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The Availability and Dimensions of Tree Hollows that Provide Nest Sites for Cockatoos (Psittaciformes) in Western Australia

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Abstract

A 15-ha plot of salmon gum woodland contained 241 hollows with an entrance diameter and depth exceeding 90 mm, in 173 trees, the majority (95%) in salmon gums. Occupancy of these hollows during the spring of 1978 was 47%; eight species of bird (six Psittaciformes, one Anseriformes and one Falconiformes) were involved. Galahs, corellas, red-tailed black cockatoos and Port Lincoln parrots were the most numerous hollow-nesting birds in the area; there were differences in the sizes of hollows they used, which were separable on entrance size and on inside diameter of the hollow 0·5 m below the entrance. There was a trend for hollow size to decrease in the order: red-tailed black cockatoos, corellas, galahs and Port Lincoln parrots. Red-tailed black cockatoos nested in more dead trees, or trees which were lower and had smaller canopies, than did the other three species. The woodland contained few young trees, trees were dying rapidly and there was no regeneration. This situation is typical for woodland throughout the agricultural area, and future prospects are discussed.

Introduction

Hollows in trees provide resting and breeding sites for many different animals and therefore constitute an important aspect of woodland and forest ecology. Little is known about the causation, incidence or distribution of cavities in trees anywhere in Australia, largely because such damaged trunks are of little use commercially. As the native vegetation is cleared from land for primary production, the total number of hollows available to animals must decrease. Such changes must affect the fauna, some species more than others, and it is important to try to understand the factors involved and to recognize the importance of hollows as a resource for wildlife.

In Western Australia most of the agricultural land has been cleared recently compared with that in the rest of Australia. Between 1917 and 1968 more than 98 000 km^2 were cleared, 65% of it since 1948 when heavy machinery became available. Nowadays the only timber remaining in most of the wheatbelt is along roadside verges, around buildings and in widely scattered 'islands' of woodland interspersed by large expanses of farmland. These 'islands' are the only refuges available for species that depend on hollow trees for their survival, and competition for the cavities is inevitable.

The Division of Wildlife Research, CSIRO, has been studying the biology of several species of cockatoo in the south-west of Western Australia, all of which use hollows in trees as nest sites. Although most of these studies have been carried out at different locations, one place (Nereeno Hill) supported five species of cockatoo in sympatry and offered an opportunity to study competition between and within species, for a limited resource.

This paper analyses the differences in the sizes and positions of hollows required by the different species of bird nesting in cavities found in 15 ha of aging woodland in 1978.

Study Areas and Methods

Nereeno Hill is located 23 km north-east of the town of Three Springs (Fig. 1) and the general area is described in detail in Saunders and Smith (1981). The woodland studied is a 15-ha block left standing after the surrounding land was cleared of native vegetation and developed for mixed wheat and sheep farming. This woodland is dominated by salmon gum *Eucalyptus salmonophloia* with smaller numbers of york gum *E. loxophleba* and morrel *E. longicornis* interspersed. The understorey is dominated by jam *Acacia acuminata* and at the southern end of the block there is an area of mallee *Eucalyptus* spp. When the property containing the study area was originally taken up, in about 1925, it was covered with woodland on heavy soils, and thicket dominated by tamma *Casuarina campestris* on the higher, stony ground. Wheat was grown initially, but in 1929 sheep were introduced, and thereafter had access to most of the uncleared land. Rabbits *Oryctolagus cuniculus* invaded the area and were common in burrows and in holes in fallen logs throughout the woodland. The last clearing of vegetation was done in the early 1970s and isolated the section of woodland chosen for our study block, which is now included in a fenced paddock and provides shade and shelter for sheep.

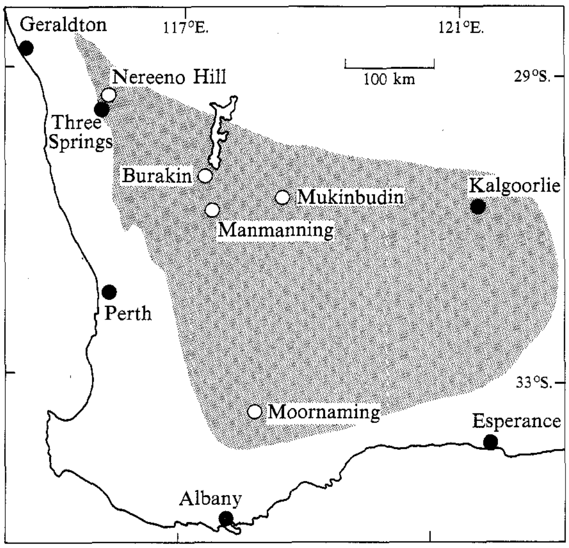

Fig. 1. Location of the study areas and the distribution of salmon gum *Eucalyptus salmonophloia*. The latter is based on a map produced by Dr D. M. Churchill and Dr G. M. Storr and used with their kind permission.

The following species of cockatoo had nested in the area in the previous 4 years: the galah *Cacatua roseicapilla*; the short-billed form of the white-tailed black cockatoo *Calyptorhynchus funereus latirostris*; the red-tailed black cockatoo *C. magnificus*; the long-billed corella *Cacatua pastinator pastinator*; the little corella *C. p. gymnopis* (corella nomenclature follows Schodde *et al.* 1979); the Major Mitchell cockatoo *C. leadbeateri*; and, in addition, the Port Lincoln parrot *Barnardius zonarius*.

