Ecology of Black Cockatoos at a Mine-site in the Eastern Jarrah-Marri Forest, Western Australia

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Three threatened black cockatoos inhabit the Jarrah *Eucalyptus marginata*-Marri *Corymbia calophylla* forest of southwestern Australia: Baudin's Cockatoo *Calyptorhynchus baudinii*, Carnaby's Cockatoo *C. latirostris*, and Forest Red-tailed Black Cockatoo *C. banksii naso* [FRTBC]. Their local ecology in relation to anthropogenic disturbance is poorly known, hampering effective conservation management. Therefore we studied their group size, site occupancy patterns, habitat use, and food plants at a mine-site and its surrounds in the eastern forest over three years. FRTBC showed similar group sizes and occupancy across seasons, suggesting year-round residency and no marked seasonality in movements and grouping patterns. In contrast, Carnaby's Cockatoos were up to twice as abundant in spring and summer, indicating migrating or transient flocks and some year-round residents. Few Baudin's Cockatoos were present in summer, but their abundance increased at other times. All three cockatoos were observed in modified or human-made habitats such as mine-site rehabilitation, farm paddocks, and pine plantations. Carnaby's Cockatoos used the broadest habitat range. We documented feeding on 16 plant species, with Carnaby's Cockatoos eating at least 10. Examination of feeding residues as well as observations of behaviour were essential to obtain a complete picture of feeding. Current mine-site rehabilitation protocols provide food for all three black cockatoos within a decade and should continue to do so long-term if Marri is maintained in the seed mix. However, because climate change scenarios predict declining rainfall over much of southwestern Australia, the plant species used to revegetate mine-sites and other landscapes may need to be reconsidered. For areas that do not specify restoring a jarrah forest landscape, the selective use of exotic or non-endemic flora better adapted to lower rainfall conditions may be an option.

Key words: black cockatoos, ecology, group size, feeding, Jarrah forest, *Calyptorhynchus*

INTRODUCTION

THREE threatened black cockatoos occur in the Jarrah *Eucalyptus marginata*-Marri *Corymbia calophylla* forest of Western Australia: Forest Red-tailed Black Cockatoo *Calyptorhynchus banksii naso* [FRTBC] (a sub-species), Carnaby's Cockatoo *C. latirostris*, and Baudin's Cockatoo *C. baudinii*. They are listed as threatened under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* and as Schedule 1 fauna [species that are 'rare or likely to become extinct and in need of special protection'] under the Western Australia *Wildlife Conservation Act 1950* (see also Cale 2003; Chapman 2008; Garnett *et al*. 2011).

The Jarrah-Marri forest also supports timber and mineral production, water catchments, and other land uses (Conservation Commission of Western Australia 2004). Loss of breeding and feeding habitat within the Jarrah-Marri forest through logging and mining are a potential concern for black cockatoos (Mawson and Long 1994; Calver and Dell 1998; Wardell-Johnson *et al*. 2004; Chapman 2008; Garnett *et al*. 2011), although the significance of these impacts is debated (Stoneman *et al*. 1997; Abbott 1998; Abbott and Whitford 2002).

Black cockatoos are especially vulnerable because they nest in large hollows occurring only in mature and senescent trees generally more than 150 years old (Saunders *et al*. 1982; Whitford 2002; Whitford and Williams 2002; Whitford and Stoneman 2004). FRTBC and Carnaby's Cockatoos breed throughout the Jarrah-Marri forest, while Baudin's Cockatoos breed in southern sections (Saunders *et al*. 1985; Johnstone and Storr 1998; Johnstone and Kirkby 2008).

All three black cockatoos feed in the Jarrah-Marri forest year-round, seasonally, or during seasonal migrations (Saunders 1974a, 1980; Johnstone and Kirkby 1999, 2008; Biggs *et al*. 2011). Studies of crop contents and observations of feeding behaviour indicate that Jarrah and Marri are the main foods within the forest (Saunders 1974a,b, 1980; Johnstone and Kirkby 1999, 2008). This reflects the energetic characteristics of Jarrah and (in particular) Marri seeds and the dominance of these two over-storey species across the Jarrah-Marri forest (Pryor 1959; Abbott and Loneragan 1986; Whitford 2002; Cooper *et al*. 2003; Koch and Samsa 2007).

Baudin's Cockatoos are considered Marri specialists, although they also eat proteaceous shrubs, insect larvae, orchard fruit, and other plants, including the buds and flowers of *Banksia* spp. and *Eucalyptus* spp. (Saunders 1974b; Johnstone and Storr 1998; Cale 2003; Chapman 2007; Johnstone and Kirkby 2008). Marri and Jarrah seeds comprise around 90% of the diet of FRTBC, although they also eat seeds of other eucalypts, Forest Sheoak *Allocasuarina fraseriana* and Snottygobble *Persoonia longifolia* (Robinson 1965; Johnstone and Storr 1998; Johnstone and Kirby 1999; Cooper *et al*. 2003). The foraging

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PACIFIC CONSERVATION BIOLOGY Vol. **19:** 76–90. Surrey Beatty & Sons, Sydney. 2013.

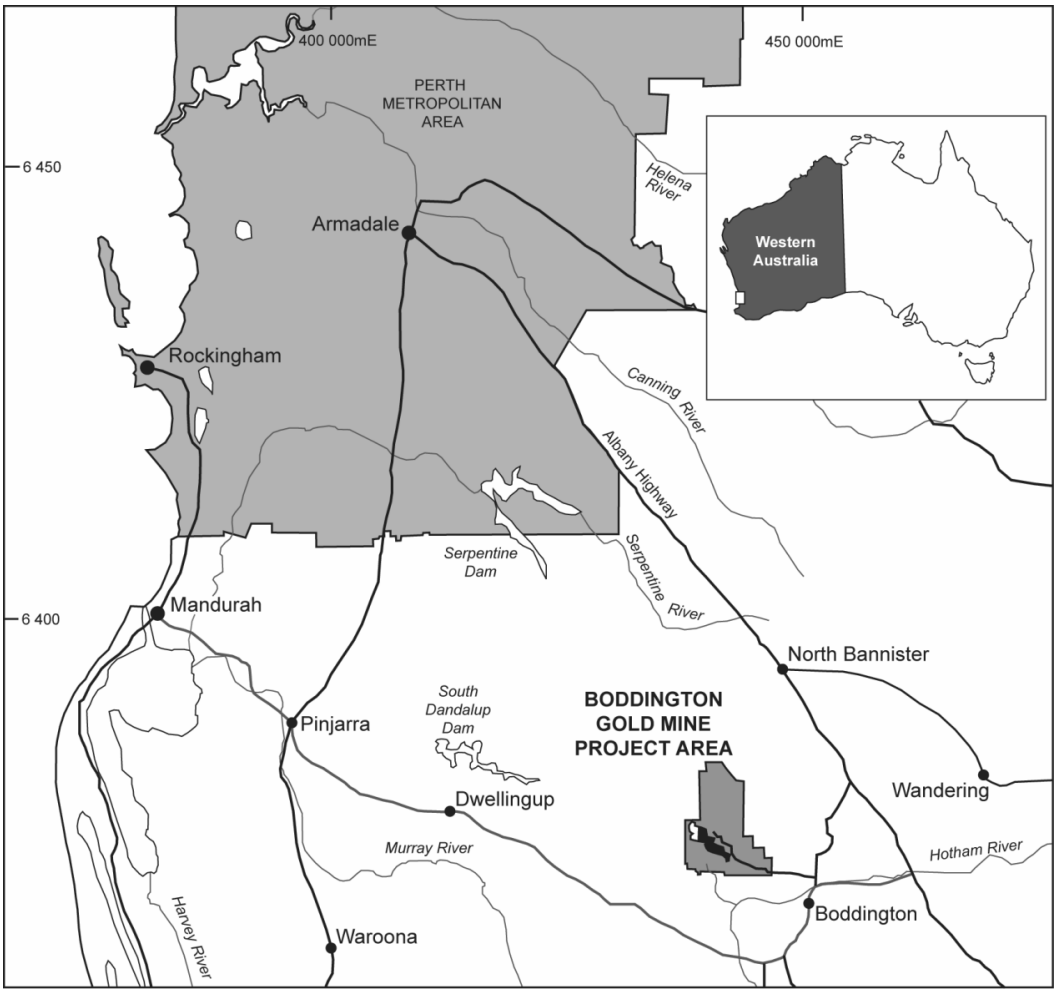

Fig. 1. The location of the study site near Boddington, southwestern Australia (from Biggs *et al*. 2011).

