Use of tree hollows by Carnaby’s Cockatoo and the fate of large hollow-bearing trees at Coomallo Creek, Western Australia 1969–2013

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A B S T R A C T

The loss of hollow-bearing trees and lack of replacements are important issues throughout the world where development of intensive agriculture has resulted in the reduction and fragmentation of natural woodlands. Many species of animal depend on hollows (cavities) for breeding and shelter, and are impacted by these changes. One such species is the endangered Carnaby’s Cockatoo Calyptorhynchus latirostris, an endemic of southwestern Australia, which nests in large hollows in eucalypt trees. Nest hollow selection by a breeding population at Coomallo Creek, in the wheatbelt of Western Australia, was studied from 1969 to 2013. The cockatoos nested in any hollow large enough to access (mean entrance diameter 270 mm, floor diameter 407 mm and depth 1.24 m). Nesting attempts in shallow hollows (<400 mm) were less successful than those in deeper hollows (>1000 mm). Breeding females returned to the same hollow they used previously, provided they had been successful in the previous breeding attempt and the hollow was not occupied.

During the study, the cockatoos used 252 large hollow-bearing trees. By 2013 40% of these had fallen or been pushed over, had been burnt deliberately or by wildfire, or had been damaged such that they were no longer suitable for use by the cockatoos; an average annual loss rate of 0.91%. Based on this rate of loss, only 29% of large hollow-bearing trees standing in 2013 will be extant in 2125 and not all of these can be expected to offer useable nest hollows. The conservation implications arising from the results of the study are discussed.

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1. Introduction

The biggest threats to terrestrial biodiversity are land use change and habitat conversion. One of the major drivers of these changes is agricultural intensification (McNeely et al., 1995). Throughout the world agricultural intensification has resulted in the reduction and degradation of woodland and forest habitat, including large old trees that support hollows (or cavities) (Fischer et al., 2010). Tree hollows are known to be a limiting resource for a wide range of species dependent on them for breeding and shelter (Newton, 1994). Of particular conservation concern are those species that depend only on large hollows, which typically form over centuries and only in large old trees (Saunders et al., 1982; Mackowski 1984; Bennett et al., 1994; Mawson and Long 1994; Newton, 1994; Gibbons and Lindenmayer, 2002; Gibbons et al., 2002; Marsden and Pilgrim, 2003; Vaughan et al., 2003; Goldingay 2009, 2011; DeMars et al., 2010).

The decline of hollow-bearing trees and the reduced rate of tree replacement in modified landscapes are of growing concern in Australia because 18% of terrestrial bird species nest in hollows in trees and 11% are obligate tree hollow nesters (Saunders et al., 1982). This is twice the percentage of the avifauna of northern America and southern Africa nesting in tree hollows (Saunders et al., 1982). Both of these regions have primary excavators; that is, bird species such as members of the Piciformes which create hollows in trees for nest sites, which other species subsequently use. There are no primary excavators in Australia. While some species such as Rainbow Lorikeet Trichoglossus haematodus, Galah Cacatua roseicapilla and Sacred Kingfisher Halycon sancta have been recorded excavating nest hollows in soft substrates such as the exposed trunk between the bases of the palm fronds (Saunders and de Rebeira, 1993; Higgins, 1999; Forshaw 2002; DAS pers. obs.), most Australian species lack the anatomy and behavioural repertoire to excavate hollows in hardwood trees (Saunders et al., 1982).
Austalian land birds have co-evolved with the Myrtaceous vegetation, particularly those members of the genera Eucalyptus and Corymbia which supply the bulk of tree hollows used by fauna (Saunders et al., 1982; Mackowski, 1984; Mawson and Long, 1994; Gibbons et al., 2000, 2002; Goldingay, 2009, 2011). These hollows are formed by agents of decay such as fungi and termites (Forests Department, 1971; Saunders, 1979a; Mackowski, 1984). Throughout the extensively cleared agricultural areas of southern temperate Australia, hollows are becoming limiting as attrition outstrips replacement of large, hollow-bearing trees (Abensperg-Traun and Smith, 1993; Gibbons and Lindenmayer 2002; Saunders et al., 2003; Manning et al., 2013).

