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Factors influencing nest-site occupancy and low reproductive output in the Critically Endangered Yellow-crested Cockatoo *Cacatua sulphurea* on Sumba, Indonesia

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Summary

We studied nest-site selection and nesting success in the critically endangered Yellow-crested Cockatoo *Cacatua sulphurea* throughout a breeding season in Manupeu-Tanadaru National Park, Sumba. Within a 6 km^2 study area, which supported about 60 birds, cockatoos displayed disproportionate interest in cavities in trees containing other active nests, and cavities already actually occupied by parrots or owls. Actual nesting attempts were made at only eight cavities, and a single chick fledged. Interspecific interactions were observed at every one of these nests. Breeding activity was negatively correlated with monthly rainfall, which was the heaviest for at least 10 years, and it is possible that adverse weather conditions disrupted cockatoo nesting this season. Whether this is the case or not, our study shows how low reproductive output can be in the species and this has serious implications for survival of the population on Sumba.

Introduction

The Yellow-crested Cockatoo *Cacatua sulphurea* has suffered catastrophic population declines across its range in Indonesia and Timor Leste. Unsustainable exploitation for trade, habitat loss, fragmentation and degradation are all thought to have contributed to its decline and the species is currently classified as Critically Endangered (BirdLife International 2001). The Yellow-crested Cockatoo was fully protected under Indonesian law in 1997 (Ministerial Decree Keputusan Menteri Kehutanan No. 350//Kpts-11/1997) although some illegal capture continues (PHPA/LIPI/BirdLife International 1998).

The species' current strongholds are the Komodo National Park (subspecies: *C. s. parvula*) and Sumba (10°S 120°E) in Nusa Tenggara Timur where the distinct and endemic subspecies, the Citron-crested Cockatoo *C. s. citrinocristata*, occurs (PHPA/LIPI/BirdLife International 1998). Forest loss on Sumba has been acute in recent years and less than 10% of the island is currently forested (Sujatnika *et al.* 2000). The remaining forest occurs as 34 forest blocks, nearly half of which are smaller than 500 ha (O'Brien *et al.* 1997).

Research on the species has focused on abundance, habitat use and nest-site selection of the population on Sumba. The subspecies there has a distinct preference for undisturbed forest <500 m above sea level (m.a.s.l.) (Jones *et al.* 1995) and is patchily distributed across the island, being absent from, or rare in blocks <1,000 ha (O'Brien *et al.* 1997). It also has strong nest-site preferences; Marsden and Jones (1997) found nest-cavities to be located high up ($\bar{x}$ = 22 m) in very large ($\bar{x}$ = 37 m tall) deciduous trees and suggested that local population densities might be strongly influenced by the availability of suitable, safe nesting sites. Better understanding of nest-site requirements and of the factors that affect recruitment is essential for the long-term conservation of the Yellow-crested Cockatoo (PHPA/LIPI/BirdLife International 1998, Snyder *et al.* 2000).

Our aim was to investigate the importance of nest location and characteristics in nesting success of the Citron-crested Cockatoo on Sumba (hereafter referred to as the cockatoo). Nest use was, however, very low during the field season. Consequently, this paper documents the low productivity within the area's cockatoo population and discusses whether this low reproductive output is unusual and possible factors associated with it.

Methods

Study sites

We conducted research at four forest sites: two situated in West Sumba, and two in East Sumba (Figure 1). Two of these sites were located within the 87,984 ha Manupeu-Tanadaru National Park (MTNP). Manupeu (09°40′30″S; 119°30′00″E; 200–450 m a.s.l.) is a semi-deciduous monsoon vine forest (Banilodu and Saka 1993)