ecology of FRTBC has changed over the past 12 years, including changes in the proportions of different food plants, probably in response to changing food availability (Ron Johnstone and Tony Kirkby, Western Australian Museum, personal communication). Carnaby's Cockatoos also feed within forested areas, but have a more varied diet, including seeds, flowers, and nectar of Jarrah, Marri, *Banksia* spp., *Hakea* spp., and *Pinus* spp. These food plants occur within proteaceous scrubs and heathland, eucalypt forests and woodlands, and pine plantations (Saunders 1974a,b; Saunders 1980). They also consume insects (Saunders 1980; Scott and Black 1981). All three black cockatoos forage on mine-site revegetation (Lee *et al*. 2010).

Despite this basic understanding of the ecology of black cockatoos in the south-west, little is known of their response to anthropogenic disturbance. While Weerheim (2008) and Lee *et al*. (2010) present preliminary data, their work covered only short periods. Given that the feeding ecology of black cockatoos can vary markedly between years in response to the irregular flowering of Jarrah and Marri (e.g., Johnstone and Storr 1998; Johnstone and Kirby 1999), this is a significant limitation. Furthermore, because black cockatoos are highly mobile and occur at low density, observational methods are imperfect for species detection (e.g., Craig and Roberts 2005) and for assessing food use. Searches for distinctive feeding residues beneath plants (Cooper 2000, Johnstone and Kirkby 1999, Biggs *et al*. 2011) can overcome these difficulties.

Here we describe four aspects of the black cockatoos' ecology at the Newmont Boddington Gold Mine (NBG), located at the eastern margin of the Jarrah-Marri forest, based on data collected over three years. We used behavioural observations and assessments of feeding residues to investigate: (1) group sizes, including seasonal changes; (2) habitat use, especially of mine-site rehabilitation; (3) food plants; and (4) occupancy patterns, including seasonal and inter-annual changes. This provides a baseline to assess the value of the NBG landscape to black cockatoos, the likelihood and severity of human impacts associated with mining and other activities, and the value of rehabilitated mine-sites as a food resource.

MATERIALS AND METHODS

Study site and species

The NBG mine-site is an open-cut gold and copper mine located 130 km southeast of Perth along the eastern margin of the Jarrah-Marri Forest (Figure 1). Mean annual rainfall is between the 700 mm and 800 mm isohyets and the site occurs along the ecotone where the landscape changes to the Wandoo *E. wandoo* woodland of the neighbouring Avon Wheatbelt bioregion (Thackway and Cresswell 1995; Rayner *et al*. 1996).

The study site includes NBG mining tenements and lands immediately adjacent to them. NBG tenements contain active mining areas (mining pits, waste rock dumps), mine-site infrastructure (buildings, roads, water reservoirs),

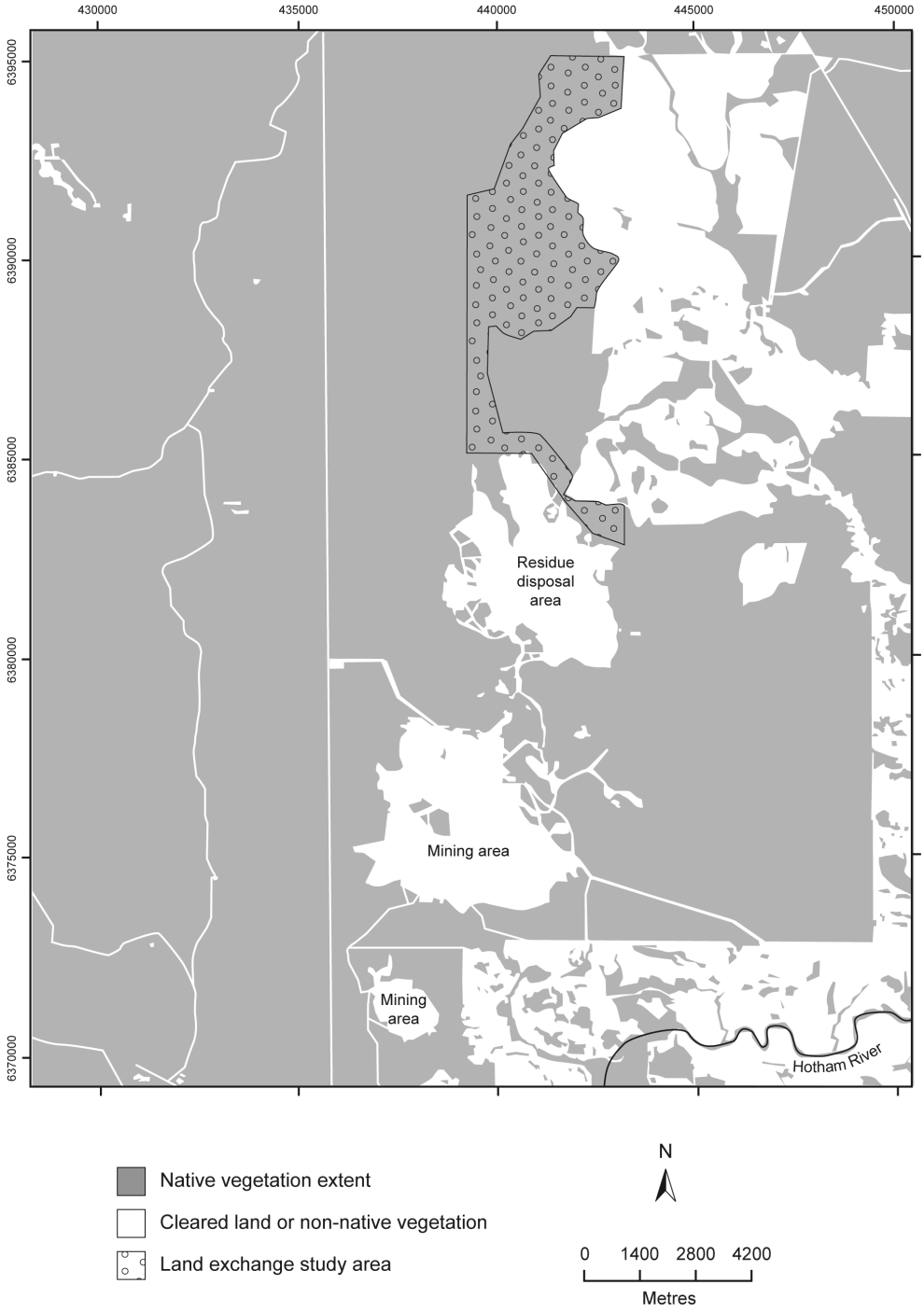

Fig. 2. Map of study area showing the mining areas and residue disposal area, the Land Exchange Area, and surrounds. The cleared land/non-native vegetation to the north-east of the residue disposal area is largely pine plantations and blue-gum *Eucalyptus globulus* plantations, while that to the east and south-east is mainly paddocks.

residue disposal areas (RDAs), water supply reservoirs (WSRs), rehabilitated mining pits, and remnant native forest. Adjacent lands include native forest (within State Forest, Monadnocks Conservation Park, and private lands), agricultural operations (livestock pastures), and plantations (principally Radiata Pine *Pinus radiata* and Tasmanian Blue Gum *E. globulus*) (Figure 2).