During May 1978 the woodland (as it will be called from here on) was searched for trees possessing hollows of at least 90 mm diameter and at least 90 mm deep. This was the minimum-sized hollow that we thought the smallest cockatoo (galah) could use. The following data were recorded (see Fig. 2). For each tree:

(1) Species;
(2) Height (*A*);
(3) Distance from ground to base of canopy (*B*);
(4) Diameter of canopy (*C*);
(5) Circumference at breast height (*D*);
(6) Ground coordinates for mapping;
(7) A photograph was taken;

(8) Condition of tree was rated on the following scale: 0, dead (Fig. 3*a*); 1, dying back from the top and showing a 'staghorn effect' (Fig. 3*b*); 2, broken off along the trunk (Fig. 3*c*); 3, tree apparently healthy (Fig. 3*d*).

For each hollow:

(1) Height of entrance(s) to hollow from ground (*E*);
(2) Aspect of entrance(s) (*F*) (the direction towards which the entrance faces);
(3) Horizontal diameter of entrance(s) (*G*);
(4) Vertical diameter of entrance(s) (*H*);
(5) Internal diameter of hollow 0·5 m below the entrance(s) (*I*);
(6) Depth of hollow (*J*).

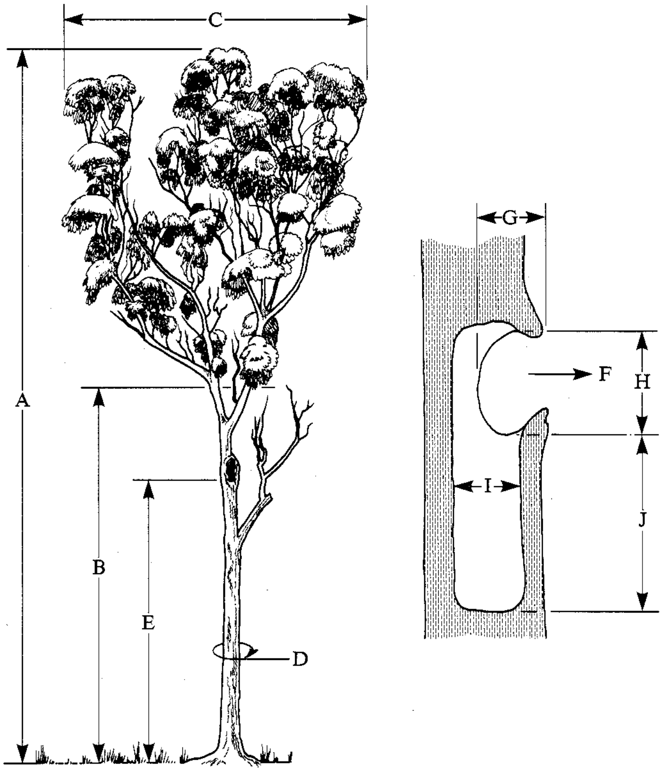

Fig. 2. Measurements taken on the survey trees and their hollows: *A*, height of tree; *B*, height from ground to base of canopy; *C*, diameter of canopy; *D*, circumference of tree at breast height; *E*, height of entrance of hollow from ground; *F*, aspect of hollow entrance; *G*, horizontal diameter of hollow entrance; *H*, vertical diameter of hollow entrance; *I*, diameter of interior of hollow 0·5 m below the entrance; *J*, depth of hollow.

Each hollow was re-examined during the first week of September 1978 and again during the second week in October 1978 to note which species, if any, was using the hollow during that breeding season. These times were chosen to cover the known laying periods for each species of cockatoo. In July 1981 the circumference at breast height and condition of every tree in the woodland was noted.

Hollow usage by red-tailed black cockatoos in the study area during the period 1975–80 was known (Saunders 1977*a*), and any hollows used by them during that time but not used in 1978 have been included in the sample for analysis of differences between species in tree or hollow dimensions. The data were first subjected to an analysis of variance; where the results were significant, differences between species were examined by a *t*-test where variances were equal and a *d*-test (with adjusted degrees of freedom) where they were not equal (Bailey 1959). Unless stated specifically, differences are regarded as significant at the 5% level.

