowth eucalypts (e.g. Gadgill and Bawden 1981, Incoll and McKimm 1985, White and Kile 1991, Wardlaw 1995).

In an *E. delegatensis* R. T. Bak. espacement trial, Incoll and McKimm (1985) showed that at age 20, rot and incipient rot were associated with at least 45 per cent of occluded branches greater than 1 cm diameter, but with only 7 per cent of branches less than 1 cm diameter. They also showed that the volume of occluded branches at 1.7 m initial spacing was significantly less than at wider spacings (2.4 m, 3.4 m, 4.9 m, 6.9 m). They found that the mean diameter of live branches was not significantly affected by espacement, but that at spacing greater than 1.7 m, branches persisted for longer, giving rise to deeper crowns. Similarly Schuster (1978) has reported that in 6-year old regrowth karri, height to crown base is inversely proportional to stocking, and these observations have been confirmed by Breidahl and Hewett (1995) in 14-year old trees.

Jacobs (1955) showed that in eucalypts, large branches do not occlude as cleanly as small ones. Marks *et al.* (1986) have presented detailed observations of branch shedding in *E. regnans* F. Muell., particularly in relation to large branches and their observed role as entry points for wood rotting fungi. They have shown that when heartwood has formed in a branch, splits associated with the brittle zone may only extend into the branch sapwood, and that sapwood rots may begin at this point. In these large branches, branch shedding is rarely clean, cracks may develop between the branch and stem as a result of the weight of the branch and downward growth of a pad of wood which eventually overgrows the occluded limb; kino also often develops at this point. Thus there are opportunities for wood rot fungi to gain access to stem heartwood not just through dead branches, but also through cracks which develop in and around branches as they are being shed.

These observations are extremely important because persistence of branches can be manipulated by spacing, and this may provide an option for minimising the incidence of incipient rot and rot.

Regrowth karri trees growing in a stand with low basal area are likely to have deeper crowns and more persistent branches than trees growing in a dense stand (Schuster 1978, Breidahl and Hewett 1995), and as large branches are not shed as readily as small ones, we would expect incipient rot and rot to be more abundant in the surveyed coupes with the lowest crown break. Thus we would predict that trees at Graphite 8, the stand with the lowest crown break, would have a larger proportion of the billet surface area affected by incipient rot and rot than Nairn 7, the stand with the highest crown break. Ranking stands shows that this generalisation does not occur (Table 24), because although Graphite 8 has the lowest crown break, it also has the lowest incidence of incipient rot and the second lowest incidence of incipient rot and rot combined, while Nairn 7, the coupe with the highest crown break, has the highest incidence of incipient rot and incipient rot and rot combined.

In our survey kino was associated with branches in 87.6 per cent of cases, and with insect galleries in the remainder, so we would expect the stand with the lowest crown break to have the highest incidence of kino. Table 24 shows that this is so, Graphite 8 had the highest incidence of kino.

Attempts to relate the proportion of billet surface area of dominant trees affected by incipient rot and rot by multiple regression analysis of stand and tree characteristics across all coupes have not been very successful (Table 28). The proportion of surface area affected was positively correlated with total height, DBHOB and height to the lowest green branch, but negatively correlated with crown break and ratio of crown depth to total height. The worst affected trees are likely to be taller, of larger diameter, and with a deeper crown and lower crown break than trees which are least affected (Table 28). These tree characteristics, however, only give an R^2 of 0.47.

Similar attempts to relate insect infestation in dominant trees to stand and tree characteristics have also not given clearcut results (Table 29). The proportion of surface area affected by insect galleries was positively correlated with total height and DBHOB, but negatively correlated with crown break, bark thickness and the ratio of crown depth to total height. The worst affected trees are therefore likely to be taller, of larger diameter, with thinner bark, a deeper crown and lower crown break than trees which are not as severely affected. These tree characteristics, however, only give an R^2 of 0.46.

These deductions need to be tested in other stands of different aged trees.

Dominance class
A comparison of the most and least dominant trees showed, as would be expected, that they differed significantly in total height, DBHOB, crown break, height to the lowest dry limb, billet surface area, heartwood surface area and sapwood width (Tables 6 and 7). Because of the great differences in size of the most and least dominant trees, it is more meaningful to compare the proportion of trees affected by different symptoms (Tables 10 and 11) than the proportion of billet surface area affected (Tables 8 and 9). There were significantly more dominant or co-dominant trees with discolouration and incipient rot than sub-dominant or suppressed trees (Table 11). More of the most dominant trees also had rot, insect galleries and kino, but these differences were not significant in this small sample (Table 11). There was no significant difference in the proportion of affected trees from different coupes (Table 11).