Jarrah is the dominant canopy species within native forest, with admixtures of Marri and Wandoo and occasional patches of Yarri *E. patens* and Flooded Gum *E. rudis* (Worsley Alumina Pty Ltd. 1999; Biggs *et al.* 2011). Mid-storey species include Forest Sheoak and Bull Banksia *Banksia grandis*. The shrub layers include several proteaceous food species for black cockatoos, including Parrot Bush *B. sessilis*, Harsh Hakea *Hakea prostrata*, and Wavy-leaved Hakea *H. undulata* (Dell *et al*. 1989; Worsley Alumina Pty Ltd. 1999; Biggs *et al.* 2011).

Nest sites for Carnaby's Cockatoos and FRTBC occur within NBG tenements and their surrounds (J. Lee and H. Finn, Murdoch University, unpublished data). NBG is beyond the breeding range of Baudin's Cockatoos, which breed in the southern Jarrah-Marri forest and even further south in the Karri *Eucalyptus diversicolor* forest from spring to autumn (Johnstone and Kirkby 2008). However, their breeding range may be shifting, with recent records of breeding in the Wungong catchment in the northern Jarrah-Marri forest (Johnstone and Kirkby 2008).

General Distribution Survey (GDS)

We conducted vehicle-based surveys monthly from December 2007 to July 2010 within the NBG mine-site and similar native forest to the north known as the Land-Exchange Area (LEA) (Figure 2). The eastern margin of the LEA adjoined an extensive pine and eucalypt plantation. To distinguish this sampling method from others, we call it a 'general distribution survey' (GDS). Surveys within the NBG mine-site and within the LEA were separate and are called either the NBG GDS or the LEA GDS. We considered the areas separately to contrast species occurrence and to gather habitat use data within the LEA's mixed forest-plantation landscape.

A GDS involved driving a pre-determined route through the NBG mine-site or LEA, following roads and tracks while looking and listening for cockatoos at defined survey points. At NBG, several factors limited where survey points could be located or prevented sampling the complete route. They included: construction, mining, and maintenance activities; restrictions on access; blocked or dead-end roads; safety and practicality; and closure of forest after heavy rainfall (a protocol to limit the spread of plant pathogens). Therefore, the NBG GDS varied monthly in length and the survey points sampled. The extensive network of unsealed forest tracks in the LEA and the lack of human activities allowed complete sampling of a defined route.

The survey route measured 24–33 km for an NBG GDS and 27 km for the LEA GDS. After initial site inspections, we established 38 designated survey points for the NBG GDS and 33 points for the LEA GDS. At NBG, distances between survey points ranged between 0.7 and 1.2 km. At LEA, points were roughly equal distances (0.8 km) apart. During the survey period at the NBG site, survey points 17–27 were lost to the mine expansion (near the RDAs) and survey points 6–8 to a large bushfire.

A GDS usually commenced at first light and continued into the early afternoon. This captured the peak activity when birds leave roost sites and disperse to feeding sites. The survey route for the LEA GDS was always driven in the same direction because the site lay-out made it impractical to modify the direction. We alternated the direction of the NBG GDS from month-to-month, avoiding potential biases associated with the sampling time. The time to complete an individual survey ranged from two to seven hours, depending on encounters and environmental conditions.

This protocol risks double-counting birds because: (1) black cockatoos may move several kilometers a day as they shift among roosting, drinking, and feeding sites and (2) it is not possible to recognize individual black cockatoos (or flocks). Nevertheless, we attempted to keep track of where birds were observed and heard and determine the direction in which flying birds were moving. These methods may have reduced double-counting for survey points sampled within a short time of each other (i.e., within 15–20 minutes), but do not justify using the data to estimate population sizes.

At each survey point, we stopped for two minutes to listen and watch for black cockatoos. Auditory and visual observations were recorded separately. For analyses, we only included detections in which we identified the species. When birds were detected at a GDS survey point, we tried to locate them and collect data on species, group size, habitat use and activity.

Behavioural methodology

We performed a behavioural survey each time that we observed black cockatoos, whether opportunistically or during a systematic search. During behavioural surveys we approached as closely as possible without causing disturbance.

Table 1. Habitat types identified within study area.

Habitat Type	Description
Native Forest	Continuous to nearly continuous canopy, usually with *E. marginata* and *C. calophylla* main canopy forming trees; mid-storey layer including *A. fraseriana*, *B. grandis*, *B.* sessilis, *Persoonia longifolia*, and *Hakea* spp.; ground and shrub layer including *Banksia* and *Hakea* spp.
Native Woodland	Open habitat with discontinuous canopy, usually with *E. wandoo* as the main canopy forming tree; ground and shrub layer including *Banksia* and *Hakea* spp.
Modified Landscape	Human-modified aspects of the landscape not characterised by other habitat types (e.g., mining infrastructure such as powerlines, haul roads)
RDA/WSR	Residue Disposal Area (RDA) or Water Supply Reservoir (WSR). Large (> 1km^2) man-made waterbodies
Mine-site Rehabilitation	Young (<12 years post-establishment) revegetation with high stem densities; Canopy species include *E. marginata*, *C. calophylla*, and *E. wandoo*; diverse and well-developed shrub layer comprising species such as *Banksia* and *Hakea* spp.
Sump	Small man-made waterbodies designed as drainage and seepage sumps
Pine plantation	Stands of pine trees within a commercial forestry landscape
Paddock	Agricultural pasture areas with large open areas of grass and occasional single paddock trees
Remnant Vegetation	Patch of remnant native vegetation within a forestry or agricultural matrix

Behavioural data were collected for the first ten minutes of the observation period using a scan sampling protocol (Altmann 1974). Efforts were made to observe all the individuals present and to ascertain their activity state (Altmann 1974). We recorded predominant activity (the activity state of >50% of individuals during the 10-minute scan sample); group size; predominant habitat type (the habitat type used by >50% of individuals during the 10-minute scan sample, all samples met this criterion); and any foods eaten. We classified habitat type to one of nine categories (Table 1).

We refer to each behavioural survey as an 'encounter', to distinguish behavioural surveys from other field surveys (e.g., GDS) and from visual or acoustic detections during a GDS. While we attempted to conduct a behavioural survey for every detection during a GDS, this was often not practical or feasible (e.g., the birds were too distant).

Group size

We focused on group (or "flock") size as a measure of local abundance. Density estimation is problematic for black cockatoos because they occur in very low densities within the Jarrah-Marri forest (Craig and Roberts 2005; Weerheim 2008). Temporal factors are also important, because flocks may feed in an area for only hours to days, then move elsewhere nearby (e.g., for flocks resident within a locality) or further away (e.g., for flocks migrating between breeding and non-breeding areas) (Saunders 1980; Finn *et al*. 2009).

