Gnangara Sustainability Strategy

An across-government initiative

Groundwater – Biodiversity – Land use

PINES AND THE ECOLOGY OF CARNABY'S BLACK-COCKATOOS (*CALYPTORHYNCHUS LATIROSTRIS*) IN THE GNANGARA SUSTAINABILITY STRATEGY STUDY AREA

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Report for the Forest Products Commission

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Contents

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Pines and the ecology of Carnaby's Black-Cockatoos (*Calyptorhynchus latirostris*) in the Gnangara Sustainability Strategy Area

Key Conclusions

1. This study examined the behavioural ecology of Carnaby's Black-Cockatoo in the Gnangara Sustainability Strategy study area, with a focus on habitat use of pine plantations. The study confirms that the pine is the main food source for Carnaby's Black-Cockatoos within the GSS area during the non-breeding season (January-June). The value of the Gnangara-Pinjar-Yanchep pine plantations as a food source for Carnaby's Black-Cockatoo should not be underestimated. Large congregations of birds (~3000) utilised the pine plantations for an extended period, mainly January-March but with birds continuing to feeding within the plantations through June. The pine plantations have provided an important and dependable feeding habitat since the 1940s, a period that has seen the abundance of this species decline by at least 50% and its range contract by one-third.
2. The impact of pine removal should also be considered within a suite of broader changes to the GSS landscape. These changes include the loss of feeding habitats off-plantation (e.g. thickets of *Banksia sessilis* around Neerabup and within the Northwest Corridor) and predictions of declining productivity within areas of Banksia woodland due to reduced rainfall and the spread of dieback, *Phytophthora cinnamomi*.
3. There is uncertainty about whether the remnant native vegetation in the GSS area will provide an adequate food source following the removal of pine plantations, particularly from January to March when feeding within the plantations is most intensive. This topic requires further investigation.
4. In April and May 2009 (_dryandra period), at least 4000 birds were concentrated between Neerabup and Boongarra as large aggregations form to feed within thickets of *Banksia sessilis*. These aggregations probably draw together flocks that through February and March had been feeding: (a) in and around the GSS pine plantations; (b) in the suburban areas to the south and west of the plantations; and (c) in areas to the north of Boongarra.
5. When the _dryandra' feeding period is completed, the aggregations most likely broke apart again, with birds either returning to feed on pine again or in Banksia woodland areas. This also roughly coincides with the period when breeding birds will begin transitioning back to breeding habitats inland, and from June through August birds may mass into large flocks of several thousand as they shift away from feeding habitats on the Swan Coastal Plain. Large flocks have been observed in July and August around the northern end of the Yanchep plantation, suggesting that birds migrating to breeding sites to the north and east of the GSS area may aggregate in areas of the pine plantations where some food remains and/or the large areas of *Banksia* woodland.
6. Not all adult birds breed each year, and some birds remain on the Swan Coastal Plain, and between 600-1500 birds are likely to be present within the GSS area during the non-breeding season

7. Food availability in Banksia woodland habitats probably peaks in the late winter-spring period (August-November), since this is the season when the majority of *Banksia* species on the Swan Coastal Plain are flowering and the fruits of *B. attenuata* mature. It is unknown how much food remains available in the Banksia woodlands throughout the year, and this topic requires further research.
8. Given the lack of information on the seasonal availability of food for this species, a precautionary conservation step would be the retention of some form of pine. Lower stand densities and larger breaks between stands would encourage greater canopy growth and thus greater production of cones, thereby compensating for an overall decrease in the area covered by pine.
9. If full pine removal is effected, feeding habitat can be restored quickly and at relatively low cost through the seeding and/or planting of native and non-native food species that are well-adapted to growth in a high-disturbance environment. These species include: *Banksia sessilis* and similar ‗Dryandras', *Hakea* spp., marri, *Erodium*, and *Pinus* spp. However, given the potential negative impacts of introduced species (e.g. *Erodium*) on other elements of biodiversity, the use of such species as food sources for Carnaby's Black-Cockatoo should be avoided.
10. The provision of roosting habitat is a potentially over-looked function of pine, particularly in landscapes where there are few large trees to roost. Thus, restoration objectives for Carnaby's cockatoos could possibly be integrated into current strategies to create ecological corridors or be developed as offset measures. The key issues are the need to find suitable roost tree species and to replace feeding habitat that provides food in the January to April period, to compensate for the removal of roost sites and food from pine plantations.
11. Further research is required to identify the potential carrying capacity of the remnant Banksia woodland following the removal of pine plantations. In particular, this research should identify availability of food (and watering points) during January – March.

GUIDANCE FOR THIS DOCUMENT

This document is a companion report to another Gnangara Sustainability Study (GSS) technical report:

Valentine, L. and Stock, W. 2008. *Food Resources of Carnaby's Black-Cockatoos in the Gnangara Sustainability Study Area*.

The 2008 report is available from:
http://portal.water.wa.gov.au/portal/page/portal/gss/Content/reports/Valentine%20and%20Stock_Food%20Resources%20for%20Carnaby's%20Black-C.pdf

The objective of this report is to improve the scientific basis for the GSS by providing information on the role of pines on the ecology of Carnaby's Black-Cockatoos in GSS area. This report also addresses how this species might be affected by the removal of pine from the Gnangara, Pinjar, and Yanchep pine plantations.

Part I provides background information on the ecology and conservation biology of Carnaby's Black-Cockatoos and their association with the Swan Coastal Plain and the pine plantations in the GSS. It also provides a brief statement of the key issues associated with the impact of pine removal on this species.

Part II describes various aspects of the ecology of Carnaby's Black-Cockatoos in the GSS area based on field research in 2009 and previous studies.

Part III examines how the removal of pine may affect Carnaby's Black-Cockatoos and potential responses, provides an initial risk assessment framework, evaluates pine removal as a possible controlled action under the *Environmental and Biodiversity Conservation Act 1999*, and addresses landscape management and restoration for Carnaby's Black-Cockatoos conservation.

PART I
BACKGROUND & PROBLEM FORMULATION

1. Carnaby‘s Black-Cockatoos & GSS Pine Plantations

A. Introduction

> The establishment of large areas of *Pinus pinaster* forests in the South-west portions of Western Australia has had an interesting effect on the population density of the White-tailed Black Cockatoo (*Calyptorhyncus baudinii*) in this region. Under natural conditions in the heavy forested corner of the South-west, these birds congregate in flocks of from 12 to 30 and rarely is a greater number met with. The limitation is, of course, imposed by the amount of food material available under natural conditions. As soon as the food supply is stepped up in any given locality, the cockatoo population increases in a most amazing way. The writer has seen flocks of these birds over Forest Department plantations estimated to contain 5,000 to 6,000 individuals.
>
> D.H. Perry, *Western Australian Naturalist*, 1948 (p.133)

Although Perry‘s attribution of the species is incorrect, he illustrates a fundamental feature of the ecology of Carnaby‘s Black-Cockatoos—this species has adapted to the availability of an abundant anthropogenic food (plantation pine) almost since the first pines planted by then Forests Department in the Perth area began to bear cones (about 1933) (Perry, 1948). Perry goes on to describe an ecological pattern that still largely holds today:

> The cockatoos stay on the plantations until all the cones have been stripped from the trees and then disperse again in small bands. They usually commence to leave about August and September and re-appear about February and March. It will be interesting to see if, when further large areas of pine are planted, the birds will ever leave the plantation. (p. 135)

Thus, the presence of plantation pine in Perth has influenced the distribution and abundance patterns Carnaby‘s Black-Cockatoos for almost eight decades, a period that has also seen, for example, the population size of the species decline by more than one-half and its range contract by more than one-third. In many ways, the Perth pine plantations have provided a source of stability in an otherwise disappearing and fragmenting landscape. Indeed, if one needed to develop an ideal food resource for Carnaby‘s Black Cockatoos, pine would possess many of the requisite features—it is abundant, provides high energetic value, and the cones ripen (January and February) just when breeding pairs have completed the demanding process of gestating, brooding, and fledging a chick (Saunders 1974b; Valentine and Stock 2008). Despite the apparent benefits associated with pine consumption the impact of the extensive consumption of pine on Carnaby‘s Black-Cockatoo fitness remains unknown.

The Forest Products Commission (FPC) currently manages about 15 000 ha of Maritime pine (*Pinus pinaster*) (previously as high at 23 000ha) spread across three plantation areas: Gnangara, Pinjar, and Yanchep (Fig 1). The three plantation systems vary in size and the age-structure of standing crop of pine. Plantings in the Gnangara area began in the late 1920s, with the most recent plantings dating from 1989-1999. Some of the original plantings are still standing just north of Gnangara Road. The dead pine material in the Gnangara plantation is infested with European house borers (EHB), an introduced softwood pest. Most of the Pinjar plantation was planted between 1970-1978 with smaller areas planted before (1961-1969) and after (1979-1988). The oldest plantings in the Yanchep plantation date from 1961-1969, but more than half of the current standing crop was planted after 1970 (Fig 2).

B. 1930s – 1950s

Perry (1948) suggested that Carnaby‘s Black-Cockatoos began to feed on pine in the Perth area soon after they were planted in 1926 and the first cones had reached maturity (about 1933 as pine cones take seven years to mature post-planting) (Saunders 1974). By 1950, there were three large pine plantations in the Perth metropolitan area at Collier (405 ha), Somerville (810 ha), and Gnangara (1000 ha), along with several smaller ones (Fig 3, Perry 1948, Saunders 1974). Perry observed flocks estimated to include 5000-6000 birds over the plantations. These estimates likely establish a peak abundance for birds feeding within the pines at this time, as the plantations were too small to sustain such a biomass of birds for a sustained period (based on food availability estimates for pine in Valentine and Stock 2008). However, the plantations then may have possessed somewhat different characteristics (e.g. in canopy volume, cone productivity, stand density, and stand age-structure) that might have allowed them to support a large standing crop of cones (and thus more birds). Although Perry (1948) does not specifically say so, it appears that birds during this period consistently ‗stripped‘ each year‘s crop of cones from standing trees in the plantations, e.g. he notes that birds tended to ―remove most cones before they are properly ripe” and indicates that birds descended to feed on fallen cones when they were no longer any remaining in the canopy. This latter behaviour made birds ―easy prey” for foxes, based on the masses of feathers he observed. Birds appeared around the plantations in about February and March each year and departed around August and September.