One Australian species dependent on large tree hollows for breeding is Carnaby's Cockatoo Calyptorhynchus latirostris which is endemic to southwestern Australia (Saunders, 1979a). The species has undergone a major decline in range and abundance as a result of changes to land use since European settlement of Australia (Saunders, 1990). It is specially protected as “Fauna that is rare or likely to become extinct” in Schedule 1 of the Western Australian Wildlife Conservation Specially Protected Fauna Notice 2013 under the Wildlife Conservation Act 1950. It is listed as endangered under the Australian Environment Protection and Biodiversity Conservation Act 1999 and under the IUCN Red List category and criteria (IUCN, 2012). This species is also the subject of a recovery plan which has recently been revised (Department of Environment and Conservation, 2012).

The ecology and behaviour of this species has been extensively studied (Saunders and Ingram, 1998; Saunders et al., 2013, 2014 and references therein). One population of Carnaby’s Cockatoo, at Coomollo Creek, on the western edge of the northern wheatbelt, has been studied at various intervals from 1969 to the end of 2013 (Saunders, 1982; Saunders and Ingram, 1998; Saunders et al., 2013, 2014) and the woodland in which it nests has been monitored.

This paper reports on a long-term study of an endangered species dependent on the persistence of large hollow-bearing trees for breeding sites. The results of this study have relevance to the plight of many other hollow-dependent species worldwide. Given our knowledge about agricultural practices throughout the world we predicted that: the availability of large hollow-bearing trees would decline over the study period; the rate of decline of such trees would exceed the replacement rate; that human intervention was the primary agent of tree decline; and that hollows would deteriorate and need renovation to allow continued use.

2. Methods

2.1. Carnaby’s Cockatoo

Carnaby’s Cockatoo is a large, black bird with a conspicuous white tail band. Adult females are about 540 mm long, weigh around 650 g, measure 104 mm across the shoulders with their wings closed and have a long tail (260 mm, about half the body length) (Saunders, 1974; Saunders et al., 1982). Once the birds attain breeding age at four years, they form long-lasting pair bonds, display breeding location fidelity and attempt to breed every year (Saunders, 1982). They return to the breeding area in late winter, select a tree hollow in which to nest and lay one or two eggs, most commonly two and usually move one young. As the birds enter their nests backwards, the hollows must be large enough to allow them to manoeuvre their long tails into the entrance and down into the hollow. The female incubates the eggs for four weeks and hatching to fledging takes 10–11 weeks (Saunders, 1982). Once the fledgling leaves the nest hollow, the family do not return to the hollow that season, but leave the breeding area to join foraging flocks closer to the coast (Saunders, 1980).


2.2. Study area

The 11,855 ha study area at Coomollo Creek (30°08’S; 115°30’E) is located 200 km north of Perth, Western Australia (Fig. 1). The birds breed in a 9 km strip of Wandoon Eucalyptus wandoon woodland. This uncleared, and largely ungrazed (by domestic livestock) woodland strip is virtually an island of breeding habitat surrounded by cleared agricultural land and uncleared Kwongan (sandplain heath) (Pate and Beard, 1984). Some of the original woodland has been cleared for agriculture, but many larger trees have been retained in agricultural paddocks as parkland woodland. The area was settled for farming comparatively recently. In 1959 when the earliest aerial photography was taken, only 10% of the study area had been cleared for sheep farming and cereal cropping (Saunders and Ingram, 1998). At that time, woodland occupied 8% of the study area and was dominated by Wandoow, with small pockets of Powderybank Wandoo E. accedens on the heavier, gravel soils and some York Gum E.ioxophleba on brown, sandy loam soils. Kwongan, where the birds feed on native vegetation, occupied 82% of the study area and was dominated by Proteaceae, particularly members of the genera Banksia, Grevillea, Hakea and Lambertia (Saunders, 1980). Extensive clearing of native vegetation for agriculture took place in the study area in the 1960s, 1970s and early 1980s. By 1996, native vegetation occupied about 35% of the study area (Saunders et al., 2014). This was the situation in the period 2009–2013.