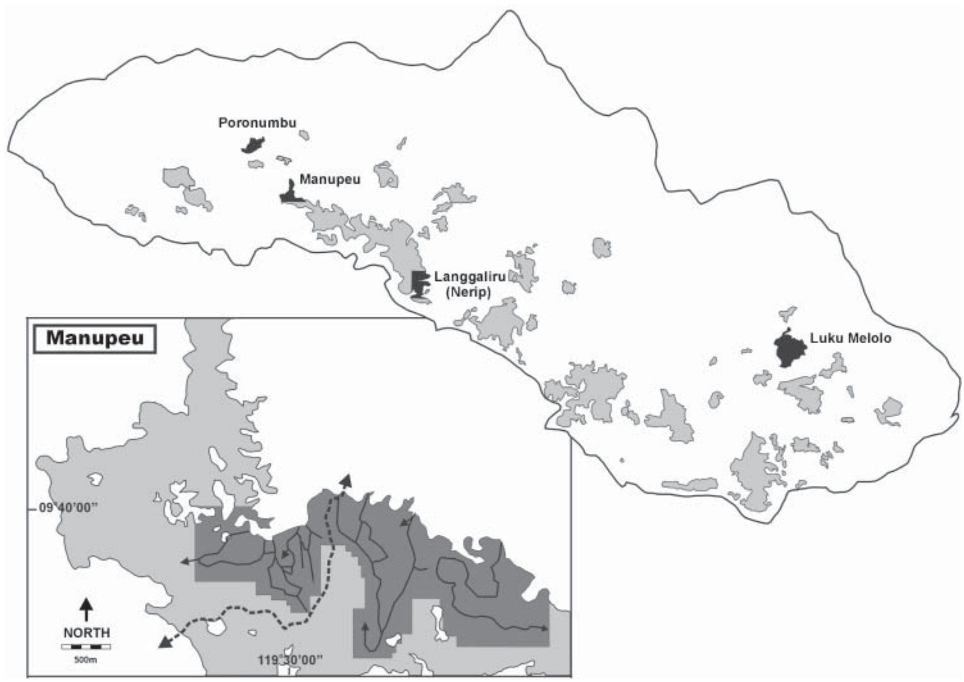

Figure 1. Map of Sumba showing remaining forest cover and the location of our four study sites. Inset: the Manupeu locality and our study area (dark grey shaded). The network of major trails are shown (black lines) and the position of a river that bisected the study area (dashed line).

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in the western end of MTNP within West Sumba, while Langgaliru (09°49′30″S; 119°45′00″E; 405–620 m a.s.l.) is monsoon vine forest (Banilodu and Saka 1993) in the eastern end of MTNP within East Sumba. We also visited two isolated forest blocks: Poronumbu (09°33′30″S; 119°25′00″E; 550–800 m a.s.l.), a 907 ha block of sub-climax rain forest (Banilodu and Saka 1993) in West Sumba; and Luku Melolo (09°58′30″S; 119°30′30″E; 200–600 m a.s.l.), a 7,747 ha block of evergreen and semi-deciduous monsoon vine forest in East Sumba (Banilodu and Saka 1993). Manupeu was our focal site and where all nest monitoring was conducted. Cockatoo surveys were undertaken at Manupeu in February and March 2002 (Cahill *et al.* in press). A point-count distance sampling method, involving 135 point-counts, yielded a density at Manupeu of 9.9 individuals per km^2 (95% CI 5.3–18.4). The three other sites were visited briefly to determine cavity availability and to measure vegetation parameters.

Monthly rainfall and temperature data were obtained for 1991–2002 for representative sites in West and East Sumba (Dept. of Agriculture and Dept. of Meteorology). We compared the 2002 rainfall data with data from these years. East and West Sumba share the same wet season, October–April, although annual rainfall is significantly greater in West Sumba (9 year annual mean = 2424 mm and 894 mm respectively; $t = 10.6$, $df = 16$, $P < 0.001$).