Flock sizes were counted as accurately as possible. If many individuals were present or it was difficult to observe every bird, the estimated number of birds present was recorded. Results were noted as counts or estimates. Groups more than 50 m apart were considered distinct flocks, while groups less than 50 m apart were considered one flock.

To examine group size, data from behavioural surveys were summarized in descriptive tables and graphs. We combined observations from the NBG GDS and LEA GDS because our interest was in general patterns in group size for the three species across the landscape. We also included opportunistic observations and observations collected during other research activities (e.g., dawn/dusk surveys).

We used two-way analysis of variance (ANOVA) to assess the influence of season and black cockatoo species on flock size, combining data for all years. We did not use a repeated measures design because we could not follow individual flocks across seasons. We classified seasons as: winter (June, July, August), spring (September, October, November), summer (December, January, February), and autumn (March, April, May). Data were highly heteroscedastic, necessitating logarithmic transformation. Significant effects were further investigated using post hoc Tukey's Honest Significant Difference (HSD) for unequal sample sizes.

Group sizes are presented as means (± standard errors) and as medians (25 and 75%, interquartile range) because of skewed distributions and because the sample size for Baudin's Cockatoos was small relative to the others.

Habitat type and use

We considered only the predominant habitat type recorded during the behavioural survey for each encounter. We did not test whether or not

encounters with each cockatoo species were distributed evenly across the habitat types at each site because we did not know the proportional land area of each habitat type at each site and could not calculate expected values. Construction at NBG and the need to change GDS routes also argued against determining proportional land areas at NBG. Instead, we used a chi-squared contingency table to test for an association between encounters with each cockatoo species and habitat type.

We combined observations from NBG and LEA because sample sizes for the two areas separately were too small for statistical analysis and because our interest was in examining differences in how the three species used the range of habitats available to them within both landscapes. We also included opportunistic observations and observations collected during other research targeted activities. Very few encounters were made in Sump, RDA/WSR, and Remnant Vegetation, so these categories were combined. A conservative rule of thumb for contingency tables is that no more than 20% of cells should have an expected value < 5, but Zar (2010) argued that this is too restrictive. We followed his advice that for testing at the 5% level, the mean of the expected values should be ≥6.

In addition, we used the diversity menu of the PAST software (Hammer *et al.* 2001) to calculate a Shannon diversity index, (with 95% confidence limits determined by bootstrapping), for the habitat types in which each cockatoo species was encountered. We then compared the Shannon diversity indices between species using PAST's diversity t-test option. Lastly, we used PAST to calculate evenness (with 95% confidence limits determined by bootstrapping) for each species' habitat use, defined as the Shannon diversity for that species divided by the maximum value it could assume if encounters occurred equally across habitat types. Evenness lies between 0 and 1, with 1 indicating observations distributed equally and low values indicating a weighting toward a few habitat categories. It thus indicates habitat generalists (high evenness values) and specialists (low evenness values).

Food plants

Black cockatoos may feed on the nectar, seeds, buds or flowers of several plants and on insects under tree bark or on flowers and fruits. We considered a plant species to be a food plant if we observed black cockatoos feeding on it or if we observed black cockatoo feeding residues for it (e.g., eaten seed casings, cut branches). Black cockatoos may leave species-distinctive markings on residues from some plant species (e.g., Marri) (Cooper 2000, Johnstone and Kirkby 1999, Biggs *et al*. 2011). However, it is generally not possible to attribute residues confidently to just one black cockatoo species.

Flora surveys at NBG recorded at least 30 known food plants for black cockatoos (Worsley Alumina Pty Ltd. 1999; Mattiske Consulting Pty. Ltd. 2005), based on published reports of food plants for black cockatoos (Saunders 1980; Johnstone and Kirkby 1999, 2008; Johnstone and Storr 1998; Valentine and Stock 2008) and observations at NBG (H. Finn, Murdoch University, unpublished data). These include: four eucalypts (Jarrah, Marri, Yarri, and Wandoo), seven *Banksia* species and ten *Hakea* species. Most of the potential food plants flower or seed briefly or are rare, and therefore represent only short-term or low abundance foods. Of the eucalypts, black cockatoos are not thought to feed on Wandoo seeds (but just on the flowers and nectar), in contrast to the other three eucalypts (Johnstone and Storr 1998; Valentine and Stock 2008).

To examine species differences in food plant use, we used only behavioural observations and only observations in which the black cockatoo species or sub-species was known. We used observations collected during GDS and opportunistically during other research activities.

We used a chi-squared contingency table to test for associations between cockatoo species and food plants. We also calculated a Shannon diversity index and evenness (with 95% confidence limits determined by bootstrapping), for each cockatoo's predominant food plants. We then compared Shannon diversity indices between species using the diversity t-test option in PAST (Hammer *et al.* 2001).

Site occupancy

"Occupancy" refers to temporal patterns in presence within a defined area, e.g., differences across seasons. For black cockatoos, this ranges between year-round residency and transience (e.g., migrating and present for a few hours or days) (Johnstone and Storr 1998, Cameron 2007). Individuals may be resident for part of the year if, for example, they nest within the study area or if they use the study area as a feeding habitat during non-breeding seasons.

To examine seasonal and annual patterns in occupancy, we examined black cockatoo detections from the NBG GDS and the LEA GDS. We did not consider observations collected outside GDS sampling sessions. Data were summarized in tables documenting, for each GDS location (NBG or LEA), the numbers of sightings for each species within: (1) each year of study (2007, 2008, 2009, 2010) with all seasons combined and (2) each season of study (winter, spring, summer, autumn) with all years combined.

Fig. 3. Flock sizes of three species of black cockatoos seasonally at NBG and LEA, using data aggregated over the period 2007–2010.

We then analysed these data with chi-squared goodness of fit tests to determine whether, for each species separately, there were similar numbers of detections at each site in each season or year. Expected values for goodness of fit tests were calculated on the assumption of equal numbers of detections in each season or year, corrected for sampling intensity. Zar (2010) states that for testing at the 5% level, the chi-squared goodness of fit test is appropriate if k = 3, n = 10, and $n^2/k = 10$ (where k is the number of categories and n is the total number of observations). We followed this advice.

RESULTS

Where appropriate, means are reported ± standard errors.

Group size

Group size for Baudin's Cockatoos ranged from two to 107, with a mean of 14.5 ± 3.5 and a median of 9.5 (25% = 3.00; 75% = 18.00) (*n* = 32 encounters). Few very large flocks of Baudin's Cockatoos were observed. The six largest group sizes were of 25 (*n* = 3 groups), 27, 45, and 107 birds; 78.1% (*n* = 25 of 32 encounters) of groups contained less than 20 birds.

Group size for Carnaby's Cockatoos varied from one to 90, with a mean of 10.1 ± 1.3 and a median of 5.0 (25% = 2.00; 75% = 11.00) (*n* = 116 encounters). Few very large flocks of Carnaby's Cockatoos were observed. The five largest group sizes were of 40, 45, 65, 72, and 90 birds; 85.3% (*n* = 99 of 116 encounters) of groups contained less than 20 birds.

Group size for FRTBC ranged from one to 45, with a mean of 7.4 ± 0.6 and a median of 5.0 (25% = 3.00; 75% = 9.00) (*n* = 127 encounters). Few very large flocks of FRTBC were observed. The five largest group sizes were of 25, 27 (*n* = 2 groups), 35, and 45 birds; 92.1% (*n* = 117 of 127 encounters) of groups contained less than 20 birds.