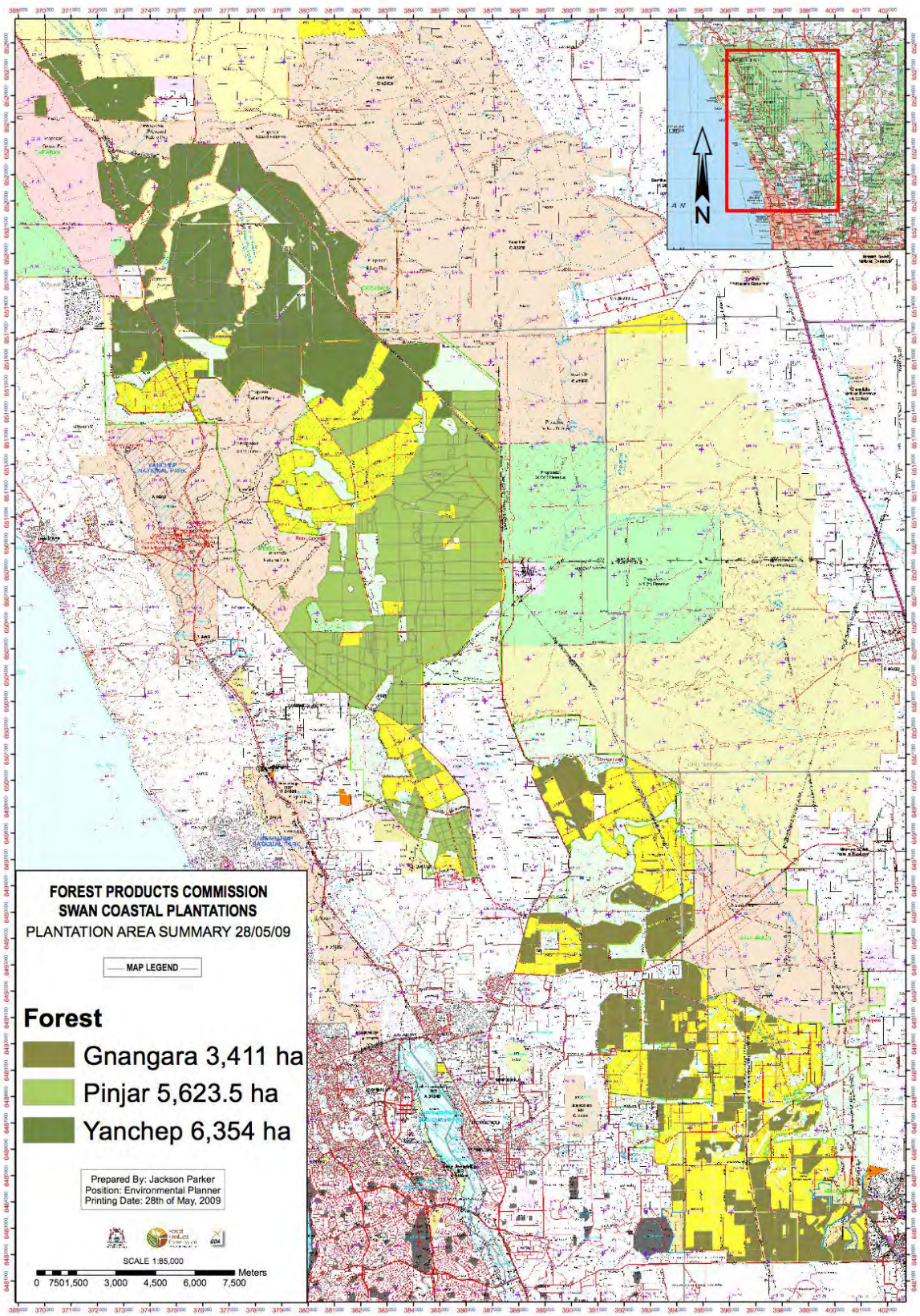


Figure 1: Extent of the three GSS pine plantations (May 2009) (from Jackson Parker, FPC)

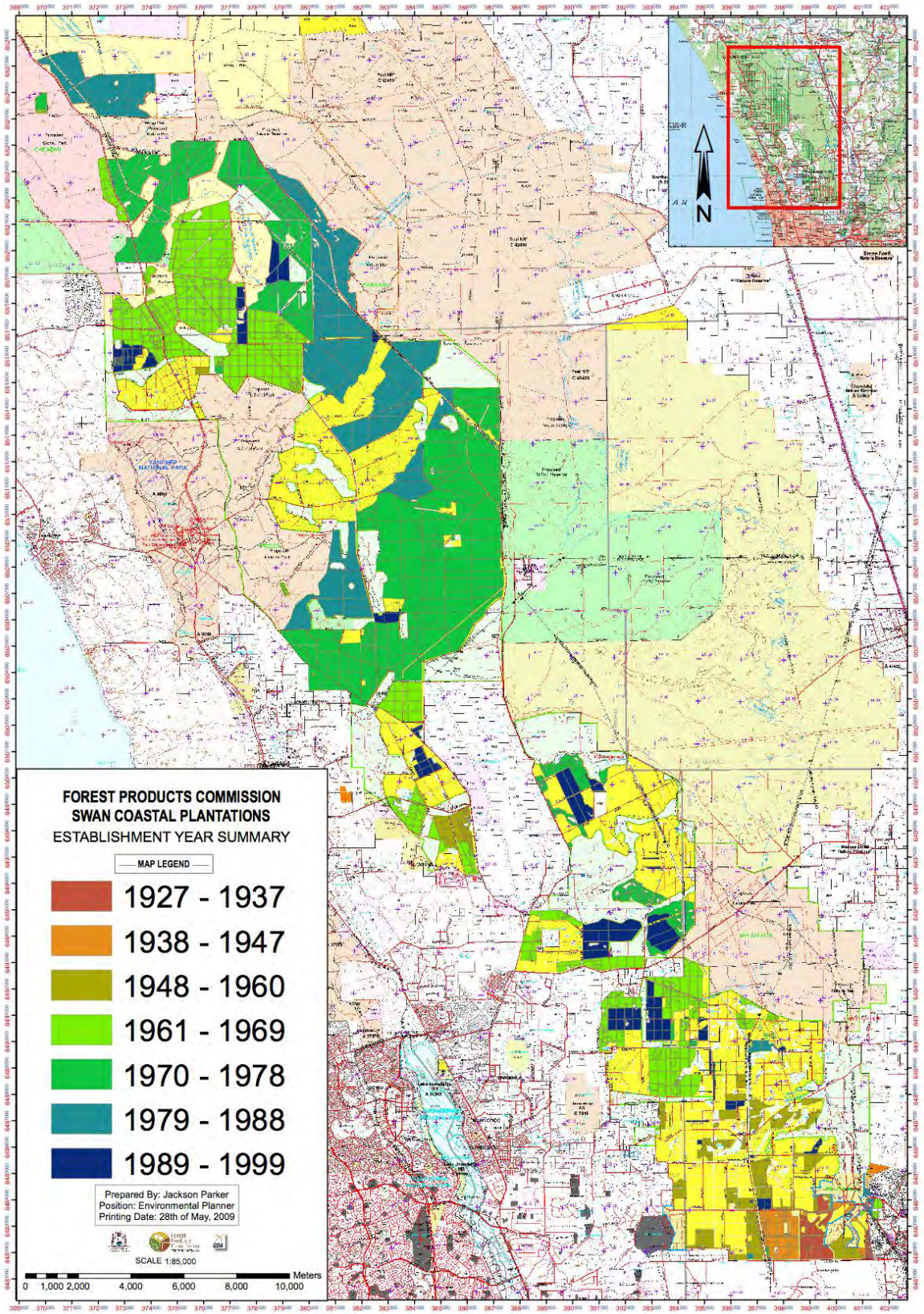


Figure 2: Plantation age plan for the three GSS pine plantations (areas in yellow have been harvested and not re-planted) (from Jackson Parker, FPC)

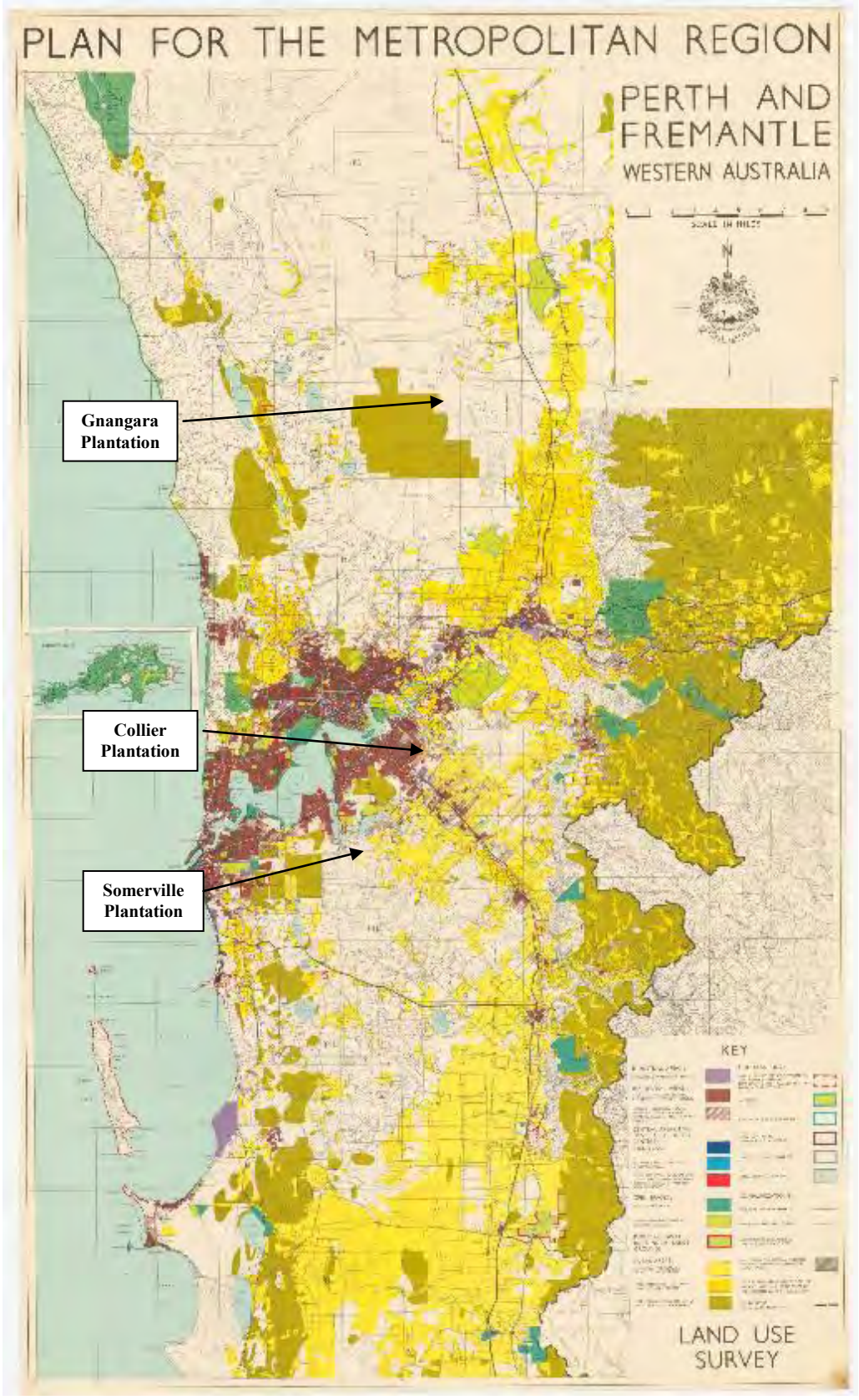


Figure 3: Perth land uses in 1953 (WAPC 2009)

C. 1960s – 1970s

Work by Denis Saunders provides a good understanding of how Carnaby's Black-Cockatoos used pine plantations in the Perth area in the 1960s and 1970s (Saunders 1974, 1980, Table 1). This period saw a decline in the size of the southern metropolitan plantations (e.g. Somerville) but a significant expansion of the plantations in the GSS area, including the planting of most of the Pinjar and Yanchep plantations and the expansion of the Gnangara plantation. Saunders (1974) suggested that, during the non-breeding season, juveniles and birds breeding in the Gnangara area might feed within the Gnangara plantation. Studies of crop contents indicated that pine was the dominant food source for birds observed within the plantations, although significant numbers of birds from the Somerville and Gnangara plantations also consumed seed from *Banksia attenuata* (34% and 14% respectively) (Table 2). Saunders (1974) observed that birds from the Mundaring plantation fed on a wider range of food items and attributed this to the fact that Mundaring was surrounded by (jarrah) forest, whereas Somerville and Gnangara were not. Saunders (1980) presented an expanded dataset of crop contents that showed a similar predominance of pine in the diets of birds within the GSS area. Feeding observations of birds between Perth and Moore River also show the importance of pine (43.7% of birds observed), but also indicate the importance of marri (*Corymbia callophylla*; 19.9%) and (to a lesser extent) *Banksia attenuata* (9.4%), as well as suggesting the breadth of diet. The latter point is important, as although birds may feed mainly on one food item (particularly for short periods of time), they may feed on other food sources either opportunistically or because they provide some nutritional value that the dominant food source does not (Cooper et al. 2002). However, the fact that birds can feed on a range of foods does not mean that they will not encounter difficulties in finding food. A highly fragmented landscape may, for example, contain a diversity of foods but none in adequate abundance to sustain flocks for any duration of time. Pine plantations possess the unique attribute of providing a food source that is sufficiently abundant and densely distributed that birds can remain resident in an area for several months at a time.