Breeding success

We conducted research in Manupeu on cockatoo breeding success during the bird's September 2001 to May 2002 breeding season. We hired former parrot-trappers to lead us to known cockatoo nest-cavities within a 600 ha study area. To find additional nests we searched the study area by walking 18 km of available trails (Figure 1), leaving the trail each time a cockatoo was heard, or a likely area for nesting was encountered. The whole of the 18 km trail system was covered at least once every fortnight over a 6 month period (i.e. at least 12 times in total). When cockatoos were seen or heard, we attempted to locate the birds and searched for a potential nest-cavity. Activity at potential nest-cavities was monitored on a monthly basis. We conducted observations between 07h00 and 12h00 that lasted approximately 40 minutes during which we recorded the presence and activity of cockatoos. The level of cockatoo activity at each nest was determined by checking the cavities from the ground. The level of cavity use was determined by quantifying the number of occasions pairs were recorded at the cavities and most importantly entering cavities, but included courtship behaviours, copulations etc. In addition, we climbed using ropes and a harness to 18 of these cavities and monitored their contents using a miniature camera with internal infrared light source. Fifteen of these were either in trees of historic cockatoo activity or in cavities that ex-trappers informed us cockatoos had used as nest-sites in the past 5 years. To reduce any possibility of abandonment through disturbance prior to eggs being laid, we did not climb to nests until a female had been seen to enter a cavity and stay inside for prolonged periods, indicating she was potentially incubating eggs. From systematic watches of active cockatoo nests we identified the time of day nests were usually left unattended (approximately 09h000–14h00) and we only climbed during these times. We undertook more thorough observations of seven focal nest-trees between September 2001 and March 2002 and recorded any inter- or intra-specific interactions. Each nesting attempt was watched 1 day every week for 9 hours over

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three equal time periods: morning (06h00–09h00), midday (10h00–13h00) and afternoon (14h00–17h00).

Characteristics of nest-sites

For each cavity-containing tree, we measured the height of the cavity above ground, the angle to vertical of the cavity entrance, the size of cavity entrance and existence of other cavities within the tree (following Marsden and Jones 1997). Around each focal cavity-containing tree, we established plots that included the nearest nine trees of diameter at breast height (dbh) ≥0.20 m. We searched for and measured cavities in these trees. All trees were identified to species and dbh measured. The architecture of each tree was described following Jones *et al.* (1995): trees that have their first major branch above half their height have generally grown up under a closed canopy (primary forest architectures), while those branching below half their height are associated with recently disturbed forest areas. Trees branching above half their height but with scars from major branches are recognizable as being associated with regenerating areas. In each plot we measured the heights of the two trees with the largest dbh using a clinometer and estimated the heights of the remaining eight trees. In order to quantify disturbance, we noted the number of fallen trees within a 30 m diameter circle around the plot centre and the cause (anthropogenic or natural). We also established 120 random vegetation plots in the four areas. We measured vegetation at these plots in the same manner as at nest-tree plots, and considered the 10 trees nearest to the plot's central point.

Statistical analysis

All variables were tested for normality using one-sample Kolmogorov–Smirnov tests and data transformed if appropriate. Standard parametric tests or non-parametric equivalents were used throughout, with the exception of the method used to investigate the relationship between monthly cockatoo nesting activity and temperature. These data are autocorrelated (sequentially non-independent) and, as sample sizes were small ($n = 7$ months), we investigated the relationship between weather and cockatoo nesting activity using a randomization test. We first standardized both variables to mean zero then calculated the mean monthly difference (MD) between the variables. If the monthly patterns of the variables were identical, the MD would equal zero, and the greater the departures from zero, the greater dissimilarity in monthly pattern between activity and temperature. The significance of the MD values over the study period was tested against temporally randomized models. This was achieved by holding the monthly temperature constant whilst randomizing the monthly order of cockatoo activity data. The 'randomized model' MD was then re-calculated. This procedure was replicated 1,000 times. The 95%, 99% and 99.9% confidence intervals (CI) were calculated for the distribution of the 1,000 MD values, and the relative value of the original MD value was examined with respect to these parameters. An MD value below the lower CI indicated a significantly similar pattern between monthly activity and temperature than random; a value greater than the upper CI indicated a significantly negative relationship between activity and temperature than expected by chance alone.

Results

Weather conditions during the study

Rainfall during our study was atypical of the previous decade. In West Sumba, rainfall between January and April was higher than monthly averages over the previous 10 years, and higher than the historic maximum in January, March and April. Rainfall during this 4-month period (2367 mm) was 63% greater than 'normal' (1,449 mm). Concomitantly, average monthly temperatures for these same months were 2.5–3.5°C lower than historic values. Mean monthly temperature and rainfall were significantly negatively correlated ($r = -0.98$, $P < 0.001$). During the 2001–2002 breeding season monthly rainfall in East Sumba, unlike the rainfall in West Sumba, differed from historic patterns during only January and March. Conversely, during the 3 months of extraordinarily high rainfall in West Sumba, East Sumba received significantly less rainfall than the historic average.