Group sizes differed significantly between species and seasons (Figure 3, Table 2). Carnaby's Cockatoos had significantly larger groups than FRTBC, but Baudin's Cockatoos

Table 2 (a). Results of ANOVA for the data in Figure 3 after logarithmic transformation. Species refers to black cockatoos and season refers to: summer, autumn, winter, spring.

Factor	df Effect	MS Effect	df Error	MS Error	F	p-level
Species	2	0.348	263	0.113	3.081	0.048
Season	3	0.605	263	0.113	5.350	0.001
Species x season	6	0.227	263	0.113	2.012	0.064

Table 2 (b). Tukey's HSD post hoc tests for unequal sample sizes to compare differences between flock sizes of black cockatoos. Significant differences are indicated with a *.

Species	Carnaby's Cockatoo	Baudin's Cockatoo	FRTBC
Carnaby's Cockatoo	—	0.70	0.03*
Baudin's Cockatoo		—	0.09
FRTBC			—

Table 2 (c). Tukey's HSD post hoc tests for unequal sample sizes to compare differences between flock sizes of black cockatoos across seasons. Significant differences are indicated with a *.

Season	Summer	Autumn	Winter	Spring
Summer	—	0.06	0.24	0.45
Autumn		—	0.10	<0.01*
Winter			—	0.04*
Spring				—

Table 3. The numbers of encounters with black cockatoos in different habitat types at NBG and LEA combined. Percentages are shown in parentheses. The Shannon diversity and evenness for the data are shown, with 95% confidence limits determined by bootstrapping.

Habitat type	Carnaby's Cockatoo	Baudin's Cockatoo	FRTBC
Native Forest	54 (46)	20 (59)	87 (72)
Native Woodland	15 (13)	4 (12)	13 (11)
Modified Landscape	6 (5)	2 (6)	8 (7)
Mine-site Rehabilitation	23 (19)	7 (21)	0 (0)
RDA/WSR	3 (3)	0 (0)	1 (1)
Sump	1 (1)	0 (0)	0 (0)
Pine Plantation	14 (12)	0 (0)	0 (0)
Paddock	2 (2)	1 (3)	11 (9)
Remnant Vegetation	0 (0)	0 (0)	1 (1)
Shannon H	1.546	1.16	0.954
(± 95% CL)	(1.355–1.668)	(0.769–1.342)	(0.732–1.107)
Evenness	0.586	0.638	0.433
(± 95% CL)	(0.517–0.728)	(0.513–0.847)	(0.364–0.637)

group sizes were similar to FRTBC and Carnaby's Cockatoos (Figure 3, Table 2). Group sizes for all cockatoos combined were significantly larger in spring than in autumn and winter (Figure 3, Table 2). Group sizes for Baudin's Cockatoos were particularly small in summer, suggesting they occurred in pairs or very small flocks. By inspection, group sizes for FRTBC were constant across seasons, with means of less than ten birds in all four seasons. The interaction between species and season was not significant (Figure 3, Table 2).

Habitat use

Encounters with the three species were associated significantly with habitat types (χ^2_{12} = 59.25, $p < 0.001$). While all three species were encountered mainly in native forest, Carnaby's Cockatoos and Baudin's Cockatoos were encountered next most frequently in mine-site rehabilitation areas, whereas FRTBC were not sighted in rehabilitation areas (Table 3). Carnaby's Cockatoos were the only species recorded within pine plantations.

Evenness values suggested that Baudin's Cockatoo was more generalist in habitat use than Carnaby's Cockatoo, which in turn was more generalist than FRTBC (Table 3). Carnaby's Cockatoo was significantly more diverse in its habitat use than FRTBC (t_{234} = 4.62, $p < 0.001$) and Baudin's Cockatoo (t_{56} = 2.42, $p < 0.001$), but Baudin's Cockatoo and

Table 4 (a). Inventory of (a) canopy-forming tree species and (b) proteaceous shrubs that are food plant species used by black cockatoos at NBG and surrounds. The first column gives the common name and scientific name for the food plant species. The second column indicates whether a behavioural observation was made of black cockatoos feeding on this food plant within the study area. The habitat type(s) in which the behavioural observation(s) occurred is also indicated. The third column indicates whether feeding residues for the food plant were observed. The habitat type(s) in which the feeding residues occurred is also indicated, as if the form of residue observed. The middle three columns indicate which black cockatoo species we observed feeding on the food plant (during a behavioural observation); shading indicates that an observation occurred for that species. The last three columns indicate the habitat type(s) in which feeding on the food plant occurred, based on behavioural observations and feeding residues; shading indicates that an observation occurred for that species. Codes: NF = Native Forest; RV = Mine-site Rehabilitation; PP = Pine Plantation; fc = fruit capsule; br = branch; fl = flower; sd = seed; fs = flower spike; sc = seed casing; co = cone.

Food Plant	Behavioural Observation	Feeding Residue	Baudin's Cockatoo	Carnaby's Cockatoo	FRTBC	Native Forest	Mine-site Rehabilitation	Pine Plantation
Jarrah (*Eucalyptus marginata*)	NF	NF **fc**	■	■	■	■		
Marri (*Corymbia calophylla*)	NF RV	NF/R V/PP **fc**	■	■	■	■	■	■
Sheoak (*Allocasuarina fraseriana*)	NF	NF **fc**		■	■	■		
Yarri (*E. patens*)	NF	NF **fc**			■	■		
Montery/Radiata Pine (*Pinus radiata*)	NF/ PP co	NF/P P/RV **co**		■			■	■

Table 4 (b). Inventory of proteaceous shrub species that are food plant species used by black cockatoos at NBG and surrounds. The first column gives the common name and scientific name for the food plant species. The second column indicates whether a behavioural observation was made of black cockatoos feeding on this food plant within the study area. The habitat type(s) in which the behavioural observation(s) occurred is also indicated. The third column indicates whether feeding residues for the food plant were observed. The habitat type(s) in which the feeding residues occurred is also indicated, as if the form of residue observed. The middle three columns indicate which black cockatoo species we observed feeding on the food plant (during a behavioural observation); shading indicates that an observation occurred for that species. The last three columns indicate the habitat type(s) feeding on the food plant occurred, based on behavioural observations and feeding residues; shading indicates that an observation occurred for that species Codes: NF = Native Forest; RV = Mine-site Rehabilitation; PP = Pine Plantation; fc = fruit capsule; br = branch; fl = flower; sd = seed; fs = flower spike; sc = seed casing; co = cone; ? = black cockatoo species could not be determined from residue.

Food Plant	Behavioural Observation	Feeding Residue	Baudin's Cockatoo	Carnaby's Cockatoo	FRTBC	Native Forest	Mine-site Rehabilitation	Pine Plantation
Parrot Bush *Banksia sessilis*	NF/ RV **br**	NF/R V	?	?	?			
Pingle *B. squarrosa*	RV	NF/R V **br**	?	?	?			
Couch Honeypot ***B. dallaneyi***	**FT**							
Bull Banksia *B. grandis*	NF/ RV	NF **fs**	?	?	?			
Prickly Hakea *Hakea amplexicaulis*		RV **br**	?	?	?			
Ram's Horn *H. cyclocarpa*		RV **br**	?	?	?			
Marble Hakea *H. incrassata*		RV **br**	?	?	?			
Honeybush *H. lissocarpha*		RV **br**	?	?	?			
Harsh Hakea *H. prostrata*	RV	NF/ RV **br sc**	?	?	?			
Wavy-leaved Hakea *H. undulata*	RV	NF/ RV **Br sc**	?	?	?			
Two-leaf Hakea *H. trifurcata*		RV **br sc**	?	?	?			
Variable-leaved Hakea *H. varia*		NF/R V **br sc**	?	?	?			