Table 1: Patterns in the presence, abundance, and feeding effect of Carnaby's Black-Cockatoos in plantations in the Perth area in the 1960s and 1970s. Adapted from Saunders (1974)

Location & Size	Time birds present	Abundance/Index of Abundance	Note
Mundaring (1620 ha)	Jan-Mar, few or none observed rest of year	mean number of birds seen per month: 600-1000 for Jan-Mar	Plantation stripped of cones; based on counts of flocks between 1960-1963
Somerville (610 ha)	Peak in Jan-Mar, decline in April, then few/none Jun-Oct, increase in Nov/Dec	Total number of cones eaten	Plantation stripped of cones; based on counts of fallen from Nov 1965-Oct 1968
Gnangara (5870 ha)	Present throughout year; peak in June-July; fewest Oct-Nov	Total number of cones eaten	Plantation not stripped of cones; some birds breed locally; large stands of marri to south (Whiteman Park)
Collier (400 ha?)	Same as Somerville		Plantation stripped of cones

Table 2: Crop contents of black cockatoos from three pine plantations in the Perth area. Values are the percentages of crops that contained seeds of each species.

Seed	Somerville	Gnangara	Mundaring
Pinus spp.	97	98	86
Banksia attenuata	34	14	
B. grandis			4
Hakea undulata		1	12
Dryandra nivea			8
D. sessilis			8
Eucalyptus calophylla		1	8
Unidentified		3	4
No. of crops examined	35	134	49
Samples collected	February-May 1966	March-August 1970	April 1971-October 1972

From**:** Saunders (1974)

D. Why cockatoos eat pine

Pine in the GSS plantations possesses several characteristics that provide a high rate of energetic return at minimal foraging cost (Table 3). The characteristics—and the overall ecological role of pine—should be seen within the context of the annual cycle of Carnaby's Black-Cockatoos, an issue that is addressed further in Part II and Part III.

Table 3: Characteristics of pine that enhance its value as a food reserve.

Characteristic	**Comments**
abundance	The GSS area pine plantations provide a large feeding habitat for Carnaby's Cockatoos, covering an area of 18 000 ha (in late 2007). Birds feed throughout the Gnangara-Pinjar-Yanchep pine plantations, as well as on solitary pine trees and patches outside of the plantations.
density	Pine occurs at high concentrations characterised by: (a) high stand densities (125-1000 trees per ha); (b) multiple cones per tree (4-60 cones per year) and multiple seeds per cone (mean seed mass of 1.54 g per cone) (Hopkins and Butcher 1992, Cooper et al. 2002, Valentine and Stock 2008). The abundance and density of pine also means that relatively large flocks can feed within the plantations.
energetic value	Cooper at al. (2002) evaluated the energy content of nine native and non-native food sources and found that pine seeds had the highest energy content (25.4 kJ $g^{=1}$). Using data on species metabolic rates, Cooper et al. (2002) estimated that 18 pine cones could support the daily energetic requirements of Carnaby's Black-Cockatoos, or about the annual number of cones that one pine tree produces in the Gnangara area (mean number of cones per year: 20.3) (Hopkins and Butcher 1992, Valentine and Stock 2008).
effort of extraction	Seeds can be extracted from pine cones relatively easily, with birds starting at the base of the cone and stripping the bracts (cone layers) back and removing the seeds within.
availability	Each year's crop of pine cones matures in January and February, thus resulting in a peak of pine cone availability during the initial stages of the non-breeding season. However, cones remain on tree throughout the year, in contrast to some other food sources that are only available seasonally (e.g. nectar in flowers). In some areas, however, birds appear to strip the standing crop of cones, but may return to these areas to forage on cones dropped to the ground at a later time.
suitability for roosting	The height and canopy of pine trees also allow them to serve as roost locations, either during the day or over-night, allowing birds to minimise travel roosting and feeding areas (although few drink sites are within the pines).

2. Problem Formulation

Scenario

The Gnangara Sustainability Study (GSS) is considering recommending the accelerated removal (without replacement) of the Gnangara, Pinjar, and Yanchep pine plantations. This would result in step-down removal of pine from a peak of ~23 000 ha of pine to ~18 000 ha in late 2007 to complete removal by about 2026. The removal of pine will reduce the amount of food available for Carnaby's Black-Cockatoos in the GSS area. Data from this study estimates that ~3000 birds are directly associated with the pine plantations (i.e. consistently feed on pine in the plantations) during the first half of the year, with a smaller number (600-1500) remaining in the area during the second half of the year and likely to also feed on pine at least some of the time. A larger number would use plantation pine on at least on occasional/transient basis and some birds are resident in the GSS area and feeding on pine year-round. The abundance of birds associated with the GSS area from February-May is thought to form the largest concentration of Carnaby's Black-Cockatoos on the Swan Coastal Plain, and pine is considered to be the principal resource sustaining this biomass of birds through much of this period.

Objective of this study

There is considerable uncertainty about the impact of pine removal on Carnaby's Black-Cockatoos, with the need for a better scientific basis for decision-making recognised for some time (e.g. Cale 2003, Mitchell 2003, Shah 2006, Valentine and Stock 2008). Given the threatened status of the species, it is highly desirable to avoid impacts which could cause population decline or interfere with the recovery of the species. This study addresses three questions raised by Mitchell (2003) in his review of the issues associated with pine removal:

1. What is the ecology of Carnaby's Black-Cockatoos in the GSS area and, in particular, what are their spatial and seasonal patterns of use?
2. How many Carnaby's Black-Cockatoos use the GSS area and the pine plantations?
3. Is the removal of pine a significant threat to Carnaby's Black-Cockatoos?

Part I and Part II address the first two questions. Part III examines the third question.

PART II
2009 GSS STUDY

Structure of Part II

Section 1 describes the methods and data sources used for this report. Section 2 provides descriptions of the abundance and general ecology of Carnaby's Black-Cockatoos within six locations in the GSS area: Gnangara, Jandabup, Pinjar, Neerabup-Nowergup-Carabooda, Yanchep, and Boongarra. Section 3 examines temporal patterns in the occurrence of Carnaby's Black-Cockatoos within the GSS area and their distribution and abundance within the GSS area. Section 4 evaluates aspects of the general ecology of Carnaby's Black-Cockatoos in the GSS area and Section 5 discusses their feeding ecology. This information provides the basis for the ecological model provided in Section 6. The model provides a conceptual framework for the ecology of Carnaby's Black-Cockatoos in the GSS area and, in particular, how their movement patterns, distribution, and food use relate to food availability and vegetation phenology. The model is open to refinement, but provides an initial framework from which to interpret previous observations and the findings from this study and apply this understanding to an examination of the potential impact of pine removal on Carnaby's Black-Cockatoos.

1. Methods and Data Sources

Data Sources

This report draws on a number of data sources. These include: (a) data collected during a field study in the GSS area from February-April 2009; (b) roost counts conducted at over-night roost sites in the GSS area from February-June 2009; (c) data in published and unpublished reports (e.g. Shah 2006, Johnstone and Kirkby 2008); and (d) other sources, such as sightings data collected by staff at Woodman Point and unpublished data from Tony Kirkby (WA Museum), Leonie Valentine (DEC), and Will Stock (ECU).

Objectives of the 2009 research

The primary objective of this study was to find flocks of Carnaby's Cockatoos within the GSS area (particularly in pine plantations) and conduct *flock follows* to: a) collect data on movement, flock size, behaviour, and habitat use; b) identify overnight roost sites; and c) obtain data for abundance estimates.

Locating flocks

To locate flocks, the study area was surveyed by vehicle starting from before sunrise (to about midday) or from midday (to sunset). After an initial broad survey, a core search area was defined. This area was bounded by the eastern margin of the pine plantations (east); Wanneroo Road (west) [excepting Yanchep Beach Road, Yanchep National Park, and Breakwater Drive]; Military Road (north); and Gnangara Road (south). Areas outside of core area were searched only infrequently.

Weekly (5 field day) research efforts focused within one of three sub-areas: (a) *South* (north from Gnangara Road to Neaves Road and west from eastern margin of pine plantations to Wanneroo Road; (b), *Central* (Neaves Road to Old Yanchep Pinjar Road but including boundary of Lake Pinjar); and c) *North* (Old Yanchep Pinjar Road to Military Road). Focusing on a sub-area allowed for repeated observations of the same flock over multiple days.

Data collection protocols

Each observation of black cockatoos was referred to as a *sighting*. When birds were observed, a *behavioural survey* was completed for the sighting to systematically collect location, behavioural, abundance, and habitat data based on a 10-minute scan sampling interval (i.e. a defined ten minute period to identify and determine the behaviour of the animals present). However, if birds were in flight or could not be directly observed, only the time, GPS location, and number of birds observed (if possible) were recorded for the sighting.

If observation conditions allowed, a flock follow was initiated. During flock follows, the following data were collected at 15 minutes point samples: GPS location, number of birds observed, estimated number of birds present, predominant activity, other activities, behaviours observed, predominant habitat type, other habitat type, microhabitat, and vegetation used (Tables 4 & 5). The point samples were based on a three-minute scan sample of the group, in which the observer attempted to observe as many individuals as possible. The predominant activity state of a group was defined as the activity state of $\geq$50% of individuals during the scan sample. The predominant habitat type of the group was defined as the habitat type occupied by $\geq$50% of individuals during the scan sample. Supplementary activity states and habitat types were also recorded and were defined as the activity state or habit type of <50% of individuals observed in a point sample. _PROB' indicates behaviour appeared to occur but couldn't be confirmed.

Observations were only considered as flock follows if flocks were observed for at least 10 minutes or to move between two locations greater than 500m apart, i.e. brief sightings, particularly of birds in flight, were not used for flock follows.

Estimating abundance

It is generally difficult to count birds that are roosting or feeding in vegetation, as birds are often obscured by vegetation. Counts of flocks in flight or on the ground in the open provide the best opportunities for accurate counts or—for larger flocks—count estimates. In this study, abundance estimates in this study are based on counts of flocks in flight. The quality of a count was categorised as: poor, medium, good, excellent, exact. Where it was not possible to count each individual (i.e. where it was necessary to count in ‗clumps'), a ‗best', minimum, and maximum estimate of the number of individuals present was also recorded. Two measures were recorded at each point sample during a flock follow: a) number of individuals observed during the three-minute scan sample (the ‗group' for the purpose of behavioural sampling) and b) the estimated number of birds present.

Flock follows provided a good way to obtain abundance estimates as flocks were often ‗all in flight' at some point during the follow, thus providing an opportunity to count or estimate all of the individuals present. Counts at dawn or dusk (i.e. when birds are entering or leaving over-night roosts) are also useful time periods because flocks often take flight all together; flocks may also fragment during the day but reassemble at the overnight roost. Drink sites are similarly useful as birds can be counted as they arrive or depart. Finally, roads, powerlines, fire breaks, or similar features provide a useful frame for counting birds as individuals can be counted as they move across the feature.