Nest checking behaviour and phenology

Levels of cockatoo nesting activity peaked in October (Figure 2). Cockatoo activity at cavities was significantly linked to warmer and drier weather conditions as the observed relationship between cockatoo activity and ambient temperature (MD = 0.307) was significantly lower than the 99.9% CI of the randomized models (mean = 0.330; lower 99.9% CI = 0.328, upper 99.9% CI = 0.333). When cockatoos were initially observed pair-bonding, cavity checking and mating in September/October, rainfall was within the normal monthly range. The drop in activity in November was consistent with a drop in temperature that month; increased activity in

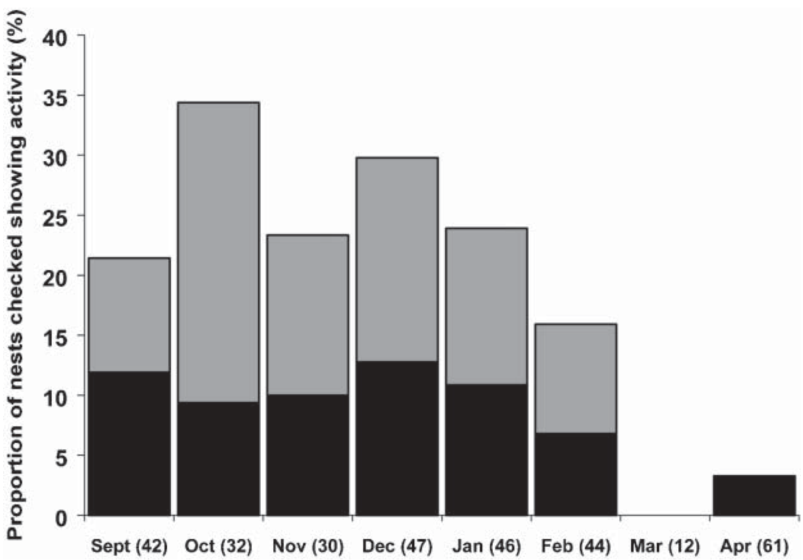

Figure 2. Monthly patterns of cockatoo activity at cavities in Manupeu. Cavities with activity were categorized as observations of either a bird inside the cavity (black) or a bird perched at the nest entrance or "checking" the nest from outside (grey). Values in parentheses are the number of nests checked; data are not included for March as the sample size was very small.

December corresponded with an increase in temperature to seasonal norms. After December, activity declined steadily to April with decreasing temperatures and increasing rainfall.

Nest uptake and success

We monitored 62 cavities for cockatoo activity; 33 were historic cockatoo nests and eight historic nest-sites of the Eclectus Parrot *Eclectus roratus*, of the Great-billed Parrot *Tanygnathus megalorynchos*, or both. The remaining 21 trees were 'new locations', identified from observations of potential activity, such as birds in or near the cavity or clearing small branches around the cavity entrance. Twenty-four cavities were checked by cockatoos, 14 at historic cockatoo nest-sites, one at an historic Eclectus Parrot nest-site and nine at locations new to this study. At 16 cavities (see below) cockatoo activity was witnessed on a single, or rarely two occasions. Cockatoos were repeatedly present at eight cavities (13% of all nest-sites monitored and 33% of sites where any cockatoo breeding behaviour was recorded), which we considered potential nesting attempts. At the end of fieldwork in May 2002, after 9 months of monitoring cavities in western MTNP, we recorded only one successful cockatoo nesting attempt. This nest fledged a single chick.