Incipient rot and rot Incipient rot and rot in regrowth karri can be caused by at least two fungi, *Stereum hirsutum* and *Hymenochaete* sp. (Davison and Tay 1990). Our survey work shows that more dominant and co-dominant trees than sub-dominant and suppressed trees are affected by these symptoms, and this difference is highly significant (Table 12), but there is no difference in the association with entry points. By definition, the least dominant trees are not as fast growing as the most dominant trees and they have shorter crowns (Table 7). Branches in these least dominant trees are therefore likely to be less persistent and be shed more cleanly than in the most dominant trees, so that there will be fewer opportunities for wood rot fungi to invade along branches and around branch stubs (Marks *et al.* 1986).

The most dominant trees have wider sapwood than the least dominant trees (Table 8). Experimental work has shown that axial spread of incipient rot in karri heartwood is significantly correlated with sapwood width and time since inoculation ($P<0.01$ for *S. hirsutum* and $P<0.001$ for *Hymenochaete*) (Davison and Tay, unpublished), so that infections will spread more slowly in least dominant than most dominant tree. Thus in sub-dominant and suppressed trees there will be fewer opportunities for wood rotting fungi to invade the heartwood, and when infections do occur, they will spread more slowly. As our survey only examined the incidence of incipient rot and rot at 1 m intervals, we may have missed more infections in sub-dominant and suppressed trees than in the dominant and co-dominant trees. Comparison of our survey data with that from older trees will indicate whether differences in incidence are a function of dominance class or tree size.

Insect infestation Although there were no differences in the proportion of most dominant and least dominant trees attacked by insects (Table 11), there were significant differences in the location of borer galleries within the trees (Table 19). In sub-dominant and suppressed trees they were mainly in the butt, whilst in the dominant and co-dominant trees they were mainly in the stem (Table 19, Fig. 6). Regrowth karri can be attacked by at least four species of borers: the longicorn beetles *Tryphocaria acanthocera* (Macleay), *Coptocercus* sp. and *Spondylis* sp., and at least one species of the cossid *Xyleutes* (J. D. Farr, pers. comm.). *Spondylis* larvae attack the roots and stem base (J. D. Farr, pers. comm.). Our observation that there are significantly more borer galleries in the butt of the least dominant trees implies that these trees are preferentially attacked by *Spondylis*. It is unlikely that root damage caused by this insect is sufficiently severe to reduce subsequent growth because Schuster (1978) reports that in karri regrowth some stems have been suppressed by age 6.

T. acanthocera, Coptocercus and *Xyleutes* attack the stem. Our observations show that borer galleries occur both above and below crown break, with most being between 2 m and 6 m above the ground (Fig. 6) but we do not know whether these trees were attacked by one or all species of borer. We also do not know whether each borer preferentially lays eggs at particular locations such as at branch crotches or splits in the bark. We do not know whether all of these species are equally abundant at each of our survey sites.

The young trees in our survey appear to have been infested recently with most infestations being apparent on no more than two adjacent billets (Table 22) even though larvae may cause galleries extending over 3.6 m (Brown 1983). Once infested, however, the trees are attacked quickly with one tree having a minimum of four separate infestations (Table 21). Abbott *et al.* (1991) record that karri becomes infested with borers at about 14 years, although Galloway (1985) records infestation of 5-, 7- and 9-year old stands planted on rehabilitated minesites. Our data indicate that trees are infested by at least 12 years (Table 5).

When trees are infested with *T. acanthocera* the larvae both bore through the sapwood just internal to the cambium and construct large galleries in the heartwood (Brown 1983, Abbott *et al.* 1991). Damage to the cambium results in large kino veins.

Effect of symptoms on log quality

Although regenerating karri stands may be initially stocked with several thousand seedlings ha^{-1}, by maturity only 100 stems ha^{-1} may remain (Bradshaw 1985). Dendrochronology has shown that the largest karri trees are only 350 years old, and many stands are less than 250 years old Rayner 1992b). When such mature stands are clear-felled about 60 per cent of logs are sawlog quality, the remainder are chiplogs ((M. E. Rayner pers. comm.). Apart from standards relating to their physical dimensions, sawlogs must have at least 30 per cent millable wood on the worst face (CALM 1993). Extensive rot is one of the commonest reasons for downgrading sawlogs to chiplogs.