2.3. Hollows used for breeding

The first cockatoo surveys of the area took place in the breeding season of 1969, when the area was visited five times and 12 active (defined as being used for breeding by Carnaby’s Cockatoo) nest hollows were found. The area was visited during 27 breeding seasons between 1969 and 2013. Each time an active nest hollow was found, the species of tree was identified, it was assigned a unique number, its location plotted, and the following dimensions of the hollow taken: entrance width and height (mm); depth (mm) of the hollow from the lowest point of the entrance; aspect of the hollow (vertical, north, north-west, west, south-west, south, south-east, east or north-east); and the height (mm) of the hollow from the ground to lowest point of the entrance. The diameter of the floor (mm) was measured only if it could be reached from the entrance; this precluded measuring the floors of deeper hollows. In addition, attempts were made to check the identity of every female occupying a breeding hollow. Once a tree with a hollow used by a breeding Carnaby’s Cockatoo was marked, the hollow was examined each year until the tree had been destroyed or the hollow was no longer suitable for use.

2.4. Marking of individual Carnaby’s Cockatoo

From 1969 to 1976 inclusive, Carnaby’s Cockatoo adults and nestlings were individually marked with Australian Bird and Bat
Banding Scheme size 21 stainless steel leg bands (rings) and patagial tags. However, while patagial tags allowed individuals to be identified without having to recapture them, the tags proved detrimental to the birds and from 1977 birds were marked with leg bands only (Saunders, 1988). This made it difficult to identify individuals without recapturing them. Since 2009, with advances in digital photography, leg bands have been easy to read using the technique described by Saunders et al. (2011) without having to recapture the birds.

2.5. Mapping of study area

In 1978, the Australian Survey Office (ASO) produced a map of the study area with the locations of all trees known to have been used as nest sites in the period from 1969 to 1977. Early in 2009, staff from the Western Australian Department of Environment and Conservation (DEC) (now Department of Parks and Wildlife) used the ASO map to prepare an electronic version of the map overlain on a DEC photo-mosaic. This map of the area was used
to resurvey the area in 2009 to find all previously recorded hollow trees, including the locations of those no longer standing or which had disappeared completely. During the 2009 breeding season surveys, each extant recorded hollow tree was re-measured as described above. During the 2009–2013 breeding seasons, any newly found trees with active hollows were measured and contents noted.

2.6. Sizes of trees at Coomaloo Creek

During November 2009, the diameter at breast height (dbh) (mm) of every extant tree with a hollow used by Carnaby’s Cockatoo was measured. In addition, the dbh of the 10 trees closest to every tree with an active Carnaby’s Cockatoo nest were recorded. In subsequent years, the dbh of any newly discovered hollow trees used by Carnaby’s Cockatoo was also recorded.

2.7. Repair of damaged tree hollows

During the period 2009–2013 any hollows that had been used by Carnaby’s Cockatoo and were no longer suitable for use were renovated. Repairs carried out included fixing metal sheeting around the sides of hollows where they had been split, inserting sterilised wood chips into hollows where the floor had fallen and was too small or too jagged for use, and removing large shards of wood that had fallen from the inside of the tree and blocked the hollow.

2.8. Wildfire in the study area

On the morning of 29 December 2009, during an extremely hot day (43.5 °C), a fire started on agricultural land to the west of the southern end of the study area. The fire extended 20 km beyond the study area (27,000 ha in total), burning out several patches of Carnaby’s Cockatoo breeding habitat outside the study area (Fig. 1).

3. Results

3.1. Selection of hollows by females

The hollows furthest apart in the study area were separated by 9.0 km; the length of the study area from south to north. The successive nesting histories of 101 marked females (including 15 females of known age) were recorded; these included breeding attempts in successive seasons as well as successive breeding attempts within the same breeding season. Of 197 cases where the next hollow used was known, 43% were in the same hollow, 13% were within 100 m of the previous hollow, 32% were between 101 and 1000 m and 12% greater than 1000 m. Of 267 cases where at least two breeding attempts were recorded, but not in successive attempts, 39% were in the same hollow, 12% within 100 m, 33% were between 101 and 1000 m and 16% greater than 1000 m. Females demonstrated fidelity to nest hollows, where they had bred successfully in the hollow the previous season. Of the 153 successive breeding attempts by individually marked females, the outcome was not known) made by individually marked females (even though not necessarily over successive breeding seasons), 53.3% were made in the same hollow or one within 100 m of the earlier hollow and 85.5% were within 1000 m of the earlier hollow.