Nest-site selection

Nest checking and nesting attempts were observed in five of the 66 tree species recorded within the vegetation plots. Nineteen of 24 trees where these behaviours were observed were either *Chisocheton* sp. ($n = 14$) or *Tetrameles nudiflora* ($n = 5$); however, *Chisocheton* sp. was more common than *T. nudiflora* (38 vs 11 of the 500 trees sampled in vegetation plots). Other identified tree species used were *Aglaia ensiderexylon* ($n = 1$) and *Palaquium* sp. ($n = 2$). Of 49 historic nests identified by former parrot-trappers, 20 were in *T. nudiflora*, 16 in *Chisocheton* sp., 16 in *Palaquium* sp. and 10 in *A. ensiderexylon*. The smallest tree in which we observed interest by cockatoos was dbh ≥0.68 m and we regard this size as the minimum tree size acceptable to cockatoos. To establish nest-tree preference, we calculated expected numbers of nests in each of these four species from the frequency of trees dbh ≥0.68 m in the 500 trees sampled in 50 vegetation plots. Cockatoos had a strong preference for both *T. nudiflora* and *Chisocheton* sp. ($G_{adj} = 80.6$, $df = 1$, $P < 0.001$), with *T. nudiflora* the most preferred nest-tree species.

Nest-trees had significantly larger dbhs ($\bar{x}$ = 1.40 m vs 0.82 m; $t = 6.19$, $df = 72$, $P < 0.001$) and were taller ($\bar{x}$ = 48.7 m vs 42.6 m; $t = 3.19$, $df = 48$, $P < 0.01$) than the largest of the 10 trees in each of the 50 random vegetation plots. Trees of a size that cockatoos preferred as nest-sites (dbh ≥1.16 m, $n = 8$) were uncommon (*c.* 7 ha^{-1} or 1.2% of the 500 trees sampled). Suitably sized individuals of *Chisocheton* sp. were rare (*c.* 2 trees ha^{-1}; or just 2 of the trees sampled) and *T. nudiflora* of this size were not recorded among the 500 trees sampled.

A significantly lower proportion of trees in the nest plots branched below half their height than in the random plots ($\bar{x}$ = 0.27 vs 3.62 trees per plot respectively; $t = 2.67$, $df = 67.1$, $P < 0.01$), indicating that trees in nest plots had grown up in forest of a more primary nature than those in random plots. In contrast, nest plots had suffered greater recent disturbance than random plots; natural disturbance was significantly higher

Table 1. Relative frequency of the four main nest-tree species at Manupeu across Sumba.

	Manupeu		Luku Melolo		Poronumbu		Langgaliru	
n:	500		280		200		220	
dbh:	≥.02	≥1.16	≥.02	≥1.16	≥.02	≥1.16	≥.02	≥1.16
Tetrameles nudiflora	2.2	0.0	5.0	0.0	0.5	0.0	3.2	0.5
Chisocheton sp.	7.6	1.2	0.0	0.0	3.5	0.5	0.0	0.0
Aglaia ensiderexylon	5.0	0.4	4.3	0.0	1.0	0.5	5.5	0.0
Palaquium sp.	8.6	0.0	2.5	0.0	16.5	0.0	4.1	0.0
Total	23.4	1.6	11.8	0.0	21.5	1.0	12.7	0.5

Values represent the percentage of all trees within vegetation plots (dbh ≥0.2m) and trees of a size in which all 'serious' nesting attempts were made (dbh ≥1.16m). The total is the percentage of trees sampled that were suitable nest-tree species (four identified at Manupeu).
dbh, diameter at breast height.

in nest plots than random plots ($\bar{x}$ = 1.91 vs 0.72 trees per plot; $t = 2.36$, $df = 33.3$, $P < 0.05$) and anthropogenic felling was also higher, but not significantly so ($\bar{x}$ = 2.96 vs 2.00 trees per plot respectively; $t = 1.92$, $df = 71$, $P = 0.06$).

The distribution of preferred nest-tree species was disparate across the four study sites. The most frequently used nest-tree at Manupeu, *Chisocheton* sp., was present in Poronumbu but was not recorded from the two sites in East Sumba (Table 1). In addition, the distribution of the most preferred tree species, *T. nudiflora*, varied greatly between sites; it was generally very rare as a large tree but was relatively most common at Langgaliru.