FRTBC were not significantly different (t_{64} = 0.94, p = 0.35). These conclusions are unchanged if the critical value for each test is adjusted to 0.017 to allow for multiple tests.

Food plants

Sixteen native plant species at NBG within native forest and mine-site rehabilitation habitats were used as food plants (Table 4). Feeding residues from *Pinus radiata* were also observed in the pine plantation and occasionally within native forest or rehabilitation areas close to pine stands.

Carnaby's Cockatoos fed much more extensively on proteaceous shrubs (*Banksia*, *Hakea* spp.) than the two other species, which fed mainly on Marri (χ^2_{12} = 112.92, p < 0.001) (Table 5). Carnaby's Cockatoos and Baudin's Cockatoos were observed peeling back bark to search for grubs. Evenness values suggested that Carnaby's Cockatoo was more generalist than the other species, which were similar. The diet of Carnaby's Cockatoo was significantly more diverse than that of FRTBC (t_{136} = 9.34, p < 0.001) and Baudin's Cockatoos (t_{28} = 4.39, p < 0.001), but Baudin's Cockatoos and FRTBC were not significantly different (t_{31} = 0.28, p > 0.5). These conclusions are unchanged if the critical value for each test is adjusted to 0.017, allowing for multiple tests.

Site occupancy

After corrections for GDS sampling intensity, there were annual fluctuations in GDS detections of Carnaby's Cockatoos and FRTBC at NBG

Table 5. Plants on which black cockatoos were observed feeding at NBG and LEA combined. Percentages are shown in parentheses. The foods were flowers and seeds in most cases, but lifting bark to search for grubs is entered separately. "Dryandra" spp. refers to *Banksia sessilii* and *B. squarrosa*.

Food plant	Carnaby's Cockatoo	Baudin's Cockatoo	FRTBC
Banksia spp.	11 (15)	0 (0)	0 (0)
"Dryandra" spp.	14 (19)	1 (4)	0 (0)
Hakea spp.	10 (14)	0 (0)	0 (0)
Jarrah	15 (20)	1 (4)	21 (30)
Marri	2 (3)	16 (70)	46 (65)
Pine	14 (19)	0 (0)	0 (0)
Forest Sheoak	1 (1)	0 (0)	1 (1)
Yarri	0 (0)	0 (0)	3 (4)
Grub (Wandoo)	1 (1)	4 (17)	0 (0)
Grub (Marri)	0 (0)	1 (4)	0 (0)
Shannon H	1.789	0.966	0.835
(± 95% CL)	(1.583–1.87)	(0.462–1.241)	(0.621–0.985)
Evenness	0.748	0.525	0.576
(± 95% CL)	(0.709–0.920)	(0.476–0.844)	(0.516–0.812)

Statistical tests for differences in Shannon H:
Carnaby's Cockatoo vs Baudin's Cockatoo $t_{28} = 4.39$, $p = 0.000145$
Carnaby's Cockatoo vs FRTBC $t_{136} = 9.34$, $p < 0.0001$
Baudin's Cockatoo vs FRTBC $t_{31} = 0.28$, n.s.

Table 6. The number of detections of three species of black cockatoo at sites sampled for the General Distribution Surveys within Newmont Boddington Gold (NBG) tenements and the Land Exchange Areas (LEA) in each year over the duration of the study. The number of samples in each year is given in parentheses in the year row. The chi-squared tests the null hypothesis of equal numbers of detections in each year against the alternative that detections varied with year. In calculating the expected values for the chi-squared tests, equal numbers of detections were assumed in each year and those values were then adjusted for the sampling intensity. The expected values are given next to the observed in parentheses. For example, the expected number of detections of CBC at NBG in 2007 was calculated as 58 (number of samples in 2007)/904 (sum of all samples) x 21 (sum of all CBC detections over the study period).

Location	Cockatoo species	2007 (58)	2008 (439)	2009 (267)	2010 (140)	Chi-squared test
NBG	Carnaby's Cockatoo	7 (1.4)	9 (10.4)	5 (6.0)	0 (3.2)	$\chi^2_3 = 25.96$, $p < 0.0001$
NBG	Baudin's Cockatoo	0	3	1	0	Not calculated — sample size too small
NBG	FRTBC	7 (3.8)	36 (27.8)	12 (16)	1 (8.4)	$\chi^2_3 = 12.63$, $p = 0.006$
Location	Cockatoo species	2007 (0)	2008 (165)	2009 (396)	2010 (231)	Chi-squared test
LEA	Carnaby's Cockatoo	—	3 (8.75)	32 (21)	7 (12.25)	$\chi^2_2 = 11.79$, $p = 0.003$
LEA	Baudin's Cockatoo	—	1	1	0	Not calculated — sample size too small
LEA	FRTBC	—	3	3	1	Not calculated — sample size too small

Table 7. The number of detections of three species of black cockatoo at sites sampled for the General Distribution Surveys within Newmont Boddington Gold (NBG) tenements and the Land Exchange Areas (LEA) in each season over the duration of the study. The number of samples in each season is given in parentheses in the top row. The chi-squared tests the null hypothesis of equal numbers of detections in each season against the alternative that detections varied with season. In calculating the expected values for the chi-squared tests, equal numbers of detections were assumed in each season and those values were then adjusted for the sampling intensity. The expected values are given next to the observed in parentheses.

Location	Cockatoo species	Summer (302)	Autumn (247)	Winter (209)	Spring (146)	Chi-squared test
NBG	Carnaby's Cockatoo	13 (7.01)	0 (5.74)	3 (4.86)	5 (3.39)	$\chi^2_3 = 12.31$, $p = 0.006$
NBG	Baudin's Cockatoo	0	1	2	1	Not calculated — sample size too small
NBG	FRTBC	20 (18.70)	16 (15.3)	12 (12.95)	8 (9.04)	$\chi^2_3 = 0.31$, $p = 0.96$
Location	Cockatoo species	Summer (198)	Autumn (198)	Winter (198)	Spring (198)	Chi-squared test
LEA	Carnaby's Cockatoo	2	18	7	15	$\chi^2_3 = 15.33$, $p = 0.002$
LEA	Baudin's Cockatoo	0	0	2	0	Not calculated — sample size too small
LEA	FRTBC	1	3	0	3	Not calculated — sample size too small

(Table 6). Despite the low sampling intensity in 2007, more Carnaby's Cockatoos were seen than expected. For FRTBC, there were fewer detections in 2010 than expected given the sampling intensity. Within the LEA, Carnaby's Cockatoos detections fluctuated significantly across the years. In 2009, more Carnaby's Cockatoos were seen than expected. The sample size for Baudin's Cockatoos was too small for analysis.

There were seasonal fluctuations in detections for Carnaby's Cockatoos but not for FRTBC (Table 7). Detections of Baudin's Cockatoos were too few to examine for seasonal variation, but they were not detected during summer GDS samples, although present in the study area (based on non-GDS observations) (Figure 3). Detections for Carnaby's Cockatoos were highest in spring and summer. At NBG, FRTBC were detected much more frequently than the other species, whereas within the LEA Carnaby's Cockatoos were detected most frequently (Tables 6 and 7).