3.2. Distance between hollows from which a female fledged and her breeding hollows

Breeding data are available on 15 females that fledged in the study area. The mean distance between the hollow from which they fledged and the one in which they were first recorded breeding was 2.19 ± 1.92 km (range 0.05–5.90 km). When recorded breeding first, five were four years old, three were five, one was six, two were seven, and one each were eight, 10, 19 and 26.

3.3. Characteristics of hollows

At Coomaloo Creek, two species of tree provided hollows used by Carnaby’s Cockatoo, with Wandoo providing the majority of hollows (228 or 98.7%) compared with Powderbark Wandoo (3). An additional 21 trees were first encountered as dead stags and could not be identified to species level. Twelve breeding attempts were made in Powderbark Wandoo, compared with 1281 in Wandoo. The dimensions of hollows used by Carnaby’s Cockatoo at Coomaloo Creek 1969–2013 and the tree that contained them are shown on Table 1.

Of 221 breeding hollows for which data on aspect of the hollow were recorded, 58% opened vertically. With the other 42% there was no significant departure from a random grouping of entrances around the eight compass classes (Table 2) \((\chi^2 = 9.33, \text{df.} = 7, \ p = 0.32)\). From our data, it is apparent that females selected hollows regardless of aspect in proportion to the availability of hollows (Table 2). Choice of aspect did not seem to confer any advantage in breeding successfully \((\chi^2 = 9.24, \text{df.} = 8, \ p = 0.32)\).

3.4. Use of hollows

The average number of hollows available for Carnaby’s Cockatoo each year from 1974 to 2013 was 146 (Table 3). Data from 1969 to 1973 have been excluded as the area being searched was being expanded in that period. Between 1974 and 2013, Carnaby’s Cockatoo used on average 32% of available hollows annually (range 9–47%).

3.5. Competition for hollows

Nine other species were recorded breeding in hollows used by Carnaby’s Cockatoo (Galah; Western Corella Cacatua pastinator; Regent Parrot Polytelis anthopeplus; Barn Owl Tyto alba; Nankeen Kestrel Falco cenchroides; Southern Boobook Ninox novaeseelandiae; Australian Ringneck Barnardius zonarius; Laughing Kookaburra Dacelo novaeguineae; and European Honey Bee Apis mellifera (Table 3)). On average 10% (1–18%) of available hollows were used annually by species other than Carnaby’s Cockatoo.

3.6. Change in depth of hollows

We examined the change in depth of 95 hollows over periods of up to 41 years. The average was a fall of 29 ± 66 mm/year (range +49 mm/year to −120 mm/year). The floor of one hollow rose by 1800 mm over 37 years and another fell by 4400 mm over 38 years, but the floor was then too narrow to be used by Carnaby’s Cockatoo.
3.7. Status of hollow-bearing trees

A total of 252 hollow-bearing trees used by Carnaby's Cockatoo were recorded between 1969 and 2013. By the 2013 breeding season, 40.1% of trees had been lost or damaged in such a way that they no longer had a large hollow suitable for use by Carnaby's Cockatoo (Table 4). Of the extant trees, 22.2% had hollows in good condition and suitable for use by Carnaby's Cockatoo.

3.8. Sizes of trees surrounding nest trees

There were 39 large hollow-bearing trees in use by Carnaby's Cockatoo in November 2009 when measurements were made of their ten nearest neighbouring trees. Seventeen of these were in uncleared native vegetation and 22 were in paddocks. There was no significant difference in the mean size (dbh mm) of hollow trees in the bush (dbh 536 ± 81; range 370–660) and in the paddocks (585 ± 113; 410–920) (t-test; p = 0.11). Examining the 10 nearest neighbouring trees to each of the occupied hollow trees revealed that there were significantly more larger, neighbouring trees in paddocks (mean 301 ± 136; 50–835; N = 220) than in the bush (211 ± 134; 59–775; N = 170) (t-test; p = 0.000).