Our small survey has shown that 83 per cent of dominant and co-dominant 12- to 14-year old trees have incipient rot and rot in them. Experimental work has shown that it takes two to four years for rot to start to develop from incipient rot (Davison and Tay, unpublished). If the trees we have examined are a representative sample of juvenile karri, even if there is no further infection by wood rotting fungi, these trees will have extensive rots in them at the end of the rotation. Donnelly *et al.* (1994) found that 70 per cent of medium sawlogs from thinnings from 50-year old regrowth stands had incipient rot and rot in them. These logs would have been a sample of the best logs from the slowest growing trees. If the tree characteristics shown in Table 28, and discussed above, are relevant for immature as well as juvenile karri, we would expect trees in thinned stands to have a higher incidence of rot and incipient rot than the trees removed during thinning.

Effect of symptoms on sawn recovery

Grading rules for structural hardwoods (Australian Standards 2082-1979) specify the maximum permissible limits for imperfections in sawn timber. Defects include mechanical imperfections such as endsplits, cupping bow and twist, as well as biological defects such as knots, rot, borer galleries and kino.

Not all of the symptoms recorded in this survey are defects. Discolouration and incipient rot are not defects, and grading rules determine whether, and at what size, insect galleries and kino will affect the recovery of specific products. Even those symptoms such as rot which are defects, and which must be docked out will not affect recovery if they are in the centre of the log because the central baulk is discarded during milling.

Discolouration is associated with brittleheart (although not all brittleheart is discoloured) and in 77.8 per cent of occurrences it was in the central 20 cm^2 of the billet (Table 15, Fig. 8) Discolouration is not caused by fungi (Davison and Tay 1990) but probably indicates where wood has been compressed during growth. It does not affect sawn recovery, although brittleheart is a defect and is docked out.

Incipient rot and rot occurred in all positions on the billet face (Tables 15 and 16, Figs. 9 and 10), indicating that these symptoms continue to be formed as the tree ages. Incipient rot does not affect the recovery of structural timber, but, because it affects appearance, would affect the recovery of furniture grade wood if this is a future product of sawn karri.

Insect galleries were more abundant at the periphery of billets than in the central 20 cm^2 (Table 18, Fig. 11). This is not surprising because borer galleries occur just internal to the cambium and it appears that our surveyed trees have only been recently infested. The presence of borer galleries will affect recovery not just because their size creates voids, but because their association with kino veins which may also be a defect in its own right.

Comparison of our dataset with that from older trees (e.g. Farr's survey of 20 year old karri) will indicate whether these symptoms continue to develop with increasing tree age.

Lessons for future surveys

This billet survey has provided a detailed assessment of the incidence and severity of discolouration, incipient rot, rot, insect galleries and kino in 12- to 14-year old karri and has allowed comparisons to be made between trees from different community vegetation types and dominance class. Trees which would not be suitable for sawlogs (because of size or quality) can be assessed by this method. The method, however, wastes wood, is expensive, costing approximately $ 140 per tree, and does not allow any estimation of the relationship between symptoms and recovery.

A survey of 1 m billets may not be sufficiently detailed for estimates of borer infestation because it will not detect all recent or aborted infestations. A survey of log ends will give data which is difficult or impossible to interpret because symptoms are not randomly distributed up the tree (Figs. 3, 4, 5, 6 and 7).

If cut to a standard product, a routine sawmill survey allows an assessment of the incidence and severity of some of the symptoms recorded in our billet survey. It is inexpensive, that of Donnelly *et al.* (1994) costing $ 14 per log. It does not allow comparisons of logs sourced from different stands or trees of different dominance class, it only allows comparisons of logs selected as sawlogs. It does not allow an estimate of the incidence of defects on sawn recovery.

A slab and board survey, such as that being carried out by Brennan (SPP 93/0161), can relate the incidence of symptoms to recovery of specific products, can make comparisons between trees of different dominance class and between trees from different sites. This survey, however, is extremely expensive costing more than $ 1 100 (plus analysis) per log.

The most cost effective method for future surveys would be to integrate it with a logging operation, selecting trees for the survey and making assessments of them in the forest, and then assessing the incidence and severity of symptoms in logs from these trees in a sawmill.