Limitations of the 2009 data

There are several limitations to data from the 2009 field study. Firstly, this research offers only a three-month ‗snap-shot' of the ecology of Carnaby's Black-Cockatoos, and thus cannot address important issues such as annual variation in abundance and distribution and seasonal changes in habitat use. However, the sampling period did cover the beginning of the non-breeding season, the period in which the use of the pine plantations is most intensive. Secondly, the study did not follow a systematic spatial sampling design, largely because the requirements of such sampling approaches tend to emphasise the sampling of *areas* over the sampling of the *animals* themselves. As such, it is somewhat limited in its ability to draw quantitative conclusions about the distribution of Carnaby's Black-Cockatoos. However, the study did identify distinct flocks and determine their abundance and general location, data that provide a greater level of insight into ecological patterns than estimates of density. An effort was also made to sample survey effort and observations across flocks and locations, although inevitably some areas and some flocks were sampled more often than others. Thirdly, survey effort focused on areas in and around the pine plantations, with relatively little effort expended within the extensive areas of Banksia woodland along the northern and eastern margins of the GSS area. The focus of this study was on the use of pine plantations by Carnaby's Black-Cockatoos and thus concentrated on locating and conducting observations of the birds occurring within or near the plantations themselves. In addition, the focus of the study was on the use of the pine plantations by Carnaby's Black-Cockatoos and thus concentrated on locating and conducting observations of the birds occurring within or near the plantations themselves. Finally, sampling effort was not spread evenly

across the day. There are statistical approaches to account for temporal biases, but they are not included here. As section 3 of Part II demonstrates the sampling effort was sufficient to identify a distinctive daily pattern and to characterise the proportion of time flocks spent engaged in particular activities. In this context, it is worthwhile emphasising that while observational approaches (such as the ‗flock follow' method of this study) often encounter various temporal and spatial biases, they are based on field observations of behaviour, abundance, habitat use, and activity patterns, and thus have a uniquely valuable role in ecological research.

Roost counts

Nocturnal roost counts were conducted at known roosting locations in the GSS area (Fig 4). Counts followed a methodology developed by DEC, Birds Australia, and others for use in monitoring of Carnaby's Black-Cockatoos in the Perth metropolitan area.

Table 4: Habitat types defined for the 2009 GSS study

Code	Meaning	Definition
PF	Pine Forest (plantation)	
PW	Pine Woodland (plantation)	pine trees <20m and/or at low stand densities; young planted pine or regenerating pine
BW	Banksia Woodland	woodland of *Banksia* spp., typically *B. attenuata* or *B. menziesii*
TW	Tuart Woodland	
OW	Other Woodland	e.g. non-tuart eucalypt or mix of marri and *Banksia* spp.
DT	Dryandra Thicket	*Banksia* (formerly *Dryandra) sessilis* with admixtures of *Xanthorrhoea* and *Banksia spp*.
HSE	Homestead	suburban or semi-rural properties (e.g. households, farms)
MO	Modified Land	e.g. quarry
MG	Market Garden	
PD	Pine-Debris (plantation)	area of felled pine with branches on ground

Table 5: Activity states defined for the 2009 GSS study

Activity State	Definition
ROOST-OVERNIGHT	over-night roosting
ROOST-REST	long-term roosting (>1 hour)
ROOST-SHORT	short duration roosting, as while feeding/foraging or during pauses in flight
FLY	in flight
FEED	consuming or processing food items, or actively searching for food items
PREEN	preening self or another individual
FEEDJUV	feeding juvenile
DRINK	drinking
SOCIAL	interaction with another individual in a manner not covered in other activities such as preening (e.g. squabble)

2. Location Descriptions

Observations and sampling effort during the 2009 study

Field-work occurred over 30 days between 2 February and 1 May 2009 and included 76 sightings and 42 flock follows (Fig 5). Flock follow observations were conducted for 98.13 hours (mean follow duration = 2.27 hours; range 0.17 to 7.42 hours) and 421 point samples. Descriptions of the sightings and flock follows are included in the location descriptions in this section.

Locations

This section describes the sightings and flock follows within six locations in the GSS area (Fig 6). These locations were defined on the basis of how flocks were distributed across the study area during February and March 2009, with each location containing one distinct flock in these months. The flocks are referred to by the location in which they were observed (e.g. Gnangara flock, Boongarra) and are described further in the location descriptions following. Observations in April 2009 indicated a different flock distribution within the GSS, which is also discussed in location descriptions. The next section examines the overall distribution of Carnaby‘s Black-Cockatoos within the GSS and the changes in this distribution pattern, as well as providing overall abundance estimates.

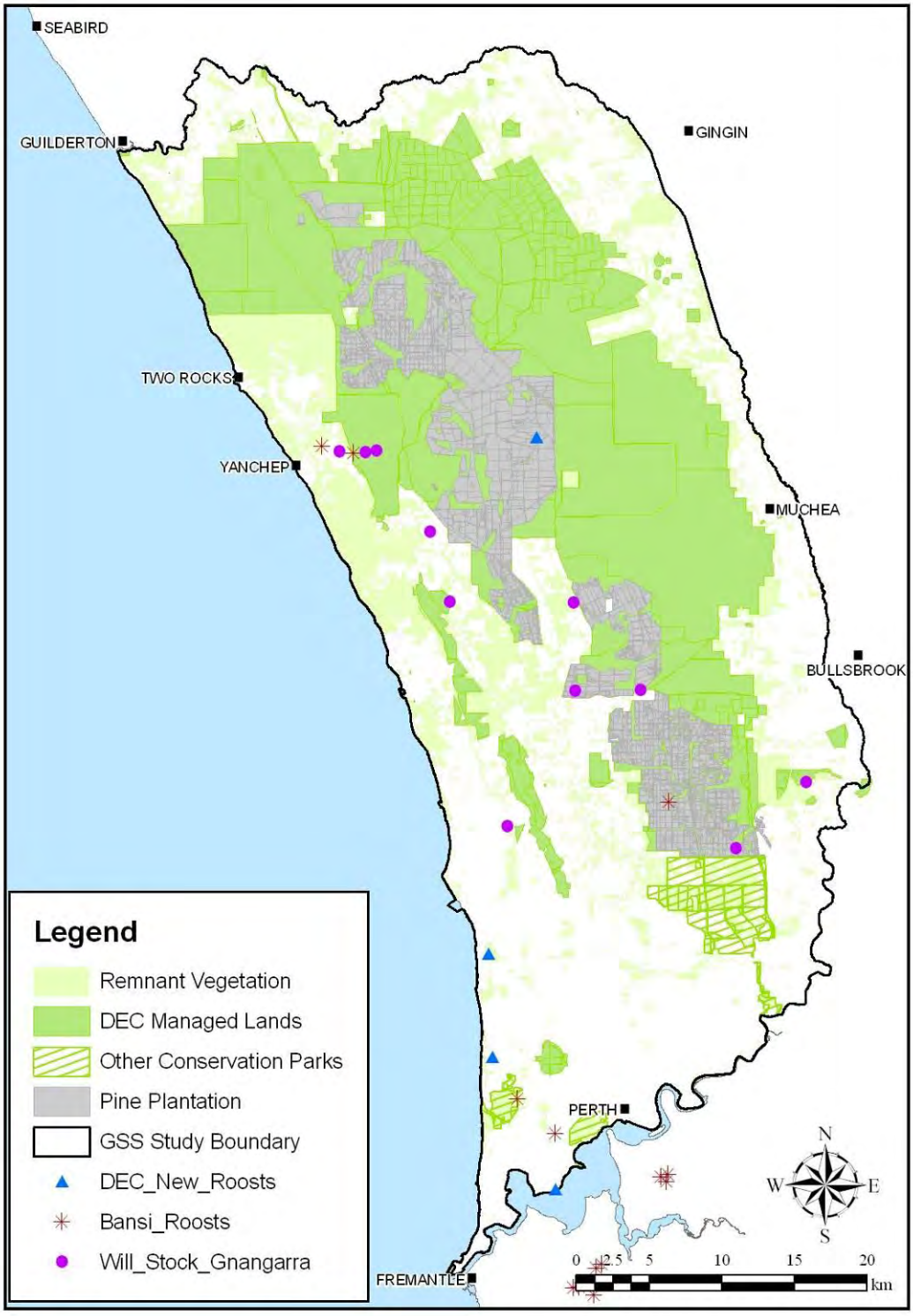


Figure 5: Location of roost sites in the GSS area. These are monitored by DEC, W. Stock (ECU), P. Berry, Birds Australia, and others. The SeaTrees roost site is located directly east of Two Rocks 1km east of Wanneroo Road.

Roost Counts

The location descriptions include observations from weekly roost count sites situated within them (W. Stock, ECU, unpublished data; DEC, unpublished data). The number of roost counts for each site varies, with some roost sites surveyed on a weekly or near-weekly basis from January-June 2009, while other sites were surveyed only a few occasions.

Other Data Sources

Some location descriptions include data collected for other studies within the GSS area (Shah 2006; T. Kirkby, WA Museum, unpublished data) and by personnel working at Yanchep National Park (H. Beswick, DEC Yanchep) and Whiteman Park (Terry Verney, Chris Rafferty, DPI). Use and ownership of these data is acknowledged in the text and the authors kindly acknowledge their use in this report. Maps for the flock follows in Shah (2006) are extracted from the original document in pdf form (available from Birds Australia website) and appear courtesy of Birds Australia. DEC personnel (C. Sanders, DEC Wanneroo and others) conducted these follows in 2006.

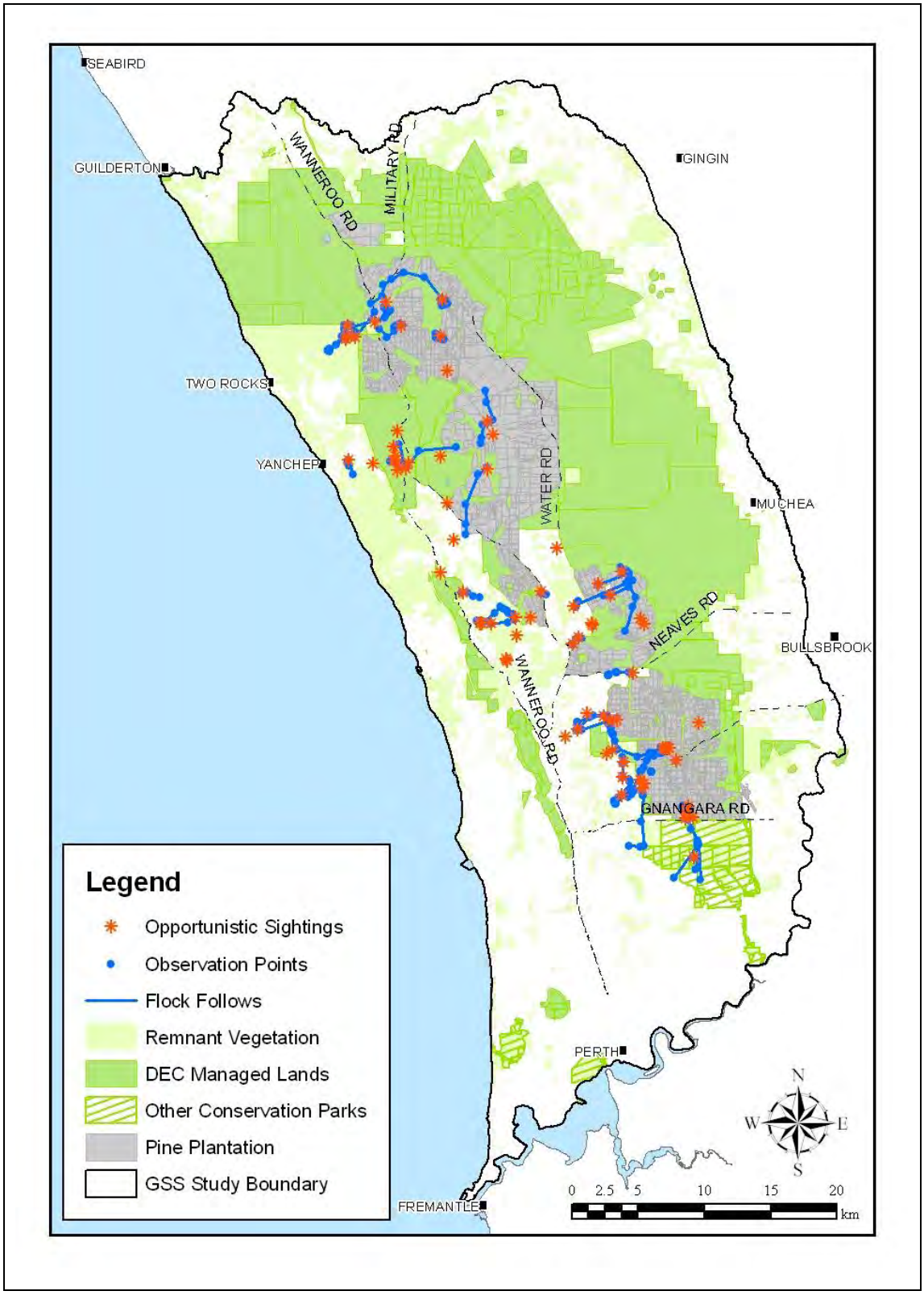


Figure 5: Locations of all sightings [*], flock follows [——], and locations of point samples [●] for flock follows during the 2009 GSS study.