Encounters (including non-GDS sightings) with Carnaby's Cockatoos occurred in all months. There were no encounters with Baudin's Cockatoos recorded in October or November and no encounters with FRTBC in June.

DISCUSSION

Baudin's Cockatoos

Group sizes for Baudin's Cockatoos are variable and seasonally dynamic, with marked differences between breeding and non-breeding periods (Johnstone and Kirkby 2008). Johnstone and Kirkby (2008, 2009) report that the species, which is typically confined to forest habitats, generally occurs in small flocks of up to 30 birds, and occasionally in larger flocks of up to 50 or aggregations of c. 1 200 birds. Our finding of a mean group size of 14.5 birds is similar to the 13 ± 2 Baudin's Cockatoos reported by Weerheim (2008), who reported group sizes ranging from one to 100 birds.

Johnstone and Kirkby (2008) report that, depending on their provenance, Baudin's Cockatoos may be year-round residents or postnuptial nomads and migrants, with the majority of the population shifting northwards in autumn to the central and northern Jarrah-Marri forest and adjacent areas of the Swan Coastal Plain, before migrating southwards in spring to breeding areas in the Karri forest and southern Jarrah-Marri forest. Johnstone and Kirkby (2008) suggested that the main wintering area for Baudin's Cockatoos is concentrated in the western portion of the northern Jarrah-Marri forest. Weerheim (2008) reported Baudin's Cockatoos to be absent or scarce in the western Jarrah-Marri forest in October, December, and February. Johnstone and Kirkby (2008) also report Baudin's Cockatoos to be absent or scarce at roost sites near Perth between October and January.

Though we detected few Baudin's Cockatoos, they were less common in summer than during autumn, winter, and spring. The birds seen in summer could have been non-breeding juveniles or adults or breeding pairs. Although Boddington lies outside the main breeding areas for the species, reports of breeding in the Wungong catchment 140 km northwest of Boddington (Johnstone and Kirkby 2009) suggest that breeding may occur within the study area.

Baudin's Cockatoos mainly occur in native forest and woodland at NBG, but also use mine-site rehabilitation. Lee *et al*. (2010) found that Baudin's Cockatoos feed on Marri in rehabilitation at NBG within eight years of establishment. Though Marri appears the main food source for Baudin's Cockatoos at NBG, our list of food plants at NBG probably excludes some food plants used by the species. For example, Baudin's Cockatoos feed on the flower spikes of Bull Banksia (Johnstone and Kirkby 2008), and thus some Bull Banksia feeding residues observed at NBG may be from this species. However, Bull Banksia flowers between September and November at NBG (H. Finn, Murdoch University, personal observation), when Baudin's Cockatoos are absent or scarce.

Carnaby's Cockatoos

We found groups of up to 90 Carnaby's Cockatoos, averaging 10.1 birds, similar to Weerheim (2008) who reported an average group size of 11 ± 2 birds (n = 34 sightings) in the western Jarrah-Marri forest (range two to 60 birds). Finn *et al*. (2009) reported larger foraging groups of 117.3 ± 28.1 (range 3 to 1785) in Gnangara pine plantations north of Perth on the Swan Coastal Plain. Similarly, Saunders (1980) reported feeding groups between Perth and Moore River varying from 2 to 1200 birds with a mean group size of 129.3. Johnstone and Storr (1998) noted that, across their range, Carnaby's Cockatoos typically occur in pairs or small flocks, though sometimes in flocks of up to 2 000 birds during the non-breeding season and in pine plantations.

Carnaby's Cockatoos fed on the broadest range of plants (at least ten species), agreeing with previous studies (Saunders 1974a,b; Saunders 1980; Shah 2006; Valentine and Stock 2008). Saunders (1974b) observed that the crops of Baudin's Cockatoos contained mostly Marri seeds (in 89% of crops examined) but no pine seeds (0% of crops), whereas crops of Carnaby's Cockatoos contained mostly pine seeds (81% of

crops), followed by seeds from 'Dryandra' spp. (20% of crops) and *Hakea* spp. (19% of crops), but rarely Marri seeds (8% of crops). The breadth of the diet of Carnaby's Cockatoos at NBG is reflected in the finding that no food plant accounted for more than 20% of feeding observations. Nevertheless, Jarrah is an important food source for Carnaby's Cockatoos at NBG.

Carnaby's Cockatoos used the broadest range of habitats (i.e., eight of the nine habitat types), including two anthropogenic habitats — mine-site rehabilitation and pine plantation — where they fed on proteaceous shrubs and pine (respectively). This agrees with previous studies documenting the use of novel habitats and food sources by this species (e.g., Saunders 1974a, b, 1980; Finn *et al*. 2009, Lee *et al*. 2010).

Carnaby's Cockatoos were most common at NBG in summer and in the LEA in autumn and spring. The peak during summer at NBG may reflect flocks migrating towards the coast at the end of the breeding season (Saunders 1980; Johnstone and Storr 1998; Johnstone and Kirkby 2009; Johnstone *et al*. 2010). The availability of reliable water and food sources at NBG (e.g., proteaceous shrubs in mine-site rehabilitation areas) may make NBG attractive to migrating flocks. The peak at LEA during autumn and spring may also reflect seasonal movement, but abundance may be closely linked to availability of mature pine cones in the plantation along the eastern edge. The strong association of this species with pine probably accounts for it being observed within the LEA more frequently than the other black cockatoos. The factors affecting occupancy are also likely to explain seasonal variation in group size.

Like Weerheim (2008), we observed Carnaby's Cockatoos throughout the year, suggesting year-round residency for some individuals. However, Weerheim (2008) found that Carnaby's Cockatoos were the least abundant black cockatoo in the western Jarrah-Marri forest. This contrasts with our findings that Carnaby's Cockatoos were the most common black cockatoo in the LEA and the second-most common species at NBG (after FRTBC). This suggests potential regional differences in the distribution of Carnaby's Cockatoos, and may also reflect differences in movements of migratory flocks and the availability of non-native foods. Canola, an important Wheatbelt food source, occurs in farms along the eastern margin of the Jarrah-Marri forest and birds have been observed feeding on canola 20 km to the southeast of NBG (H. Finn, Murdoch University, unpublished data). Johnstone and Kirkby (2009) reported small numbers of Carnaby's Cockatoos year-round in the Wungong catchment, as well as several breeding pairs. This report, along with our observation of breeding at NBG, suggests that Carnaby's Cockatoos may breed throughout the Jarrah-Marri forest, at least in low numbers. If confirmed, this would emphasize the significance of the Jarrah-Marri forest as breeding habitat.

FRTBC

We found FRTBC mostly in small groups (mean of 7.4 birds), similar to Johnstone and Kirkby (1999), who reported that FRTBC generally occurred as breeding pairs or in small family units of 3 to 5 birds, though groups of up to 200 were occasionally observed. Saunders (1977) reported that, in forested areas of the southwest, FRTBC were most commonly seen in groups of less than ten, rarely larger than twenty. The largest FRTBC flocks observed by Ford (1980) were 20 to 30 birds. Abbott (1998) reviewed 66 published records of FRTBC from 1900–1995 and found a mean number of 9.6 ± 1.5 cockatoos. He also reported a mean of 6.6 ± 1.5 for FRTBC sighted during two extensive regional surveys in southwestern Australian (in 1995–1996 and 1996–1997). Weerheim (2008) reported an average of 4 ± 0.2 FRTBC (n = 585 sightings), with groups ranging from one to 50 birds.