Characteristics of occupied versus unoccupied cavities

We tested for differences in the characteristics of potentially active nests with those of inactive historic nest-sites in an attempt to identify why certain cavities were used in preference to others. We found no differences between active and inactive nest-sites in tree density, or tree architecture around the cavity tree (Table 2). Natural disturbance around trees with currently active nest-sites and the level of anthropogenic disturbance (trees felled per plot) were higher but not significantly so. The height and girth of the 'nest-tree' did not affect its current occupancy, but there tended to be more cavities in the nest-trees that were currently active than in inactive sites (again the difference was not significant). We could detect no differences in the external characteristics of active and inactive cavities (Table 2).

Interactions and competition at cavities

At no cavity did we observe interference or aggressive interactions between pairs of cockatoos, nor did we record more than a single pair of cockatoos checking a cavity, or even different cavities in the same tree. Of the 24 cavities where cockatoo activity was recorded, 11 were in trees that contained another potentially active cavity (three of Eclectus Parrot, one of Sumba Hornbill *Aceros everetti*) and seven where another species also displayed interest or even occupancy (four of Eclectus Parrots, one of Great-billed Parrots and two of Sumba Boobooks *Ninox rudolfi*). Six of the eight serious nesting attempts were at such sites. At one of these, the presumed male of the cockatoo pair disappeared, terminating this nesting attempt. At another, Eclectus Parrots

Table 2. Differences in habitat characteristics of potentially active and unused cavities at Manupeu.

	Potentially active	Historic/unused	Test statistic
Habitat at nest-site			
Tree density trees (ha^{-1})	18.0	14.6	$t = 1.69$, $df = 45$, $P = 0.10$
Primary architecture of trees	7.21	7.83	$t = 1.00$, $df = 12$, $P = 0.30$
No. of regenerating trees (out of 10)	6.58	7.00	$t = 0.66$, $df = 45$, $P = 0.51$
No. of fallen trees	2.96	1.70	$t = 2.37$, $df = 44$, $P = 0.023$
No. of felled trees	1.91	1.22	$t = 1.12$, $df = 44$, $P = 0.24$
Nest-tree characteristics			
Tree height (m)	27.3	28.0	$t = 0.55$, $df = 45$, $P = 0.59$
dbh (m)	0.49	0.49	$t = 0.77$, $df = 45$, $P = 0.94$
No. of other cavities in nest-tree	2.04	1.43	$t = 1.92$, $df = 45$, $P = 0.06$
Cavity measurements			
Cavity height up tree (m)	30.2	27.5	$t = 1.22$, $df = 43$, $P = 0.23$
Angle to vertical (deg)	8.0	4.0	$t = 0.53$, $df = 42$, $P = 0.60$
Entrance size (m^2)	0.25	0.37	$t = 1.59$, $df = 27.4$, $P = 0.12$

Values presented are means and tested using *t*-tests. The 0.05 alpha level is adjusted to 0.0045 using a Bonferroni correction for these 11 tests; variation in the degrees of freedom reflects either missing data or compensation for inequality of variances.
dbh, diameter at breast height.

had prior occupancy while Sumba Boobooks had prior occupancy at a further nest-hole – and both maintained occupancy until the end of fieldwork. At the Great-billed Parrot nest-hole, the cockatoo pair did manage to gain occupancy but failed to breed, with Great-billed Parrots re-establishing occupancy within 14 weeks.

During extended watches of seven of the eight potential nesting attempts, interspecific interactions were recorded at every nest (Table 3) with a total of six other bird species. Interactions with Eclectus Parrots were observed at six of the eight serious attempt sites (all except where the Sumba Boobooks were occupants) with over half (53%) of all interactions being with this species.

Table 3. Interactions at seven potential cockatoo nesting attempts. Data are from watches of seven potentially active nests at Manupeu: four where cockatoos were cavity occupants and three where cockatoos were trying to gain occupancy of an already occupied cavity.