3.9. Damage to woodland by fire

There were 28 nest trees in the path of the wildfire of 29 December 2009. More than half of these were destroyed (Table 5). Three hollows contained Carnaby's Cockatoo nestlings at the time.
of the fire; all were killed. There was no significant difference in the fate of trees situated in paddocks and uncleared vegetation ($\chi^2 = 0.44$, df $= 1$, $p = 0.51$).

3.10. Use of renovated hollows

Forty-eight hollows (19.0% of hollow trees marked) (Table 4) were repaired by us because of damage that rendered them unusable or of marginal use. The hollows were not renovated in a systematic way, but only when time permitted. Fifteen of these hollows were used at least once in 2012 or 2013 and a further 15 were used in both years.

4. Discussion

We have reported on the results of a 44-year study at Coomallo Creek, focused on Carnaby’s Cockatoo, which is an endangered and endemic bird species dependent on large hollow-bearing eucalypts in southwestern Australia. Our results highlight: the loss of large hollow-bearing trees; the lack of replacement of these trees; and the long-term nature of potential solutions to the conservation problems posed by these detrimental changes. Our findings have relevance over a much greater area than southwestern Australia, including much of Australia, as well as many other regions around the world where forest and woodland have been lost and fragmented by clearing and elements of the biota are dependent on hollow-bearing trees for breeding (Connor, 1976; Saunders, 1979a; Sedgwick and Knopf, 1986; Lindenmayer et al., 1990; Abensperg-Traun and Smith, 1993; Bennett et al., 1994; Newton, 1994; Yates and Hobbs, 1997a,b; Gibbons and Lindenmayer, 2002; Gibbons et al., 2002; Marsden and Pilgrim, 2003; Saunders et al., 2003; Vaughan et al., 2003; Manning et al., 2004; Harper et al., 2005; Maron, 2005; Manning et al., 2006, 2013; Murphy and Legge, 2007; Gibbons et al., 2008; DeMars et al., 2010; Fischer et al., 2010; Goldingay, 2009, 2011; Weinberg et al., 2011).

### 4.1. Hollow selection and use

Up to 1996, 14 females banded as nestlings at Coomallo Creek returned to their natal area to breed within a distance of 50 m to 5.9 km from their natal hollow. No males banded as fledglings have been recorded breeding in their natal area. This indicates that it is likely that females retain site fidelity to their natal area. However it should be noted that males are difficult to identify as part of a pair in a breeding attempt because they need to be recorded actually entering the hollow or mating with or feeding a female associated with a breeding hollow. From 2009 we have identified most of the banded breeding females. In 2013, while three females from the 2009 fledgling cohort attempted to breed in the area; none of the 2009 male fledgling cohort was seen in the area. If one sex, in this case apparently females, displays stronger philopatry, this may assist in preventing inbreeding (Greenwood, 1980).

It is clear that over successive breeding seasons female Carnaby’s Cockatoo will favour the same hollow they used the previous season, provided they were successful the previous year and the hollow is not occupied when they return. Females select hollows in proportion to availability and not on the basis of any preferences for particular tree species. This was also true of three other populations breeding in areas with other species of dominant eucalypt (Saunders, 1979a,b).

Our results indicate that Carnaby’s Cockatoo does not demonstrate any preference for species of tree in which to nest, nor for hollows with particular aspect (Table 2). Basically they will nest in any hollow provided it is large enough for them to access. While the birds appear to need a hollow that was deep enough so that the contents are shielded from sight and to prevent the nestlings from falling out, birds using shallow hollows (<400 mm) were less successful than those using deeper hollows (>1000 mm). We have seen occasions where birds in shallow hollows were poorly protected from rain and cold winds, which may contribute to the higher failure rates.