FRTBC mostly use native forest and woodland at NBG. Paddocks are also important, as noted elsewhere (Abbott 1998). Paddocks adjacent to NBG are used for feeding and drinking, with the largest group at NBG being 45 birds at drinking site in a paddock (H. Finn, personal observation).

Water in farm dams and near mine-sites may be important for FRTBC at NBG. FRTBC have the highest basal metabolic rate and evaporative water loss of the four *Calyptorhynchus* species occurring in southwestern Australian (including the Inland Red-tailed Black Cockatoo, *C. b. samueli*), so water may determine their distribution more than for Baudin's or Carnaby's Cockatoos (Cooper *et al*. 2002).

Although we did not observe FRTBC in mine-site rehabilitation, feeding residues from this species were present in rehabilitation areas at NBG, indicating that some feeding activity occured (Lee *et al*. 2010). Weerheim (2008) also found that FRTBC were infrequent in mine-site rehabilitation less than 20 years old at sites in the western Jarrah-Marri forest. Weerheim (2008) and Lee *et al*. (2010) suggested that FRTBC may avoid mine-site rehabilitation at an early successional stage because of perceived predation risk from raptors. Observations of Baudin's Cockatoos feeding on Marri indicate that suitable food sources for FRTBC are available in rehabilitation (Lee *et al*. 2010).

FRTBC at NBG fed mostly from Marri and Jarrah, and less often on Forest Sheoak and

Yarri. This agrees with Johnstone and Kirkby (1999) and Weerheim (2008), who reported that Marri and Jarrah are the main foods for FRTBC, although they may feed on other plants with suitable energy content or nutritive value, particularly if Marri and Jarrah are limited (Cooper *et al.* 2002; Johnstone and Kirkby 1999).

FRTBC are more sedentary than the other species (Abbott 1998, Johnstone and Storr 1998; Johnstone and Kirkby 1999; Johnstone *et al.* 2010). Nevertheless, movements away from areas burned or lacking water are reported (Abbott 2001, Johnstone and Kirky 2009, DSEWPaC 2011), and birds range onto the Swan Coastal Plain to use native and exotic food sources (e.g., Cape Lilac *Melia azedarach*) (Johnstone *et al.* 2010). Johnstone and Kirkby (1999, 2009) and Weerheim (2008) reported FRTBC as present year-round in the Jarrah-Marri Forest.

Inter-annual changes of FRTBC in site occupancy at NBG occurred, but not seasonal changes in occupancy, or seasonal changes in group size. FRTBC appeared to be more locally abundant in 2007 and 2008 than in subsequent years. This may reflect landscape-level patterns in food availability for Marri, as Biggs *et al.* (2011) reported intensive feeding on Marri by FRTBC at NBG based on residues observed in 2008.

FRTBC are resident year-round at NBG, but their distribution shifts periodically, probably in response to the availability and depletion of food and, in summer, to water. Landscape-scale differences in the flowering and fruiting of Marri or Jarrah could change distributions (Johnstone and Kirkby 1999, Weerheim 2008). We did not see large transient or migratory flocks of FRTBC. The larger flocks we observed were usually temporary aggregations at drinking sites, often at dusk. FRTBC may migrate into and out of the study area, but as small flocks and without a marked seasonal component.

Management Implications

This study illustrates how, within a single landscape, these three black cockatoos exhibit distinct (though often overlapping) ecologies, including differences in group size, habitats and food plants used, and occupancy (seasonal or year-round). These differences suggest they will differ in their response to disturbance and use of anthropogenic food sources such as pine, mine-site rehabilitation, and paddock trees.

Of the three species, FRTBC appear the most vulnerable to disturbance from intensive activities such as mining and forestry because they tend to reside year-round within defined locales in the Jarrah-Marri forest. FRTBC shift their distribution locally in response to the availability of food and water, and are likely to do so in response to local disturbance. However, populations of this species appear to be small (i.e., < 150 individuals) and resident (Johnstone and Kirkby 1998), suggesting the potential for local extinctions if local carrying capacities are greatly reduced (Wardell-Johnson *et al.* 2004). In contrast, Carnaby's Cockatoos use more foods and habitats, and therefore are better able to adapt to local disturbances, either by migrating elsewhere or by shifting to other food plants. The abundance and distribution of Baudin's Cockatoos is linked to the availability of Marri, so retaining or restoring Marri is critical for this species.

Breeding success for black cockatoos depends on adequate supplies of suitable hollows and sufficient food and water within a few kilometers from the nest (Saunders *et al.* 1985; Johnstone *et al.* 2010). Leaving aside hollow availability, an issue debated elsewhere (e.g., Mawson and Long 1994; Stoneman *et al.* 1997; Abbott 1998; Calver and Dell 1998; Abbott and Whitford 2002; Wardell-Johnson *et al.* 2004), this study suggests that the availability of anthropogenic foods (e.g., pine, proteaceous shrubs in rehabilitation areas) may support breeding by Carnaby's Cockatoos within the Jarrah-Marri forest. However, as FRTBC do not feed on pine and feed infrequently within young rehabilitation, efforts to support FRTBC breeding are better focused on *in situ* conservation of native vegetation. The association between FRTBC and paddock trees suggests that they may benefit from restoration that allows Marri stems to obtain large canopy volumes.

Climate change has important implications for the conservation of black cockatoo habitat in the Jarrah-Marri forest, because the lower rainfall predicted will affect the productivity and species composition of vegetation (Charles *et al.* 2010). Climate-related changes may be most pronounced in areas such as NBG, which lie along existing ecotones where forest transitions to woodland.

We suggest two strategies to ensure that suitable feeding habitat is maintained for all three black cockatoos. Firstly, restoration and rehabilitation efforts should continue to establish a range of native food plants, including both proteaceous and myrtaceous species. A diversity of food plants adds resilience to restored sites and also helps to maintain food availability across seasons and years. The current aims of restoring a functioning Jarrah-Marri forest environment are compatible with this aim and appear to be achieving it. Secondly, consideration may need to be given to areas where restoration of Jarrah-Marri forest may be impractical in the face of climate change. In such areas, and where this does not conflict with other restoration aims, non-native (e.g., pine) and non-endemic (e.g., species from lower

rainfall regions) could be included in restoration. Several non-endemic Australian and exotic plants are used intensively by black cockatoos where they occur in Western Australia (e.g. Cape Lilac *Melia azedarach*, Lemon-scented Gum *Corymbia citriodora*, Liquid Amber *Liquidamber styraciflua* (Saunders 1980; Johnstone and Kirkby1999; Kenneally 2002). Concerns over the use of non-endemic species for restoration of disturbed sites may need to be reconsidered given the implications of changing rainfall for the region. The inclusion of plant species adapted to lower rainfall conditions may be particularly important in ensuring long-term food availability and in mitigating the short-term impacts of drought. Such an approach may be appropriate when revegetating farmland, as opposed to native forest restoration.

ACKNOWLEDGEMENTS

We thank Belinda Cale for drawing the figures and the personnel of Newmont Boddington Gold for their assistance. Newmont Boddington Gold provided the support for this research and for a postdoctoral position for one of the authors (H. Finn). Denis Saunders, Ron Johnstone, Hugh Ford, Harry Recher, and an anonymous reviewer kindly commented on earlier drafts of the paper, although they do not necessarily endorse all our interpretations.

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