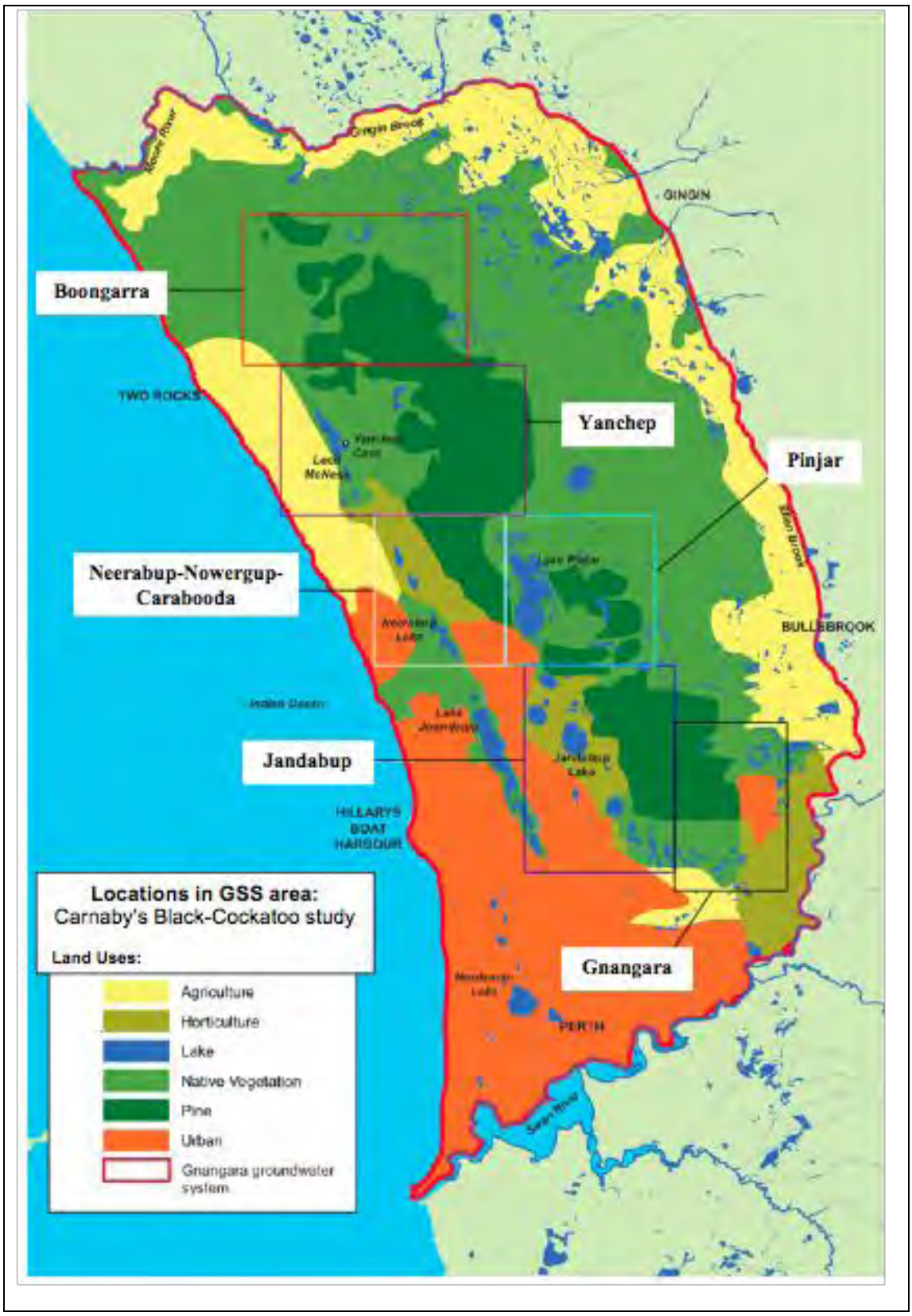


Figure 6: Locations defined for observations of Carnaby‘s Black-Cockatoos in the GSS area for the 2009 study.

A. Location Descriptions: Gnangara

Environmental Characteristics

This area includes the southern section of the Gnangara plantation, Whiteman Park (including the area around the adjacent Telstra telecommunications complex), native vegetation along the eastern margin of the Gnangara plantations, suburban areas (e.g. Ellen Brook), and market gardens. The largest section of pine within this area is just north of Gnangara Road (roughly around Centre Road and eastwards). These pines are also the oldest pines within the GSS plantations with some planted in the late 1920s. European house borers (EHB) occur within the Gnangara plantations and all, or nearly all, of the pines in this area will be removed as a part of an eradication program. Whiteman Park and other areas of remnant vegetation are relatively extensive, consisting mostly of Banksia woodland but also some areas of marri woodland (mainly in Whiteman Park). Saunders (1974) noted that birds in the Gnangara plantation bred locally and it's possible that they may have done so in the marri woodland areas.

Basis for Flock ID & Estimate of Abundance

Best estimate of size: 350
Best counts: 330 (17 March 2009), 411 (10 March 2009 – roost count)
Estimated Range: 325-425

The defining feature for this flock is its tendency to roost in the pines to the north of Gnangara Road (although the exact roosting location appears to shift), leading to several partial counts of >100 birds at dawn and dusk during the 2009 and a good dawn count of 330. Roost counts by W. Stock (ECU) recorded variable numbers of birds roosting, but also one count of 411. This suggests that birds may sometimes roost all at one location but at other times might be distributed across different roost sites or spread across a large area of the pines north of Gnangara Road. Flock follows in the 2009 study and Shah (2006) (Figs 7 & 8) indicate that the flock at least occasionally forages as a large aggregation, although more often fragmenting into smaller foraging parties.

Ecology

This flock roosts consistently in the strip of pine just north of Gnangara that runs from just west of Beechboro Road east to the western edge of the Ellen Brook development. The pines in these stands are the oldest (and probably largest) pines in the Gnangara plantation. Most also have well-developed canopies meaning that they provide good roosts and also sustain relatively large abundances of cones that birds can feed on before leaving a roost. An additional advantage of the roost is the availability of a water source at the Hammersley Centre to the south of Gnangara Road. Birds also appear to feed in the pines here in the late afternoon/evening before assuming an overnight roost. There also appear to be

other roost sites scattered through the area, including one within Ellenbrook. Water sites are probably relatively common in the area, such as around households and several wetlands.

Birds in this flock appear to feed both on pine within the plantation (probably mostly in the southeastern corner but possibly up to Neaves Road and west to Jandabup) and on native vegetation within and outside the plantation boundaries. Aside from pine in the plantation, potential feeding habitats include: Whiteman Park and around the Telstra communications centre, Banksia woodland along and adjacent to the eastern margin of the plantation, areas of remnant vegetation in the Henley Brook area, and in market gardens.

Two flock follows (Fig 7) and observations of Whiteman Park staff suggest that feeding activity within Whiteman Park is greatest during late summer (February-March). Marri is in flower in this period and birds were observed feeding on marri flowers (which would include nectar and possibly insects) during a flock follow on 17 March. However, birds are likely to feed on Banksia woodland within the park throughout the year, possibly with greater intensity later in the second half of the year when *Banksia attenuata* cones mature and *Banksia menziesii* is in flower. Outside of the plantation and Whiteman Park, the feeding ecology of birds is likely to be broadly similar to that observed for flocks in urban portions of the GSS area and for the flock observed in the Jandabup area.

There are at least two potential areas of uncertainty with this location. One, it is possible that this ‗flock' actually includes two portions: one ‗resident' group of ~130 birds through at least the beginning of May (based on combined dusk counts of ~130 birds on 21 April and 5 May) and another group of ~220+ associated with the area in February and March but moving out of the area in April. Two, dusk counts do not capture full abundance of birds in the area, with birds often divided across multiple over-night roosts (e.g. Centre Road-powerline, pines around Gaskell Road, and other sites such as Ellen Brook).

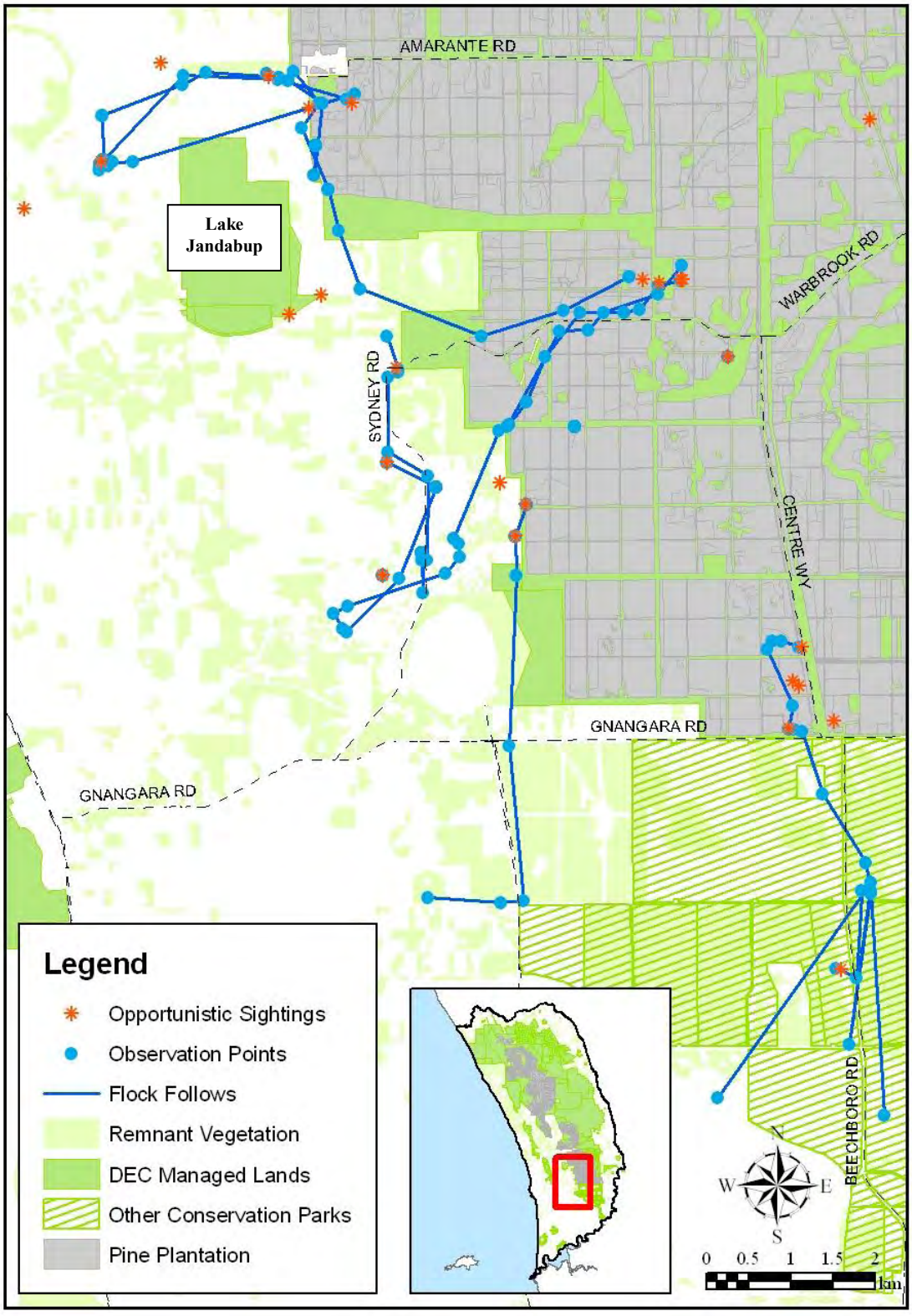


Figure 7: Locations of sightings and flock follows around the Gnangara and Jandabup study locations (2009 study).