Eight other species of bird nested in the hollows used by Carnaby’s Cockatoo at Coomallo Creek (Table 4). Galahs were the most common nest competitor and are a potential threat to breeding Carnaby’s Cockatoo. They have been recorded as entering active Carnaby’s Cockatoo hollows and smashing eggs (Saunders, 1982). This is not a major threat at Coomallo Creek where food is apparently not limiting the Carnaby’s Cockatoo population and the females seldom leave the vicinity of the nest tree when incubating eggs and brooding young (Saunders, 1982). Western Corella breeding attempts were half those of Galah and have changed little over the past 40 years despite both Galah and Western Corella

### Table 4

Status of large hollow-bearing trees used for breeding by Carnaby’s Cockatoo 1969–2013.

<table>
<thead>
<tr>
<th>Year</th>
<th># Hollows marked</th>
<th>Good condition 2012</th>
<th>Needed repair 2012</th>
<th>Been repaired that year</th>
<th>Bulldozed</th>
<th>Burnt</th>
<th>Fallen over</th>
<th>Top broken off</th>
<th>Disappeared</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>13</td>
<td>3</td>
<td>0</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1970</td>
<td>43</td>
<td>4</td>
<td>9</td>
<td>11</td>
<td>8</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>1971</td>
<td>23</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>1972</td>
<td>36</td>
<td>7</td>
<td>10</td>
<td>8</td>
<td>2</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1973</td>
<td>27</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>2</td>
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<td>9</td>
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<td>0</td>
<td>0</td>
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<td>4</td>
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<td>1976–96</td>
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<td>2</td>
<td>6</td>
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<tr>
<td>2009</td>
<td>23</td>
<td>8</td>
<td>4</td>
<td>8</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
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<tr>
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<td>2012</td>
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<td>3</td>
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<td>0</td>
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<td>0</td>
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</tr>
<tr>
<td>2013</td>
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<td>28</td>
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<td>14</td>
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</tr>
<tr>
<td>%</td>
<td>22.2</td>
<td>18.7</td>
<td>19.0</td>
<td></td>
<td>11.1</td>
<td>13.5</td>
<td>5.6</td>
<td>6.7</td>
<td>3.2</td>
</tr>
</tbody>
</table>

### Table 5

Number of large hollow-bearing trees in the area burnt in the fire of 29 December 2009. The numbers of trees in paddocks and in uncleared, ungrazed woodland (bush) are indicated.

<table>
<thead>
<tr>
<th>Year</th>
<th># In bush</th>
<th># In paddock</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>12</td>
<td>16</td>
<td>28</td>
</tr>
<tr>
<td>1971</td>
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<td>6</td>
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<td>1972</td>
<td>6</td>
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<td>16</td>
</tr>
<tr>
<td>1973</td>
<td>50</td>
<td>63</td>
<td>57</td>
</tr>
</tbody>
</table>
expanding their ranges in the agricultural area of Western Australia and increasing in numbers during that period (Saunders and Ingram, 1995; Barrett et al., 2003). In large numbers, at another location, corellas have been recorded impacting on breeding attempts by Carnaby’s Cockatoo (Saunders and Doley, 2014). However, at present, the corella population at Coomallo Creek is not large enough to pose problems for Carnaby’s Cockatoo. European Honey Bees also pose problems for Carnaby’s Cockatoo, swarming into hollows, and have been recorded causing failures of eggs and death of nestlings (Saunders, 1982). While the number of hollows impacted was low, bees have the capacity to take over a hollow and remain in it for several seasons, rendering the hollow useless for other species. Bee hives were often transient in nature, being established in late Austral winter and early spring, but failing by early summer and being absent in drought years, such as occurred in 2010.