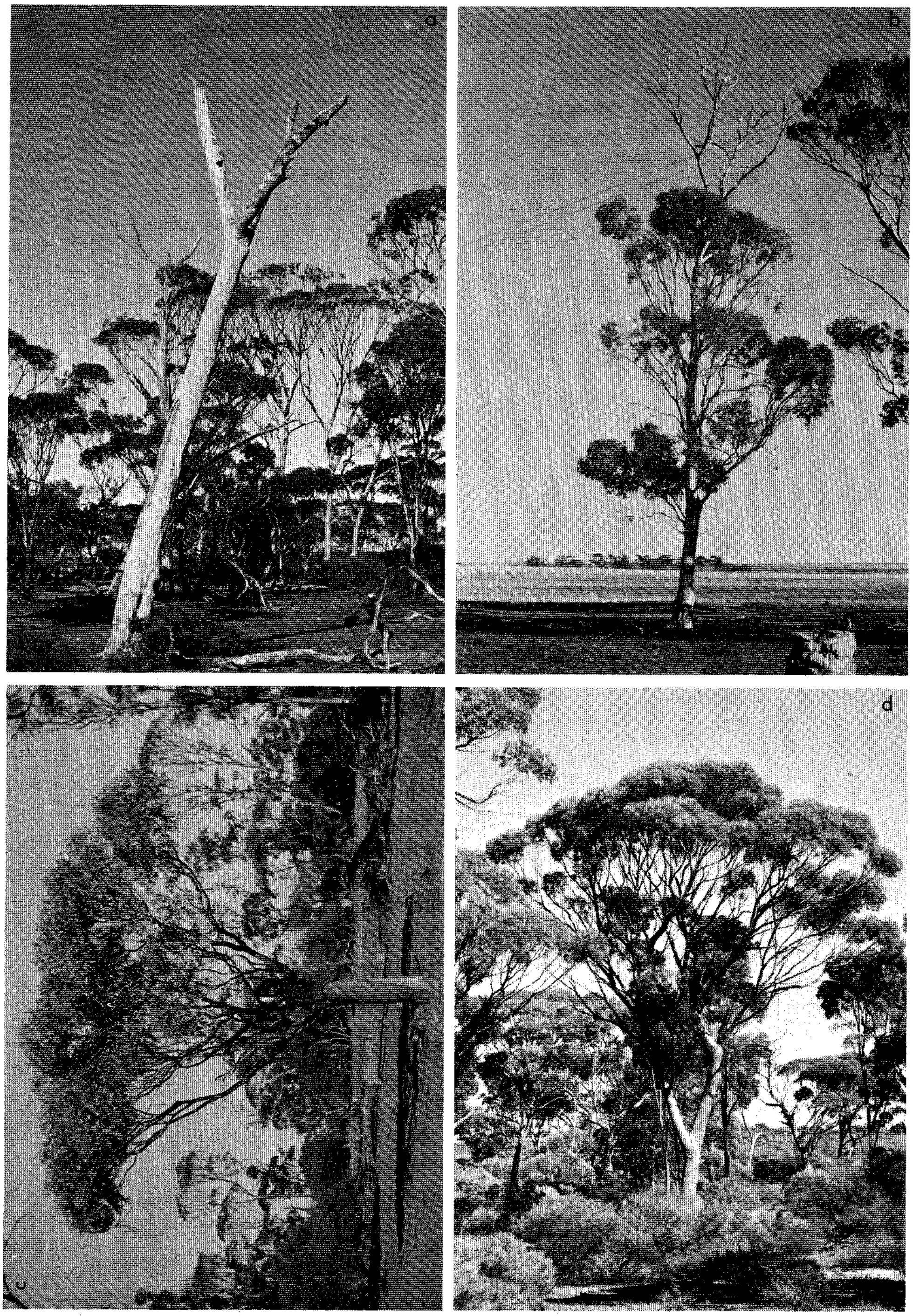

Fig. 3. Photographs of trees to show condition ratings: (*a*) dead tree, rating 0; (*b*) tree dying off at top and showing 'staghorning', 1; (*c*) tree (york gum) with broken trunk, 2 (note the lack of understorey); (*d*) healthy tree (salmon gum), 3.

Results

Usage of Hollows

There were 241 hollows, in 173 trees, which were as large as or larger than the dimensions selected. The number of hollows used by each species was as follows:

Galah *Cacatua roseicapilla*	48
Long-billed corella *C. pastinator pastinator*	14
Little corella *C. p. gymnopis*	7
Corellas (subspecies not determined)	7
Red-tailed black cockatoo *Calyptorhynchus magnificus*	16
White-tailed black cockatoo *C. funereus latirostris*	1
Port Lincoln parrot *Barnadius zonarius*	13
Mountain duck *Tadorna tadornoides*	5
Nankeen kestrel *Falco cenchroides*	2
Cockatiel *Nymphicus hollandicus*	1
Total number of hollows used as nest-sites	113

(One hollow was used first by a red-tailed black cockatoo, which failed, and then by a corella.)

Total number of hollows not used as nest-sites	128
Total number of hollows available	241
Total No. of trees with hollows fitting specifications	173
No. of hollows per tree (mean and range)	1·4 (1–4)
No. of entrances per hollow (mean and range)	1·3 (1–8)

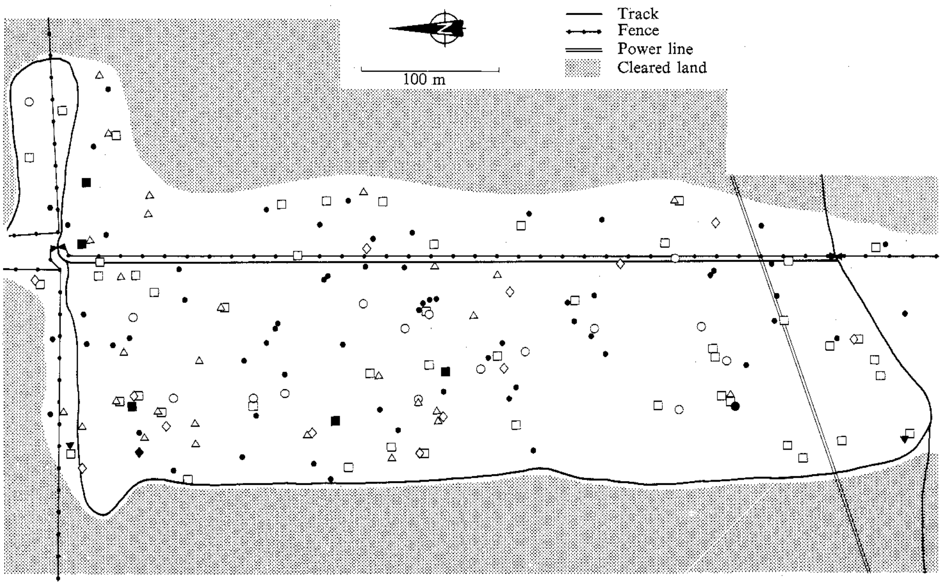

Fig. 4. Study area, showing the locations of all trees with hollows, and of those with hollows used as nest sites by birds in spring 1978. □ Galah. △ Corella. ○ Red-tailed black cockatoo. ◊ Port Lincoln parrot. ● White-tailed black cockatoo. ■ Mountain duck. ▼ Kestrel. ◆ Cockatiel. • Available hollow not used.