	Cockatoos as occupant		Cockatoos as competitor[a]		All interactions at cockatoo nest-sites	
	No. of interactions	No. of nests	No. of interactions	No. of nests	No. of interactions	No. of nests
Eclectus Parrot *Eclectus eclectus*	22	4	19	2	41	6
Great-billed Parrot *Tanygnathus megalorynchos*	8	2	0[b]	0[b]	8	2
Sumba Hornbill *Aceros everetti*	0	0	6	1	6	1
Common Dollarbird *Eurystomus orientalis*	3	2	2	1	5	2
Short-tailed Starling *Aplonis minor*	6	3	3	1	9	4

[a]At one nest a pair of Sumba Boobook were nesting although no interactions were recorded with adult birds.
[b]The eighth nesting attempt site was first occupied by Great-billed Parrots; however, this cavity was not watched.

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Cavity availability

Of the 1,200 trees of dbh ≥020 m (a total sampling area of 8.93 ha) checked island-wide, only 11 trees contained a cavity subjectively assessed to be of a size and location suitable for use by cockatoos (two of these trees contained two cavities, and one tree contained three cavities), i.e. less than 1% of trees checked contained a cavity. A more realistic, but still potentially high estimate of cavity availability was obtained by including only trees of dbh ≥0.68 m; however, as only very few nesting attempts were in trees this small (most nesting attempts were in trees of dbh 1.20–1.40 m), we also estimated cavity availability within large trees of dbh ≥1.16 m (Table 4). Using these minimum nest-tree size criteria we estimate the availability of trees with cavities potentially suitable to cockatoos to be 45 (in trees of dbh ≥0.68 m), or 67 cavities per square kilometre, and at Manupeu to be 57 cavity-containing trees (in trees of dbh ≥0.68 m), or 114 cavities per square kilometre. However, the number of cavities in trees of a size preferred by cockatoos is likely to be much lower. We monitored the contents of 18 cavities. Of these, four were occupied by other bird species, three contained invertebrates (at least two contained ants) and 11 remained empty.

Discussion

Nest success during the 2001–2002 season

The 2001–2002 season was a very poor breeding season for cockatoos at Manupeu. Within our 6 km^2 study site, we observed nest checking and preparation behaviour at 24 cavities, only eight were considered potential breeding attempts, and only one fledged a single cockatoo chick. This level of nest success was lower than that recorded for other cockatoos such as Carnaby's Cockatoo *Calyptorhynchus funereus latirostris* (78%: Saunders 1986), Glossy Black Cockatoo *Calyptorhynchus lathami* (22.6%: Garnett *et al.* 1999) and Palm Cockatoos *Probosciger aterrimus* (4 of 21 nests over two breeding seasons; Murphy 2001). The low level of recruitment in the Manupeu study site, we suggest, was insufficient to maintain the local population given natural mortality and potential illegal capture.

We do not know how abnormally low the 2001–2002 breeding output was on Sumba. Nesting success among parrots is known to vary considerably both temporally

Table 4. Potential nest-site availability in random vegetation plots at four sites.

		dbh ≥0.20 m			dbh ≥0.68 m			dbh ≥1.16 m		
Area (ha)		*n*	No. of trees with cavities	No. of cavities	*n*	No. of trees with cavities	No. of cavities	*n*	No. of trees with cavities	No. of cavities
Manupeu	3.49	500	6	9	44	2	4	6	0	–
Luku Melolo	2.37	280	0	–	15	0	–	2	0	–
Poronumbu	1.54	200	1	1	17	1	1	5	0	–
Langgaliru	1.52	220	2	3	13	1	1	2	0	–
Combined	8.93	1200	7	13	89	4	6	15	0	0

Availability is presented for three tree size criteria: dbh ≥0.20 m, dbh ≥0.68 m and dbh ≥1.16 m.
Area, the area sampled at each site; *n*, number of trees checked within plots; dbh, diameter at breast height.

and spatially in Australia (e.g. Carnaby's Cockatoo: Saunders 1982; Eclectus Parrot: Heinsohn and Legge 2003); however, no data exist for Indonesia. We do know that our site experienced abnormally high rainfall during the breeding season. Patterns of rainfall are known to influence fruit availability (Foster 1982), which in turn can affect breeding activity and success (parrots: Wunderle 1999, Renton 2002; other taxa: Bancroft *et al.* 2000), and this may have prevented breeding attempts on Sumba. Of the few serious nesting attempts that we did record, there may have been an additional or alternative problem of cavity inundation due to excessive rainfall.