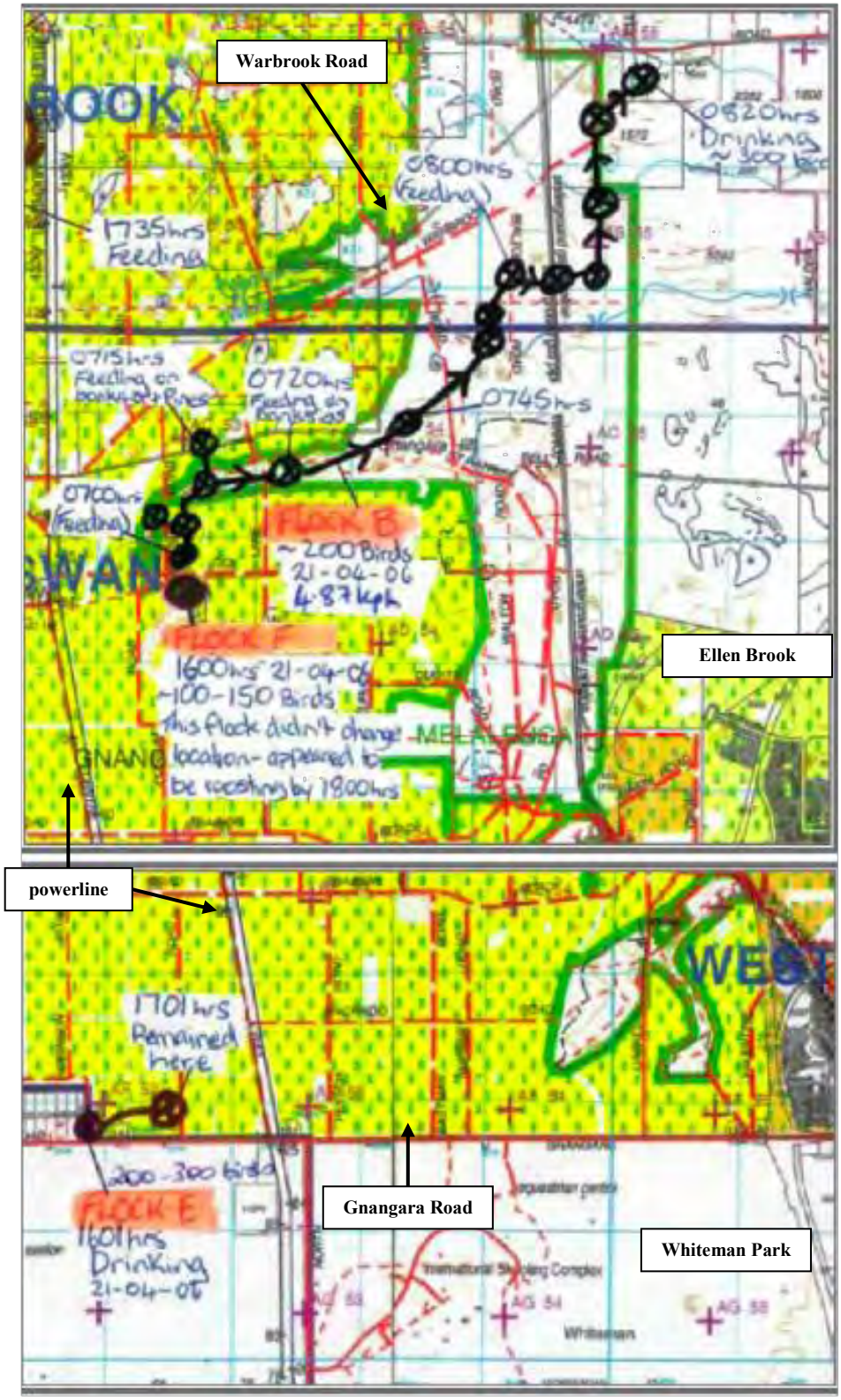


Figure 8: Flock follows from Shah (2006)
Top: **Flock B** (21/4/06, 07h00 – 08h20) and **Flock F** (21/4/06, 16h00 – 18h00) [east of powerline corridor and northwest of Ellenbrook development; ends at Warbrook Road]
Bottom: **Flock E** (21/4/06, 16h01 - 17h01) [just north of Gnangara Road on powerline corridor]

B. Location Descriptions: Jandabup

Environmental Characteristics

The dominant environmental features of the Jandabup area are the four lakes: Lake Gnangara, Lake Jandabup, Lake Maringup, and Lake Adams. The four lakes have varying degrees of remnant vegetation (potential feeding or roosting habitat) around them and it is possible that birds may occasionally drink from the shorelines. Beyond this, the area off-plantation is mixed suburban and semi-rural, with a landscape comprised of settlements, market gardens, small farms and agistments, and patches of remnant Banksia woodland (e.g. at the western edge of the Gnangara plantation). Relatively little pine remains, with the largest stands in the north-eastern corner south of Neaves. Some areas used for roosting and feeding in the 2009 study and in Shah (2006) have now been harvested.

Basis for Flock ID & Estimate of Abundance

Best estimate of size: 400
Best counts: 390 (6 February 2009), 430 (5 March 2009)
Estimated Range: 380 to 430

The combined observations of the 2009 study and Shah (2006) (Figs 7 & 9) indicate that this flock is distinct and—at least for periods of the non-breeding season—linked to the Jandabup area. The best counts for this flock indicate a flock size of around 400 birds, with the 6 February count better than the 5 March count. Observations from other sources are difficult to interpret. The Kirkby sighting of 1403 on 9 April 2008 would suggest an aggregation of several flocks, possibly aggregating in this area before beginning to feed on *Banksia sessilis* (note similarity of flock size with ‗Dryandra' flock in the 2009 study – see Neerabup-Nowergup-Carabooda section). The over-night roost sightings in Shah (2006) would appear to be close to those of the Silver Road roosts in 2009, which would equate with count of 380 on 29 April 2006 but not the count of 825 on 1 May 2006. A flock size of 400 would also be roughly equivalent with the flock sizes estimated in the Shah (2006) flock follows. The 2009 roost counts in the Neaves Road did not appear to capture the full flock size, but the counts on 3 March and 10 March 2009 coincide with the flock follow on 5 March 2009.

Ecology

This flock is associated with the western half of the Gnangara plantation south (and just north) of Neaves Road and the semi-rural areas to the west (around Lakes Gnangara, Jandabup, Adams, and Maringup). They appear to over-night roost in pines on the plantation and often to feed on pine, particularly around dawn and dusk. However, they appear to spend considerable time feeding outside of the plantation based on flock follows in 2009 and in Shah (2006). The flock does not have a consistent roost site, but moves around the Jandabup area and roosts in pine near to where they have

been feeding (and probably also to drink sites). They may break into smaller flocks, either for the day and then re-aggregating at an over-night roost, or for longer periods.

The flock follows in Shah (2006) indicate that birds may have still been in the Jandabup area in late April and little survey effort was spent around Jandabup in April 2009 to confirm the presence or absence of the flock. However, two factors suggest that this flock may have been part of a large flock (see Neerabup-Nowergup-Carabooda section) observed feeding on *Banksia sessilis* around the Wattle Avenue area in late April. Firstly, some daily movement patterns observed in February and March 2009 were almost identical to those observed in late 2009. This suggests that the loss of pine within the Gnangara plantation between 2006-9 may have caused birds in 2009 to forage more outside the plantations and to begin feeding in ‗off-plantation' feeding habitats earlier in the non-breeding season than previously. Secondly, it is also possible that 2009 was a particularly ‗good' year for *Banksia sessilis* in the GSS area, and this may have drawn birds away from the Jandabup area (and other areas).

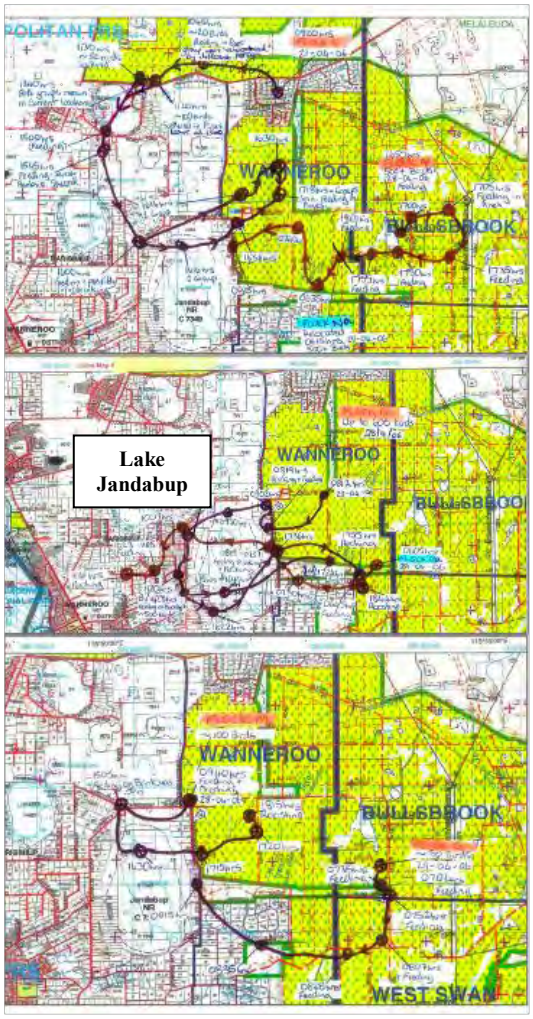


Figure 9: flock follows from Shah (2006)
Top: **Flock Na** (29/4/06, 06h15 - 08h15), **Flock N** (28/4/06, 16h50 - 18h30), and **Flock C** (21/4/06, 08h20, 10h45 - 17h18)
Middle: **Flock Ga** (29/4/06, 06h05 – 11h41) and **Flock G** (28/4/06, 08h12 – 18h44)
Bottom: **Flock O** (29/4/06, 07h02 - 09h15) and **Flock M** (28/4/06, 09h40 - 18h15)

C. Location Descriptions: Pinjar

Environmental Characteristics

The defining feature of the Pinjar area is Lake Pinjar, and while the area adjacent to the lake has little Banksia woodland there are areas of remnant woodland that provide good roosting habitat. Farms and small homesteads also provide roosting habitat, either in exotic trees (pines and eucalypts) or remnant native trees. The area also includes: a) the northern Gnangara and southern Pinjar plantations, both of which have largely been harvested and b) relatively large areas of Banksia woodland (e.g. to the east of Perry Road and to the north of Lake Pinjar.

Basis for Flock ID & Estimate of Abundance

Best estimate of size: 390
Best count: 390 (16 February 2009)
Estimated Range: 370-410

The February flock follows indicate that this is a distinct flock and is associated with the Pinjar area during at least February and March (Fig 10). It is highly likely that in April this flock shifted west to feed on *Banksia sessilis* as part of the _Dryandra' flock (see Neerabup-Nowergup-Carabooda section).