In 1978, 47% of the available hollows were used. The location of the trees used by each species is shown in Fig. 4. Hollows suitable for cockatoos were distributed throughout the woodland, and those that were used by different species showed no departure from a random distribution when analysed for 'nearest neighbour'.

Port Lincoln parrots were common, but the total number of nests in the study area was not known because many entrances were smaller than our minimum specification. Although only one nest of the cockatiel *Nymphicus hollandicus* was found, similar comments would apply. One pair of Major Mitchell cockatoos was seen investigating hollows in the woodland but they did not nest there, using a hollow in neighbouring woodland.

Of the other species nesting in the area, mountain duck *Tadorna tadornoides* had five nests scattered through the woodland, and the two kestrel *Falco cenchroides* nests in the area were at opposite ends of the block. A barn owl *Tyto alba*, which roosted in a hollow there by day, made no attempt to breed during the spring of 1978.

Table 1. Diameter at widest point, and length of tail, of adult cockatoos and parrots

Diameter at widest point was the shoulder-to-shoulder measurement of museum specimens from the agricultural area. Values are means ± standard deviations, with ranges in italics. Measurements of nine galahs and ten of each other species; weights as in Table

	Diameter at widest point (mm)	Tail length (mm)	Wt of adult female (g)	No. of birds weighed
White-tailed black cockatoo	103·5±5·8	260·9±8·9	646±57	159
	95–115	*246–274*	*560–790*	
Red-tailed black cockatoo	100·4±3·3	242·4±8·2	664±67	7
	96–106	*234–256*	*570–740*	
Long-billed corella	98·8±6·2	144·7±3·3	611±51	20
	89–109	*140–150*	*530–725*	
Little corella	93·1±4·1	136·4±3·5	489±34	17
	88–102	*131–142*	*440–560*	
Galah	80·8±3·6	140·1±4·1	305±27	17
	74–85	*136–149*	*270–355*	
Port Lincoln parrot	60·0±4·5	201·1±9·7	127±14	20
	52–65	*190–222*	*112–155*	

Since the size of the bird must influence the choice of hollows, relevant measurements are given in Table 1. Four species provided sufficient numbers of nests for us to examine the differences between the hollows used by them: galahs, red-tailed black cockatoos, corellas and Port Lincoln parrots. There were no significant differences in any of the dimensions of hollows or trees used by the two subspecies of corella, and these samples have been combined.

Dimensions of Hollows

The mean, standard deviation and range of measurements of the dimensions of all 241 hollows surveyed, and for those used by red-tailed black cockatoos, corellas, galahs and Port Lincoln parrots are shown in Table 2.

Entrance. Most hollows are exposed when the trunk or a branch snaps off, and so the majority of entrances are circular and the mean horizontal and vertical diameters are approximately the same. Fig. 5 shows that the hollows used by red-tailed black cockatoos had entrances the mean dimensions of which were significantly larger than those of entrances used by other species. Hollows used by corellas had

Table 2. Dimensions of all hollows suitable for nests, characteristics of all trees providing suitable hollows, and those of hollows and trees actually used by species with more than 10 nests

Values are means ± standard deviations, with ranges in italics. Sample for red-tailed black cockatoos includes 21 hollows used between 1975 and 1980. Corella samples have been combined, as there were no significant differences between mean values for the two subspecies

	All survey	Red-tailed black cockatoos	Corellas	Galahs	Port Lincoln parrots
Number of hollows measured	241	37	28	48	13
Horizontal diameter of entrance (mm)	189·3±95·3	272·1±123·3	185·2±67·0	159·2±80·7	138·8±55·7
	60–820	*147–820*	*78–400*	*60–410*	*64–275*
Vertical diameter of entrance (mm)	188·8±80·4	249·8±100·1	197·9±65·7	156·6±54·2	141·3±50·7
	65–535	*120–535*	*105–420*	*65–300*	*65–250*
Diameter at 500 mm (mm)	203·2±96·0	289·4±87·0	226·1±67·1	178·4±51·3	127·1±23·5
	60–770	*190–540*	*140–400*	*100–310*	*90–175*
Depth of hollow (mm)	1186·3±1039·0	1717·9±1473·1	1463·6±1066·0	1066·0±658·9	836·5±422·6
	100–7250	*450–7250*	*450–4530*	*325–3770*	*450–2130*
Height of entrance above ground (m)	8·38±2·60	7·29±2·00	9·63±2·15	8·86±2·28	7·77±1·94
	1·96–15·20	*4·40–12·00*	*6·20–14·30*	*4·65–14·00*	*5·25–11·00*
Number of trees measured	173	37	28	48	13
Circumference of tree at breast height (m)	1·577±0·444	1·573±0·396	1·771±0·453	1·603±0·534	1·538±0·564
	0·70–3·20	*1·00–2·50*	*1·00–2·50*	*0·80–3·20*	*0·90–3·00*
Height of tree (m)	16·7±5·5	14·7±5·0	19·1±3·7	18·2±5·2	16·8±5·3
	2–30	*5–24*	*12–26*	*8–29*	*5–24*
Diameter of canopy (m)	6·4±3·5	4·7±3·8	7·2±2·8	7·0±3·4	6·8±3·3
	0–14·3	*0–12·5*	*0–11·8*	*0–13·4*	*0–11·6*
Thickness of canopy (m)	10·5±5·2	7·8±5·6	11·9±3·5	11·9±5·0	10·6±4·9
	0–22	*0–17*	*0–17*	*0–22*	*5–20*

significantly larger vertical diameters than those used by galahs, and were significantly larger in both diameters than those used by Port Lincoln parrots. No significant differences were found in mean dimensions of entrances between hollows used by galahs and Port Lincoln parrots. As none of these species is capable of making their own nest hollows and must use what is available, there is inevitably an overlap in size ranges between species (Table 2; Fig. 5).