Cavity inundation is a factor known to increase chick mortality and retard growth among psittacids (e.g. Australasian cockatoos and parrots: Rowley 1990, Garnett *et al.* 1999; Eclectus Parrot: Heinsohn and Legge 2003; neotropical parrots: Snyder 1977, and other cavity-nesting bird species: e.g. Wesolowski *et al.* 2002, Radford and Du Plessis 2003).

Cavity availability and selection

Overall, our findings agree with a general cockatoo nest-site requirement for cavities within large trees (e.g. Saunders *et al.* 1982, Saunders 1986, Mawson and Long 1994, Nelson and Morris 1994, Garnett *et al.* 1999, Marsden *et al.* 2001; and more specifically Marsden and Jones 1997) and the importance of trees from the family Datiscaceae, and in particular *Tetrameles* spp., in providing nesting sites to Yellow-crested Cockatoos (Setiawan 1996, Marsden and Jones 1997). The importance of *Chisocheton* sp. as a nest-tree species at Manupeu, however, suggests that while preferences across sites may be broadly similar, there might be significant local variations in nest-tree selection, based on habitat composition.

Island-wide cavity availability was found to be very low. At Manupeu, the density of cavity-bearing trees which were within the size-range 'acceptable' to cockatoos, was approximately 57 cavity-containing trees per square kilometre. We express cavity availability as cavity-bearing trees since we believe that only one cavity per tree will be used by cockatoos at any given time (see Interactions and competition at cavities). Our estimate of cavity availability is likely to be highly inflated as most cavities of interest to cockatoos were in trees of dbh ≥1.16 m (only four of 24 were in smaller trees). At an estimated cockatoo density at Manupeu of around 10 individuals per square kilometre, or up to 5 pairs per square kilometre, taking a 40% occupancy rate by other animal taxa, there might be around eight potential nest-trees per cockatoo pair. This figure itself is undoubtedly an overestimate of availability because some of these cavities, although apparently suitable from the outside, will not have the internal dimensions or environment expedient for parrot nesting. Low cavity availability within tropical forests is not uncommon (e.g. Snyder 1977, Heinsohn *et al.* 2003, Marsden and Pilgrim 2003; see also Newton 1994; but see Saunders 1979).

Additional evidence for nest-site scarcity was the observation of interspecific interactions at all sites where 'serious' nesting attempts took place. All but one of these sites were in trees with more than one 'active' cavity, or at cavities already occupied by birds. It may be that very few nest-sites provide good possibilities for fledging young for a number of reasons (e.g. structural suitability, parasites, security against potential predators). In the case of selection for cavities in trees containing other active nests, there maybe some benefit to nesting close to another pair (e.g. nest defence: Snyder and Taapken 1977) or it may be simply that suitable cavities are aggregated within trees.

Interspecific interactions were common, but we did not record aggressive or competitive interactions between cockatoos at nest-sites. We never observed cockatoo pairs using cavities in the same tree; the nearest two 'serious' nesting attempts were 150 m apart. Dispersion of cockatoo nests (>1 km) has been recorded in the Pink Cockatoo *C. leadbeateri* (Rowley and Chapman 1991).

Conservation implications

The 2001–2002 breeding season was the wettest for 10 years in West Sumba, and we consider that this contributed to a very poor breeding season for the cockatoos. Such stochastic events that potentially reduce reproductive output have significant implications for endangered species such as the Yellow-crested Cockatoo, as they represent an unexpected pressure that might push a rare species even closer to extinction. How abnormally low reproductive output was in that year can only be gauged by assessing breeding success over several years at more than one site. A long-term study of recruitment, and the factors such as climatic cycles and change that affect it, would be valuable, especially for the Yellow-crested Cockatoo because of its low population and because more intensive trade may resume in the species.

While we were unable to conclude that nest-sites are limiting in Manupeu, we suggest that cavity availability is low and, even if not currently limiting, may put a ceiling on the breeding density not much higher than the current level. Our data also support the correlation found between local abundance of cockatoos and the availability of nest-sites (Marsden and Jones 1997), although we cannot confirm that it is indeed lack of suitable nest-sites that actually limits the cockatoo population.

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