Conclusions

1 Discolouration, incipient rot, rot, insect galleries and kino occur in 12- to 14-year old regrowth karri trees.

2 There is no difference in the incidence of these symptoms in similar age trees, with similar management histories, on the two commonest community vegetation types.

3 Of dominant and co-dominant trees, 83 per cent had incipient rot and rot in them, compared with 28 per cent of sub-dominant and suppressed trees. These differences are very highly significant.

4 There are highly significant differences between the position of borer galleries in the stems of the most dominant and least dominant trees. Insect galleries were most abundant at ground level in the least dominant trees and were most abundant between 2 m and 6 m in the most dominant trees.

5 Discolouration, incipient rot and rot were not randomly distributed with height above ground level. Discolouration was most abundant between 1 m and 9 m, whilst incipient rot and rot were most abundant at ground level.

6 Discolouration, incipient rot and insect galleries were more abundant below crown break; rot occurred only below crown break.

7 Discolouration occurred mainly in the centre of the billets, incipient rot was more abundant towards the centre of billets, rot was randomly distributed on the billet face, whilst insect galleries and kino were more abundant towards the periphery of the billets.

8 Incipient rot was associated with branches and insect galleries, but this association was not constant between coupes.

9 Of the most dominant trees which were affected by incipient rot and rot (but not attacked by borers), the most severely affected trees were likely to be taller, of larger diameter, have a deeper crown and lower crown break than trees which were not as badly affected.

10 Of the most dominant trees which were attacked by borers, the most severely affected trees were likely to be taller, of larger diameter, with thinner bark, deeper crowns and lower crown break than trees which were not as badly affected.

11 From their position on the billet face, incipient rot and rot are not confined to the centre of the tree, but continue to be formed as the tree ages.

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Appendix 1

Descriptions of Field Measurements

Dominance

Dominant	Tree crown receives light to both the top and sides.
Co-dominant	Tree crown receives light to the top and parts of the sides, but some part of the crown is shaded by more dominant tree/s.
Sub-dominant	Tree crown receives light only to the top; sides are shaded.
Suppressed	Tree crown receives little filtered light, shaded by more dominant trees.

Crown break height

Crown break is defined by active branches ie ones with healthy terminal foliage and few epiormics. If the distance between the first and second active branches is less than 5 times DBHOB then the first active branch is crown break. If the distance is greater than 5 times DBHOB then similar measurements are made between the second and third active branch, etc. Measured to nearest 0.1 m.

Crown Epicormics

1	= Normal crown - no epicormics
2	= Epicormics in the crown only
3	= Epicormics in the crown and on the bole
4	= Epicormics on the bole only

Bole Epicormics

0	= No bole epicormics
1	= 1-5 bole epicormics
2	= 6-20 bole epicormics
3	= 21-50 bole epicormics
4	= 51-100 bole epicormics

DBHOB

Diameter at breast height (1.3 m above mineral soil) over bark, measured with a tape to 0.1 cm.

Bark Thickness

Measured using a calliper inserted at right angles to the vertical, at two positions on opposite sides of the tree, 1.3 m above mineral soil. Irregularities in the tree surface are avoided. Measured to 0.1 cm.

Tree Form

D = trees that require additional measurement in the upper stem or crown due to forks or abnormal taper.

0 = trees>25 cm DBHOB with no additional measurements

1 = tree DBHOB 15-24.9 cm : bole is straight or has sweeps < 2 per cent.

2 = tree DBHOB 15-24.9 cm : 90 per cent of bole is straight (sweeps < 2 per cent)

3 = tree DBHOB 15-24.9 cm : 60 to 90 per cent of bole is straight (sweeps < 2 per cent).

4 = tree DBHOB 15-24.9 cm : less than 60 per cent of the bole is straight (sweeps < 2 per cent).

Wood Quality and Quantity

Assessed up to crown break.

QUALITY : Wood quality code as per appendix C of the jarrah inventory is recorded.

QUANTITY : The average quantity or amount of the characteristic in the section of the bole affected. Most qualities are described by a percentage of the tree size. These are cumulative eg. an assessment of 10 per cent borer and 30 per cent rot means a 40 per cent total defect, not 10 per cent of the 30 per cent.

Quadrant : The quadrants affected for all wood qualities are recorded. The height from the ground to the bottom of the section of bole affected by the quality, and the height from the ground to the top of the quality are recorded. If the quality occurs at a point, these two heights are the same.