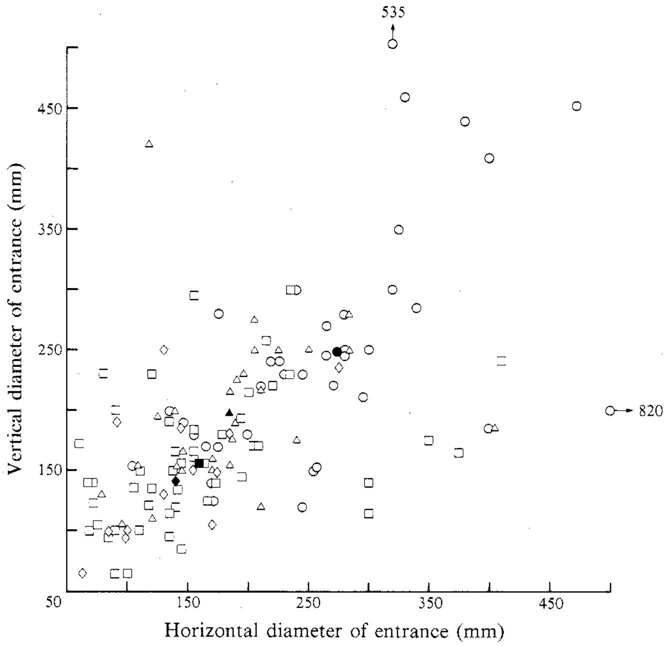

Fig. 5. Dimension of entrances to hollows used by galahs (□), corellas (△), red-tailed black cockatoos (○) and Port Lincoln parrots (◊) in the study area in spring 1978. Solid symbols indicate the mean dimensions for each species.

Internal diameter. Significant differences between the mean diameters of hollows at 0·5 m were found for each of the four species, with red-tailed black cockatoos using the largest hollows, followed by corellas, galahs and Port Lincoln parrots.

Depth. Hollows used by red-tailed black cockatoos were significantly deeper than those used by galahs and Port Lincoln parrots, but not than those used by corellas. Corellas tended to use hollows which were significantly deeper than those used by Port Lincoln parrots, but not than those used by galahs. There was no significant difference between the mean depths of hollows used by the last two species.

Height of entrance. Hollows used by red-tailed black cockatoos are closest to the ground; their mean height was significantly less than that of those chosen by corellas and galahs, but not significantly different from that of those used by Port Lincoln parrots. The latter species tended to use hollows which were significantly lower than those used by corellas but not than those used by galahs. There was no significant difference between the mean heights of hollows used by corellas and galahs.

Position of entrance. The entrance to 169 of the 241 survey hollows was located in the treetrunk, and that of 72 in a branch (even if the floor of the hollow was in the trunk). For each species, the actual number of hollows used with entrances in branches was compared with that expected if the birds had no preference. Only the red-tailed black cockatoo showed a marked preference; of 37 hollows it used none had entrances in branches (expected number, 11; $\chi_1^2 = 11 \cdot 00$, $P < 0 \cdot 001$). None of the other species showed any significant departure from prediction: 10 of 28 hollows used by corellas, 12 of 48 used by galahs and 4 of 13 used by Port Lincoln parrots had entrances in branches (expected numbers, respectively: 8, $\chi_1^2 = 0 \cdot 50$; 14, $\chi_1^2 = 0 \cdot 29$; 4, $\chi_1^2 = 0$).

Table 3. Aspect of entrances to hollows used by three species

For all hollows, the expected number facing each compass direction is one-eighth of the total less the number of vertical entrances, i.e. 34·375. For each species, the expected number is: (total entrances with this aspect × total entrances used by the species)/324. Obs., number observed; Exp., number expected

Aspect of entrance	All hollows, observed	Galahs		Corellas		Red-tailed black cockatoos	
		Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
North	37	10	6·9	5	5·3	9	7·9
North-east	36	8	6·7	6	5·1	6	7·7
East	24	4	4·4	3	3·4	9	5·1
South-east	20	3	3·7	1	2·8	6	4·3
South	43	10	8·0	5	6·1	6	9·2
South-west	34	4	6·3	9	4·8	7	7·2
West	42	8	7·8	5	6·0	7	8·9
North-west	39	5	7·2	4	5·5	5	8·3
Vertical	49	8	9·0	8	7·0	14	10·4
Total	324	60	—	46	—	69	—
	$\chi_7^2 = 13 \cdot 90$, NS	$\chi_8^2 = 3 \cdot 94$, NS		$\chi_8^2 = 5 \cdot 97$, NS		$\chi_8^2 = 8 \cdot 27$, NS	

Number of entrances per hollow. Hollows had up to eight entrances each, with a mean of 1·3; 190 of the 241 hollows had only one entrance. Again, the red-tailed black cockatoo was the only species tested to show a distinct preference, using significantly more hollows with two or more entrances than predicted; of 37 hollows it used, 22 had one and 15 had more than one entrance (expected numbers 29·2 and 7·8, $\chi_1^2 = 8 \cdot 42$, $0 \cdot 001 < P < 0 \cdot 01$). For galahs, 40 of 48 hollows, and for corellas, 19 of 28 hollows had only one entrance (expected number for galahs: 37·8, $\chi_1^2 = 0 \cdot 61$, NS; for corellas: 22·1, $\chi_1^2 = 2 \cdot 06$, NS). The sample for the Port Lincoln parrot could not be tested, as the number in one of the predicted categories was too small to test for significance. Any subdivision of the multiple-entrance class has a similar result for the three species.