Ecology

In February and March this flock appeared to feed in pine to the east of Perry Road and on the west side of Lake Pinjar, with roost sites along Perry Road and in pines to the east of Perry Road and to the west of Lake Pinjar. There are several private homestead properties with native or exotic trees that are used for day and over-night roosts, including a patch of remnant woodland on Anderson Road at the eastern edge of Lake Pinjar. The flock appears to transit across Lake Pinjar to use pine to the west of Old Yanchep Pinjar Road, while returning to the eastern side to roost and probably to drink. In April this flock was not observed to the east of Lake Pinjar and is likely to have been part of a large flock (n = 1785 on 23 April, n = 1250 on 24 April) feeding in *Dryandra* thicket along the limestone ridge to the east of the Alf Barbagallo raceway and roosting in pines to the north of Wattle Ave Avenue East. This large flock is likely to have included birds from the Gibbs Road flock, and possibly also the Jandabup flock, although the aggregate of these three flocks would still leave about 700 birds unaccounted for [n = 390 (LP) + 250 (GR) + 430 (J) = 1070], suggesting that this flock may also include birds drawn from the north (YNP) or west (Joondalup).

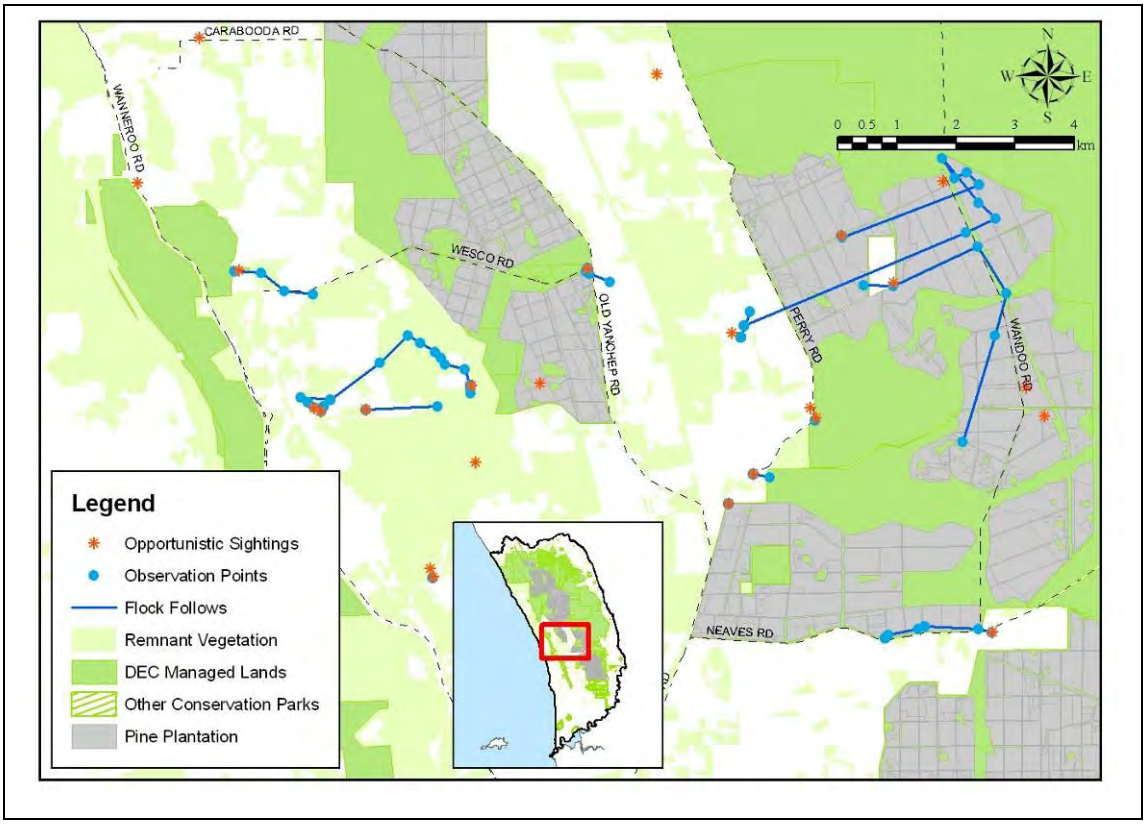


Figure 10: Locations of sightings and flock follows around the Pinjar study locations (2009 study).

D. Location Descriptions: Neerabup-Nowergup-Carabooda

Environmental Characteristics

The area contains a range of homesteads, farms, market gardens, remnant tuart woodland, and *Banksia sessilis* thickets running along an axis south of Lake Neerabup (Flynn Drive) to Lake Nowergup and up through the Carabooda area. The Pinjar plantation runs along the eastern and northern (north of Old Yanchep Pinjar Road margins.

Basis for Flock ID & Estimate of Abundance

A. Neerabup-Nowergup-Carabooda

Best estimate of size: 250

Best counts: 230+ (18 February 2009), 350 (24 March 2009), 265 (5 May 2009), 250 (12 May 2009)

Estimated Range: 230-275

There were two flocks within this area. The first, from February-March, was a flock roosting over-night at some sites in the area (e.g. the Gibbs Road and Carabooda sites), and feeding either in the Pinjar plantation or in other habitats such as the thickets of *Banksia sessilis* covering many of the limestone ridgelines in this area (Fig 11). The flock may also roost over-night in pine, moving off-

plantation to drink and day-roost. The roost counts in May suggest that the flock also occurred as a discrete unit in the area in this month.

B. _Dryandra‘

Best estimate of size: 1785
Best count: 1785 (23 April 2009)
Estimated Range: 1750-1820

The second flock (referred to here as the _Dryandra‘ flock) occurred in the area in late April feeding on *Banksia sessilis* around the Charles Searson fire tower and roosting over-night in the pine plantation northeast of the Alf Barbagallo raceway. The _provenance‘ of the birds in this flock is not known, i.e. it is not known from which locations the birds in the Dryandra flock came from. It seems likely that the flock included _local‘ birds, i.e. birds from the flocks associated with: (a) Neerabup-Nowergup-Carabooda flock (*n* = 250) and (b) Lake Pinjar flocks (*n* = 390), and possibly also (c) Jandabup (*n* = 400) and (b) Gnangara (the _non-resident‘ group of *n* = 220+). The combined presence of those four flocks (or parts of them) could account for all (or a large proportion) of the birds present at the over-night roost on 24 April (*n* = 1250), but would leave at least 500 birds unaccounted for from the large feeding aggregation observed on 23 April (*n* = 1785) (and probably more if not all of the four flocks mentioned above were present).

This suggests the presence of an _outside‘ flock, i.e. a flock moved into the area in April that had not been observed in February and April. This flock may have come from the urban areas to the west or south (e.g. from around Joondalup) and/or areas north of Boongarra. It is also possible that this flock included some or all of the _extra‘ birds observed at Yanchep at this time, although issues of timing and distance suggest the lack of overlap (see further below and in _Yanchep‘ next section).

Ecology

A. Neerabup-Nowergup-Carabooda

The flock appears to range within the area roughly defined by Wanneroo Road to the west (but including *Banksia sessilis* thickets west of Wanneroo Road), Flynn Drive to the south, Lake Pinjar to the east, and probably the boundary between the Pinjar and Yanchep plantations to the north. The flock uses sites within Neerabup-Nowergup-Carabooda as day and over-night roosts and water sources, feeding within the Pinjar plantation to the north and east and within *Banksia sessilis* thickets. There are also areas of *Banksia sessilis* and Banksia woodland to the east of Wanneroo Road and birds may feed there. The area contains several areas of remnant tuart woodland and also some good stands of tall exotic eucalypts. The farms, homesteads, lakes, and wetlands provide potential water sources. It is likely that some _overlap‘ with flocks associated with Yanchep National Park and the pines directly north of Old Yanchep Pinjar Road, i.e. birds observed in those areas of the pine plantation may be drawn from either the Neerabup-Nowergup-Carabooda flock or those birds associated with Yanchep

National Park (see next section). For example, it is not clear which location the birds observed in flock follow ‗D' in Shah (2006) belonged to (Fig 12).

B. Dryandra

The Dryandra flock observed in the Neerabup-Nowergup-Carabooda appears to be distinct from a second large flock observed in the GSS period during this time. (i.e. April-May). This second flock was observed at Yanchep National Park and Bernard Road and is also thought to have fed on *Banksia sessilis* (see next section). High dusk counts were observed at Yanchep National Park on 21 and 28 April, suggesting that birds roosting in the Yanchep area were not the same as the large flocks observed on 23 and 24 April around the Charles Searson fire tower (and observed over-night roosting at the raceway in a count of at least 1250 on 24 April). It seems unlikely that birds travelled between the fire tower feeding area and Yanchep National Park given the distance between Yanchep National Park and the fire tower (>10 km) and the availability of roosting and drink sites within the Neerabup-Nowergup area.

During April and May, birds that were feeding on *Banksia sessilis* in the area also fed in market gardens, based on observations in the 2009 study and discussions with staff working at the market gardens. One individual noted that the birds started to feed in the market gardens at about the beginning of April, which appears to coincide with the time at which birds began feeding on *Banksia sessilis*.

Figure 11: Flock follow on 24 April 2009 showing movement (blue arrows) from over-night roost north of Alf Barbagallo Raceway west towards feeding areas (green) in *Banksia sessilis* around the Charles Searson fire tower and in market garden near Neerabup.

Figure 12: Flock D (21/4/06, 16h20 – 18h00) [junction of Aqua Road and Old Yanchep - Pinjar Road]

E. Location Descriptions: Yanchep

Environmental Characteristics

The dominant feature of the Yanchep area is the Yanchep National Park (YNP), as the area around the park facilities provides both roosting habitat and a water source (Yanchep Swamp). The park also includes feeding habitats in tuart woodland and *Banksia* woodland, and possibly some nest hollows in mature tuarts or other trees. There are areas of *Banksia* woodland, *Banksia sessilis* thicket, and coastal heath to the east of south of the park. The Pinjar and Yanchep pine plantations lie to the east. The fire in summer 2009 effectively removed large areas of potential feeding habitat for the 2009 study, both temporarily (burnt areas of Banksia woodland will recover within a decade) and permanently (some fire-affected plantation areas have been harvested). The Yanchep Swamp appears to be the dominant water source, but there are other water sources south of Old Yanchep Pinjar Road in wetlands and around market garden/homesteads.

Basis for Flock ID & Estimate of Abundance

The dusk counts provide the best data source for abundance estimates as the 2009 flock follow study (Fig 13) did not obtain good total counts for the birds associated with the area. Table 6 divides the dusk counts into five time periods: (1) an initial peak in abundance with birds arriving back at Yanchep from

breeding areas and possibly some birds staying briefly before moving on to other feeding areas; (2) a period of relatively static abundance through the end of March; (3) a second peak in abundance in April with another flock present (see below); (4) a three-week period in which birds were absent; and (5) a return to an abundance similar to that in March.

Table 6: Combined Yanchep dusk counts for 2009. *not including 17 March

Period	Date	Count (mean)	Probable Activity
1	3 – 17 February	939	Feeding in pine; birds traveling through to other areas
2*	24 February – 31 March	717	Feeding in pine
3	7 – 28 April	1379	Feeding on *Banksia sessilis* and pine; other flock present?
4	5 – 19 May	75	Not present - feeding on *B. sessilis*; at Bernard Road
5	26 May – 2 June	637	Back to feeding in pine and other food sources?

During at least February and March, the dusk counts may not capture the full abundance of birds associated with Yanchep National Park. Based on flock follow observations from Shah (2009) (Fig 14) and other sightings (T. Kirkby, WA Museum), some birds may: (a) roost over-night in pine to the east; (b) return in the morning to drink and roost; (c) return to pine feeding areas in the afternoon; and (d) possibly remain in pine for the rest of the day (i.e. not return to Yanchep National Park at dusk). This pattern may also change over time. For example, birds may roost over-night in pine more frequently in March than in February as feeding areas in pine that are closer to the park become depleted and birds have to travel greater distances between feeding sites and the park.

Ecology

Are the birds associated with Yanchep National Park one large flock?