Saunders and Ingram (1998) discussed changes in breeding attempts at Coomallo Creek to 1996. By 1996 the number of attempts had dropped to less than half that in the early 1970s, almost certainly as a result of clearing of native vegetation, particularly of Kwongan heath on which the birds feed. Between 2009 and 2013 the number of breeding attempts had risen; why? Using data from Table 3, and assuming the success of all breeding attempts that were still active during the final visit for the breeding season, and that only single nestlings were fledged, Carnaby’s Cockatoo fledged 0.78 of a young/breeding attempt. No data are available on how many survive to breed or how many of these return to their natal area to breed, but it is highly unlikely that the increase of eight breeding attempts in natural tree hollows between 2009 and 2012 was due to natural increases in the population. The fire of 29 December 2009 destroyed known Carnaby’s Cockatoo breeding habitat outside the area of woodland studied (Fig. 1). One female provides evidence that these increases in breeding attempts may have been the result of the influx of birds displaced from habitat destroyed by the fire. Female with leg band 210–01790 fledged from Tree 184 in the breeding season of 1986. In September 2012 this female was incubating two eggs in Tree 352, 912 m from the hollow from which she fledged. She had not been seen in the study area since she fledged. Since 2009, the legs of every female flushed from a hollow have been checked using Saunders et al.’s (2011) technique and this individual was not recorded before September 2012. We are confident that if she had been breeding in the study area between 2009 and 2011 she would have been recorded.

4.2. Changes in hollows over time

While the height above ground of hollows changes little over time, entrances and depths do. For example, a hollow with a side entrance may change to have a vertical aspect when the top of the tree breaks off (Fig. 2). Hollows may change in depth as shown by a mean fall of hollow floors of 29 mm/year. These changes may be incremental or may happen suddenly and are the result of compression of rotten heartwood as the tree is buffeted by wind, or because a crack below floor level allows the rotten material to leak out. In some cases this may result in the hollow becoming unsuitable for use by Carnaby’s Cockatoo as the floor area becomes too small or exposes a series of jagged wooden spikes. In these cases, the hollow is useless unless material drops into the hollow (which may happen if rotten heartwood above the cavity is dislodged) or the birds are able to chew protruding spikes away to level the floor. Hollows may also become shallower over time as the result of material being dislodged from the trunk above the hollow entrance. This may lead to failure if a large amount of rotten heartwood falls while the birds are breeding in the hollow, which has happened at Coomallo Creek.

4.3. Fate of large hollow-bearing trees

By 2013, for a variety of reasons, of the 252 large hollow-bearing trees recorded as being used by Carnaby’s Cockatoo since 1969, 40.1% no longer contained hollows suitable for use by the cockatoo (Table 4). This equates to an annual average rate of loss of 0.91%. There are several causes for these losses; wind throw/tree fall, fire (deliberate or wildfire), removal as part of agricultural activities or due to parts of the tree breaking off. This annual rate of loss is similar to that recorded in other parts of Australia (Heinsohn et al., 2003; Saunders et al., 2003; Goldingay and Stevens, 2009) and elsewhere (Walling et al., 2001; Vaughan et al., 2003), but is at the lower end of the reported rates of loss of nest trees from those other studies.

In parts of the study area, some large trees were left in paddocks and many of their former neighbours removed. It is possible these trees are more prone to wind throw than those in the unclered areas because they lack the protection neighbours offer in dissipating wind exposure (Harper et al., 2005). Between 1969 and 1975, 184 large hollow-bearing trees were identified; 7.6% had fallen by the end of 2013. While tree fall is not a steadily incremental loss, the average fall rate over the study period may be used to predict how many of the 141 large hollow-bearing trees standing at the end of 2013 would be still standing by the end of 2125. Taking natural causes into account, 80.1% would be standing at the end of 2125. Taking human actions such as agricultural clearing and fire...
into account, 37.5% of the 184 1969–1975 cohort were lost. Sixteen of these were lost in the fire of 29 December 2005, so the bulk of these were lost due to agricultural activities. Once again, these are not incremental changes; clearing happens periodically (Table 4), as does wildfire. While the wildfire of 29 December 2005 was the first that damaged any of the woodland in living memory, the extreme weather conditions of the day are predicted to occur more frequently. Hennessy et al. (2008, page 28) reported that “in southwest WA (SW WA), the frequency and areal extent of exceptionally hot years and exceptionally dry years are likely to increase in the future... The mean projections indicate that: by 2010–2040, exceptionally hot years are likely to affect about 80% of the region, and occur every 1.2 years on average; by 2010–2040”. The risks of wildfire damage to woodland may increase should these predictions prove correct. In fact, there was another fire on 8 January 2014 in the southern part of the study area. It burnt out 5.7 ha of agricultural land and 7.4 ha of Wandoo woodland before it was brought under control. Fortunately it did not destroy any hollow-bearing trees.