Aspect of entrance. The directions in which the entrances faced were grouped into nine classes: a vertical aspect class and eight equal segments of the compass, with the major points of the compass at their centre (Table 3). There is no way of establishing how many entrances in the sample should occur in the vertical aspect class, but the assumption that there should be an equal distribution among the eight horizontal classes was tested and showed no significant departure from random. The hollows used by galahs, corellas and red-tailed black cockatoos were also tested to see if any species favoured a particular direction. No significant departures from random were found.

Characteristics of Trees used by Different Species

The mean, standard deviation and range of measurements for the measured dimensions of all 173 hollow trees and of those used by red-tailed black cockatoos, corellas, galahs and Port Lincoln parrots are shown in Table 2.

Dimensions of trees. No significant differences among any of the species in the circumference of the tree at breast height were found. The smallest tree which provided a hollow of suitable size for any cockatoo to nest in had a circumference of 0·70 m, while the smallest tree actually nested in measured 0·80 m for the galahs and 1·00 m for the corellas and red-tailed black cockatoos (Table 2). Trees chosen by red-tailed black cockatoos tended to be significantly lower, with a canopy diameter and thickness smaller than those used by corellas and galahs, but not significantly different from those used by Port Lincoln parrots. There were no significant differences in these measurements between the latter three species.

Species of tree. Hollows of a suitable size for a cockatoo to nest in were found in 165 of 513 salmon gums, 5 of 170 york gums and 3 of 10 morrels, i.e. in 25% of the 693 trees. Salmon gums made up 74% of the trees and provided 95% of the available hollows.

Condition of Trees

All of the trees providing nest hollows were rated according to condition (Fig. 3) and, from the known distribution, the condition of trees used by galahs, corellas and red-tailed black cockatoos were examined for any departure from a random choice (Table 4). Only red-tailed black cockatoos showed any departure from random, in that they tended to nest in dead trees far more than predicted.

Change in condition over 3 years. In May 1978, 194 salmon gums were measured and rated according to their condition (Table 5). At that time, 22·7% of the sample could be classed as healthy (rating 3) and 19·1% were dead (0). In July 1981 only 4·6% of these trees were classed as healthy and 40·2% were now dead (including the four which had been blown down or fallen over in that period) (Table 5). In March 1979, tropical cyclone 'Hazel' swept through the north-western agricultural area, the eye passing within 10 km of the study area. During its passage through the woodland, two trees were blown down and nine had their trunk snapped off, the lowest break being 2 m from the ground. A total of 13 hollows (5·4%) were destroyed. Unfortunately it was not possible to conduct a survey at that time to find out how many new hollows were created as a result of damage to trees giving access to pre-existing hollows with no suitable entrance.

Size composition of the woodland. The size and condition of all salmon and york gums during July 1981 is shown in Figs 6*a* and 6*b* (the 10 morrels have been excluded). The minimum circumference at breast height was 0·11 m for the salmon gums and 0·10 m for the york gums. Both species show a similar distribution of sizes with very few in the smallest class (five salmon and three york gums) and few healthy large trees. These data indicate that this patch of woodland is dying rapidly and that no recruitment of trees is taking place.

Table 4. Condition of trees used as nest sites by three species

Expected number for each rating for each species is: (total of trees in this condition × total trees used by the species)/173. Obs., number observed; Exp., number expected. For condition rating, see Fig. 3

Condition rating	All suitable trees	Galahs		Corellas		Red-tailed black cockatoos	
		Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
0	37	5	10·3	5	6·0	15	7·9
1	86	30	23·8	17	13·9	12	18·4
2	19	3	5·3	2	3·1	8	4·1
3	31	10	8·6	4	5·0	2	6·6
Total	173	48	—	28	—	37	—
		$\chi^2_3 = 5 \cdot 57$, NS		$\chi^2_3 = 1 \cdot 45$, NS		$\chi^2_3 = 15 \cdot 52$ $0 \cdot 01 > P > 0 \cdot 001$	

Table 5. Change in the condition of salmon gums at Nereeno Hill between May 1978 and July 1981

c.b.h., circumference at breast height. For condition ratings, see Fig. 3

c.b.h. (cm)	Condition in 1978 0	1	2	3	Total trees	Condition in 1981 Fallen	0	1	2	3
0–20	0	0	0	0	0	0	0	0	0	0
21–40	0	0	0	0	0	0	0	0	0	0
41–60	0	0	0	0	0	0	0	0	0	0
61–80	0	0	1	0	1	0	0	0	1	0
81–100	3	8	0	6	17	0	6	9	1	1
101–120	5	17	2	5	29	1	11	14	2	1
121–140	6	15	6	7	34	1	17	7	5	4
141–160	6	18	1	11	36	0	10	22	3	1
161–180	8	13	4	10	35	1	14	15	4	1
181–200	5	10	3	3	21	0	8	7	6	0
201–220	2	1	1	1	5	1	2	0	2	0
221–240	2	4	1	1	8	0	3	3	1	1
241–260	0	3	0	0	3	0	3	0	0	0
261–280	0	1	1	0	2	0	0	1	1	0
281–300	0	2	0	0	2	0	0	2	0	0
301–320	0	1	0	0	1	0	0	1	0	0
Total	37	93	20	44	194	4	74	81	26	9
Percentage	19·1	47·9	10·3	22·7		2·1	38·1	41·8	13·4	4·6

Discussion

Cavities in trees provide secure resting and breeding sites for a wide range of animals all over the world. The availability of hollows for any species depends on the number of suitable hollows and how intensive the competition is for these sites. The frequency of cavities in different species of tree is not known and, anyway, would vary for any one species under different edaphic and climatic conditions. Termites and fungus are the main agents involved in hollow formation, and in Australia, at least, some species of tree are more resistant to attack than others (Anon. 1971). Nevertheless, in any one area certain species will provide more hollows than others.