Using the average annual rate of loss (0.91%) of trees from tree fall, agricultural clearing and wildfire to the end of 2013, only 29.1% of the 141 trees will be standing by the end of 2125. This is more positive than the figures for a patch of Salmon Gum woodland in the northern wheatbelt of Western Australia where only 11% were predicted to be alive by 2125 (Saunders et al., 2003). Although a large hollow-bearing tree may be standing 112 years in the future, internal changes to any hollows it bears may have rendered them unsuitable for cockatoos. As a result the loss of hollows may be more severe than indicated by the loss of trees.

There were many small Wandoo trees in the study area, the majority of these being in uncleared native vegetation. Some of these are in patches, indicating regeneration following some disturbance, most likely from fire (Yates et al., 1994). There is little knowledge of the ages of these small Wandoo, but other than the wildfires on 29 December 2009 and again on 8 January 2014, there have been no fires through the woodland in living memory (R. Raffan pers. comm.) and so the trees are over 60 years old. Saunders et al. (1982) suggested that it took at least 130 years for a Salmon Gum Eucalyptus salmonophloia to be large enough to have a hollow of sufficient size for black cockatoos. Mawson and Long (1994) stated that the lowest average estimated age of Salmon Gum nest trees they recorded for cockatoos was 446 years with a standard deviation of 222 years and 346 ± 221 years for Wandoo used by Regent Parrot. Regardless of whether one takes the age suggested by Saunders et al. (1982) or Mawson and Long (1994), it is going to be a long time before the small Wandooos will be large enough to support a hollow suitable for a Carnaby’s Cockatoo. What is certain is that large hollow-bearing trees are being lost from Coomallo Creek faster than they are being created.

4.4. Conservation implications

All remaining woodland should be retained and protected, both in areas of uncleared vegetation and where they exist in parkland clearing. In addition, woodland revegetation should take place. Little is known about disturbance regimes resulting in regeneration of Wandoo (Yates et al., 1994), but Wandoo does regenerate after fire and the fire of 29 December 2009 may result in regeneration. Such regeneration will need protection from grazing by domestic livestock, and feral and native herbivores (Shephard et al., 1997; Wann and Bell, 1997). Unfortunately this may not be possible in paddocks with parkland clearing as under the current regime, trees in paddocks are not being replaced, as indicated by their larger average size compared with those in bushland. This will result in the loss of substantial numbers of large hollow-bearing trees and the younger cohorts.

This loss of trees means that management is necessary to prolong the life of hollows in extant trees. Several large hollow-bearing trees used by Carnaby’s Cockatoo were dead in 1969 and have superficially changed little over the period since then (Fig. 2). However the hollow within may have changed and without maintenance may be unsuitable for use. The life of such hollows may be extended by raising their floors so they are large enough for reuse and approximately 1000 mm below the entrance. The filler used in such repairs will need to be clean and free of pathogens such as the plant dieback disease Phytophthora cinnamomi. Other hollows may need repairs to the sides to stop heartbeat falling out or exposing the floor to wind and rain.

The provision of artificial nesting hollows (boxes) is one obvious management solution (McComb and Noble, 1981; Brawn and Balda, 1988; Tweedt and Henne-Kerr, 2001) and one that is being trialled at Coomallo Creek. The results of this experiment will be reported elsewhere.

Who undertakes hollow maintenance and who pays? Without regular maintenance hollows will be lost at a rate that is unsustainable. One obvious source of maintenance is the owner of the property on which the woodland occurs. In the case of nature reserves, national parks and other designated conservation areas, this should be the responsibility of the managing agency. In the case of private property, as at Coomallo Creek, one of the most productive areas for breeding Carnaby’s Cockatoo, it could be the property owner. However, this is a duty of care beyond which society should expect of land-holders without adequate compensation. One obvious incentive is payment directly for services to conservation.

Without stronger protection of woodland, maintenance of extant large hollow-bearing trees, renovation of existing hollows, and encouragement of regeneration and revegetation of woodland, the future for hollow nesting species in Australia’s temperate woodlands is bleak.

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