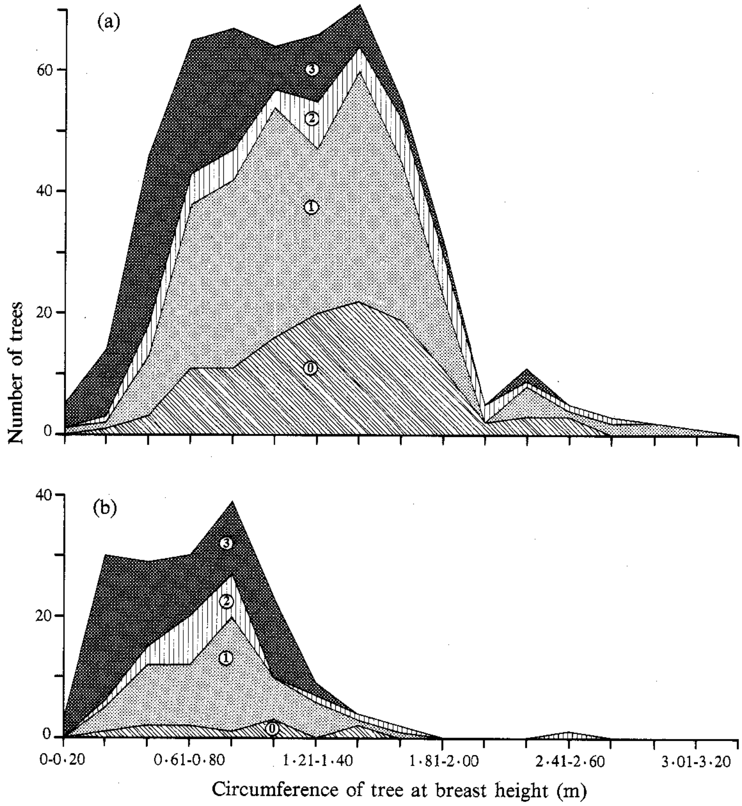

Fig. 6. Size classes and condition, during July 1981, of: (*a*) 513 salmon gums; (*b*) 170 york gums; being the total of these two species in the study area. 0, dead tree. 1, staghorned tree. 2, tree with broken trunk. 3, healthy tree.

Some species of bird are limited in their choice of nest sites by the number of suitable cavities, while others may improve existing holes to meet their requirements or may create new ones. In this regard, it is convenient to classify birds as primary or secondary excavators. Only the former have the ability to penetrate healthy wood. To be an efficient primary excavator of trees requires a specialized morphology which is largely confined to the Piciformes, none of which occur in Australia. Primary excavators in the ground or in termite mounds are far more common, and include members of the Psittaciformes, Coraciiformes, Trogoniformes and Passeriformes, in addition to the Piciformes. The extent to which secondary excavators alter hollows to suit their convenience varies widely, depending on substrate and species of bird. Most cockatoos work at their hollows sufficiently to provide a bed of wood chips on which to lay their eggs. Galahs, however, line their nests with sprays of leaves, and excavate relatively little.

Some species of bird have never been recorded nesting in anything other than hollows: these species are *obligate* hole-nesters. Many other species may depend largely on hollows for nesting but are sufficiently adaptable to use other sites. Table 6 summarizes the number of hole-nesting species, by order, for Australia,

Table 6. Use of tree-hollows as nest sites by land birds in Australia, Southern Africa and North America

Data for Australia extracted from: Reader's Digest (1976); Frith (1977); Beruldsen (1980); Pizzey (1980); Forshaw (1981). Data for Africa from Roberts (1971); data for North America from Bent (1919–1968). Primary excavators are excluded from the Table, but are indicated in footnotes

Order	No. of species in region	No. known to use tree-hollows	No. of obligate hole-nesters
	Australia (10–44°S.,113–154°E.)		
Anseriformes	19	9	4
Falconiformes	24	2	0
Psittaciformes	53	47	39
Strigiformes	8	7	5
Caprimulgiformes	7	1	1
Apodiformes	3	0	0
Trogoniformes	0	0	0
Coraciiformes	11	5	1
Piciformes	0	0	0
All non-passerines	234	71 (30%)	50 (21%)
Passeriformes	297	23	7
Total	531	94 (18%)	57 (11%)
	Southern Africa (15–35°S.,11–39°E.)		
Anseriformes	14	2	0
Falconiformes	53	1	0
Psittaciformes	6	4	4
Strigiformes	12	7	5
Caprimulgiformes	6	0	0
Apodiformes	11	2	0
Trogoniformes	1	1	1
Coraciiformes	32	17	13
Piciformes	23	1[A]	0
All non-passerines	310	35 (11%)	23 (7%)
Passeriformes	333	20[B]	13[B]
Total	643	55 (9%)	36 (6%)
	Northern America (15–75°N.,50–169°W.)		
Anseriformes	45	8	3
Falconiformes	33	4	0
Psittaciformes	2	2	2
Strigiformes	17	12	6
Caprimulgiformes	6	0	0
Apodiformes	20	2	0
Trogoniformes	1	1	0
Coraciiformes	3	1	0
Piciformes[C]	22	0	0
All non-passerines	192	30 (10%)	11 (4%)
Passeriformes	292	28[D]	13[D]
Total	584	58 (10%)	24 (4%)

[A]Sixteen species are primary excavators. [B]One species is a primary excavator.
[C]All 22 species are primary excavators. [D]Eight species are primary excavators.

Southern Africa and Northern America; it will be seen that Australia has the greatest number of obligate hole-nesters. The biggest difference between regions is among the non-passerines, in which 30% of Australian species use tree hollows and 21% are obligate users, most of these being Psittaciformes and Strigiformes. Although some of our cockatoos are physically capable of penetrating healthy wood in their search for food (McInnes and Carne 1978) they appear to lack the behavioural repertoire that would enable them to exploit this capacity to create nest hollows. In Southern Africa 13% of non-passerine species are obligate hollow-nesters but 16 of these 39 species are primary excavators. When these are excluded only 7% are obligate nesters, compared with Australia's 21%. The situation in Northern America is similar to that in Southern Africa.

Although the importance of hollows to the fauna has been recognized for some time (Cowley 1971; Tyndale-Biscoe and Calaby 1975; Ambrose 1979), few studies into the availability of this resource have been made (e.g. Saunders 1979*a*). The present study documents the availability and use of this resource in a 15-ha woodland; we found that eight species of bird used 47% of the hollows. This is comparable to the occupancy found in two other areas in the wheatbelt (Saunders 1979*a*) where, typically, remnants of woodland now form isolated 'islands' of trees surrounded by vast tracts of cleared land, or low sandplain heath. This has forced hole-nesting birds to concentrate on these areas to breed.

Although there is a great deal of overlap in the size of hollows used by each species, there is a decreasing trend in the order: red-tailed black cockatoos, corellas, galahs and Port Lincoln parrots. The latter three separate on the basis of size (Table 1) while the red-tailed black cockatoos (which are basically the same body size as corellas) separate on the basis of behaviour, since they have very much longer tails and back down into their hollows. In contrast, the other three species enter head first and an individual may use a hollow little larger than itself. Our analyses show that the hollows used by these species may be separated on entrance size and internal diameter of hollow at 0·5 m. The depth of the hollow seems less important, provided that the floor is sufficiently far below the entrance to stop the nestlings from falling out, and to shield them from predators or the elements. Aspect appeared to be unimportant, as found by Saunders (1979*a*) for white-tailed black cockatoos. With regard to the morphology of the trees used by the birds, only those chosen by red-tailed black cockatoos could be easily identified. They nested in far more hollows in dead trees which had entrances in the trunk.

That more than half of the available hollows remain unused each year does not necessarily mean that the availability of hollows is not limiting; the concentration of hollows in one area may pose behavioural problems for some species. Saunders (1979*a*, 1979*b*, 1982) showed that the agonistic interactions between female white-tailed black cockatoos when they were prospecting and preparing nest sites dispersed the birds throughout the available woodland. This effect was seen during this study, when the four pairs foraging together in the area of Nereeno Hill each nested in a separate plot of woodland. Rowley believes that similar forces operate in the Major Mitchell cockatoo, whose nests are normally more than 2 km apart. Galahs are the only cockatoo studied which retain their nest site all year round and defend it for up to 3 m all round the entrance (Rowley 1974, 1980). Both red-tailed black cockatoos and corellas appear to defend only the nest itself, and use the nest sites only for as long as it takes to complete the breeding attempt. To summarize, more corellas and red-tailed black cockatoos probably could have nested in the study area, but it is unlikely that many more galah nests could have been fitted in. Hollows were not a limiting factor for the small numbers of white-tailed black cockatoos and Major Mitchell cockatoos present, both species being near the limit of their ranges.

At present, there are ample nest sites in this woodland, but how long will this situation continue? In addition to this study at Nereeno Hill, we have conducted long-term studies at Moornaming and Manmanning (Saunders 1977*b*, 1979*a*, 1980; Rowley 1980), Mukinbudin (Rowley) and Burakin (Saunders and Smith 1981) (Fig. 1). In these areas, salmon gum is the most important tree for hole-nesting birds, and this is probably true throughout the range of this tree (Fig. 1). At Nereeno Hill it provided 165 of the 173 hollows. Our study revealed that a salmon gum with a circumference at breast height of 0·70 m was the smallest tree which could provide a hollow suitable for use by any cockatoo. Little research has been carried out on the biology of salmon gum, and the only data we could find on growth rates were supplied by Mr N. Caporn of the Western Australian Forests Department at Kalgoorlie. From these we estimate that a tree with a circumference at breast height of 0·70 m would be over 130 years old. The smallest trees in our sample probably predate 1929, when sheep were first introduced. Although these estimates are only rough, one fact is certain, it takes a long time for a salmon gum to grow to a size sufficient to provide a nest hollow for a cockatoo. Unfortunately, at the rate that the trees are deteriorating (Table 5; Fig. 6), few small trees will live long enough to develop hollows.

The bulk of the surviving salmon gum woodland in the agricultural area is in small blocks on private land, or as isolated trees left standing in paddocks, around buildings or along roads. In time these trees will die and there will be no regeneration, as any seeds that do sprout are eaten or trampled by stock or rabbits. The situation is the same in uncleared blocks where stock have access, and has been documented for many other areas (Muir 1979).

The loss of natural woodland poses serious problems for many species of animal but is not a peculiarly Western Australian one. Most agricultural areas in other parts of Australia are in a similar state, whilst both North America and the United Kingdom have the same problem (Conner 1976; Mead 1981). An assessment of the area of woodland surviving in agricultural areas and research into methods of rehabilitating, regenerating or protecting it are urgently needed.

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