Rather than being one unitary flock, the birds associated with Yanchep National Park are likely to consist of several sub-flocks. These sub-flocks probably differ slightly in food and roost preference and thus might display different movement patterns and daily patterns (Fig 13), but all are bound to the park as a drink site and as a frequent day roost.

How do the 2009 counts compare to those in Saunders (1980)?

For the February-March period, the 2009 counts are similar to those observed in 1975-6 (Saunders 1980). In both studies, there is a peak in abundance in February-March (with a maximum abundance of about 1000 birds. However, the 2009 counts showed a larger peak in abundance in April. The April peak lasts for four weeks (7-28 April), after which counts drop off to ≤150 birds for three weeks (with

655 birds observed at the Bernard Road roost on one occasion), before rising to 738 (26 May) and 535 (2 June). In contrast, Saunders (1980) shows a step-down to an abundance of ~500 birds from April-June. In the absence of pre-2009 count data, these data are somewhat problematic to interpret but do suggest a change in the ecology of birds associated with Yanchep National Park after 1975-6. One change is in the availability of pine. In 1975-6, pine would only have been available in the westernmost sections of the Yanchep plantation areas directly to the north of the park and in the southern sections of the Pinjar plantation to the southeast (Fig 2). Other stands in the Yanchep and Pinjar plantations were planted after 1970 and thus would not have produced cones until 1977 at the earliest. The second change appears to be in the use of *Banksia sessilis* as a food source. Crop content and feeding observation data in Saunders (1980) suggest that *B. sessilis* was not an important food source for birds on the northern Swan Coastal Plain. In contrast, the 2009 study indicates that *B. sessilis* is a focus for feeding activity in April and May. Further, the patterns observed in April and May 2009 can be best explained by most of the Yanchep-associated birds feeding on *B. sessilis* (see further below).

Where did the 'extra' birds in April come from?

The April counts indicate the presence of an additional ~650 birds (relative to counts from 24 February to 31 March). There are several sources that could account for this increase in abundance:

(a) some birds shifted to Yanchep from Boongarra

April observations from Boongarra did not indicate any decline in abundance from February or March.

(b) some birds shifted to Yanchep from another location (e.g. Neerabup-Nowergup-Carabooda, Pinjar)

While it is possible that birds from more southern locations did move into the Yanchep area from the southern locations, it appears more likely that the 'southern flocks' were part of the 'Dryandra' flock observed around Neerabup in late April (see previous section).

(c) more of the Yanchep birds that roosted over-night in pine were present at dusk counts

This may have occurred but is not likely to have accounted for more than a small amount of birds. There does seem to have been a shift in feeding focus from pine to *B. sessilis* and this may have changed movement and roosting patterns for birds within the Yanchep flock.

(d) flock moved in from another location (north of GSS and/or from southern urban GSS areas)

This appears to be the most likely scenario and would suggest the pattern in the next question.

What is the most plausible explanation for the shifts observed in April and May?

1. Beginning of April

A non-resident flock arrives and begins roosting at Yanchep National Park and feeding on *B. sessilis* in the surrounding area (probably within a 5-7km radius). Many of Yanchep-associated flock begin feeding on *B. sessilis*, although some (≥130) birds are feeding on pine through April (and travelling from the park eastwards at dawn).

2. May 5-19

   The non-resident and Yanchep-associated flock shifts southeast, roosting around the Bernard Road area and possibly at other locations and continuing to feed on *B. sessilis*, again within a 5-7 km radius of the roost site.

3. May 26 and after

   Yanchep resident flock is again roosting at Yanchep National Park, while the non-resident flock has moved northwards. The non-resident flock may be at Boongarra on 26 May.

Were Yanchep birds present also present in the 'Dryandra' flock observed at Neerabup in April?

It is possible that some of the birds that were roosting at Yanchep National Park in April were also in the flocks observed around the Charles Searson fire tower (_Dryandra' flock) on April 21, 23, and 24. However, on 21 April there were at least 690 roosting over-night around the fire tower and 1507 recorded at the Yanchep sites. In addition, these two sites are more than 10km distant, so it would seem unlikely that birds would move between these areas, but rather would roost closer to where they had fed during the day feeding. Indeed, the Yanchep assemblage appeared to have moved to the southeast (around Bernard Road) the first week of May. The roost counts in April are also relatively consistent, although with some changes in local roost site (e.g. Yanchep Park vs. Yanchep office), as would be predicted by a large assemblage remaining in one area rather than moving about between different areas.

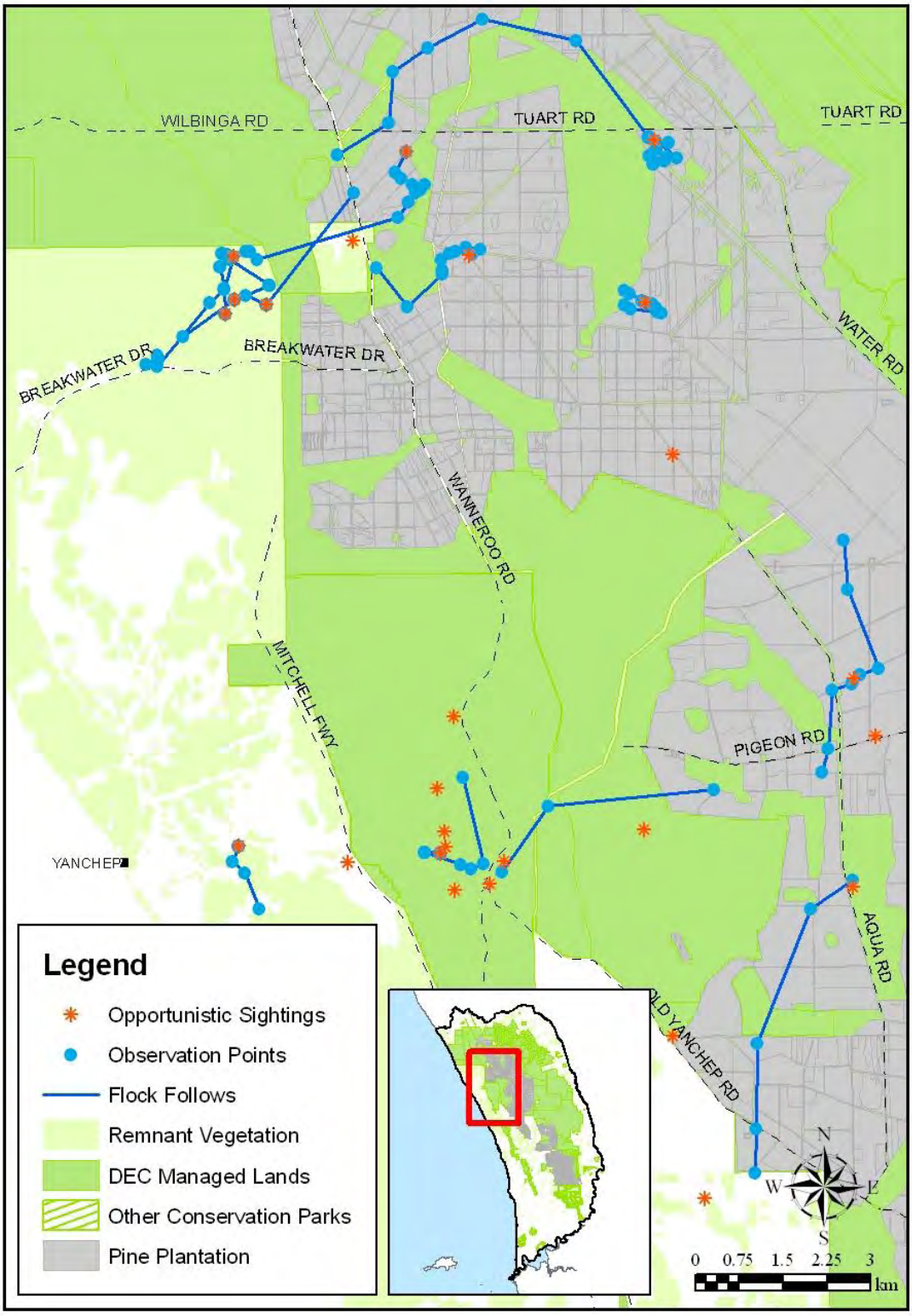


Figure 13: Locations of sightings and flock follows around the Yanchep study locations (2009 study).

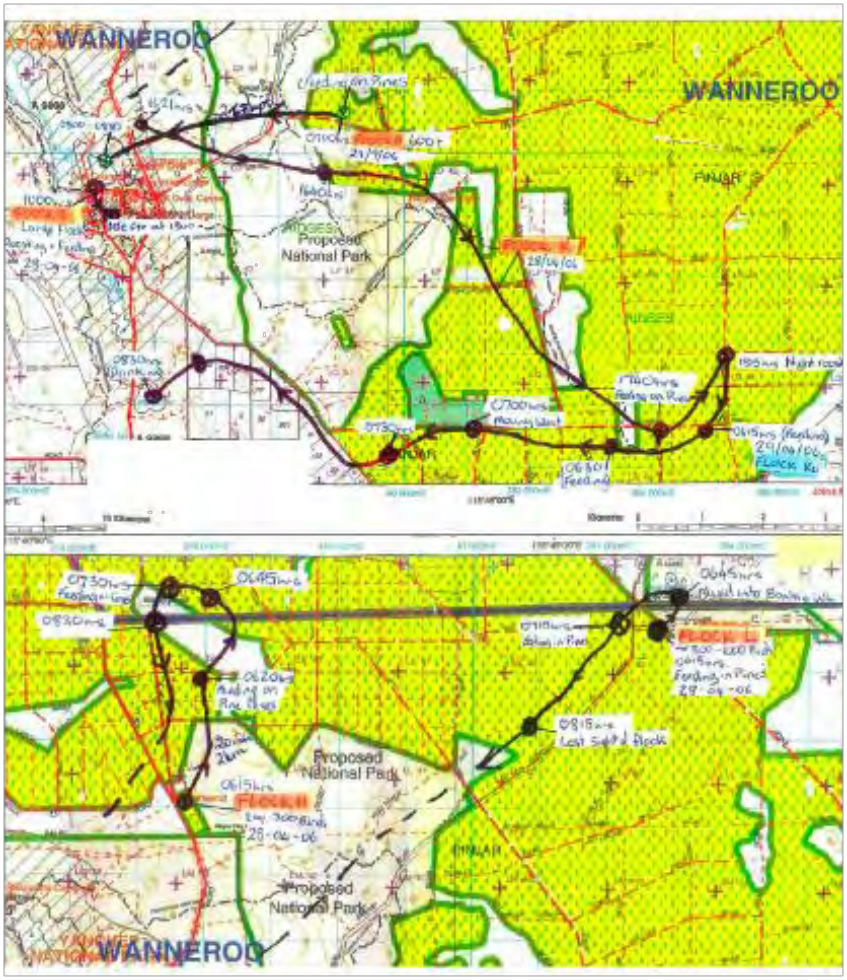


Figure 14: Flock follows from Shah (2006)
Top: **Flock A** (21/4/06, 07h00 - 08h30), **Flock I** (28/4/06, 10h00 – 13h00), **Flock K** (28/4/06, 16h21 - 18h15), **Flock Ka** (29/04/06, 06h15 - 08h30)
Bottom: **Flock L** (28/4/06, 06h15 - 08h15) and **Flock H** (28/4/06, 06h15 - 08h30)

F. Location Descriptions: Boongarra (SeaTrees)

Environmental Characteristics

The SeaTrees housing development is the focal point of this area. The development almost fully encompasses a large stand of mature tuart woodland and standing trees have largely been retained with the home-sites established over the last three years. The development and associated woodland provide roosting habitat and water sources. Some of the tuarts may have hollows suitable for breeding. The Boongarra area contains stands of pine in the Yanchep plantation, *Banksia sessilis* thicket, and *Banksia* woodland.

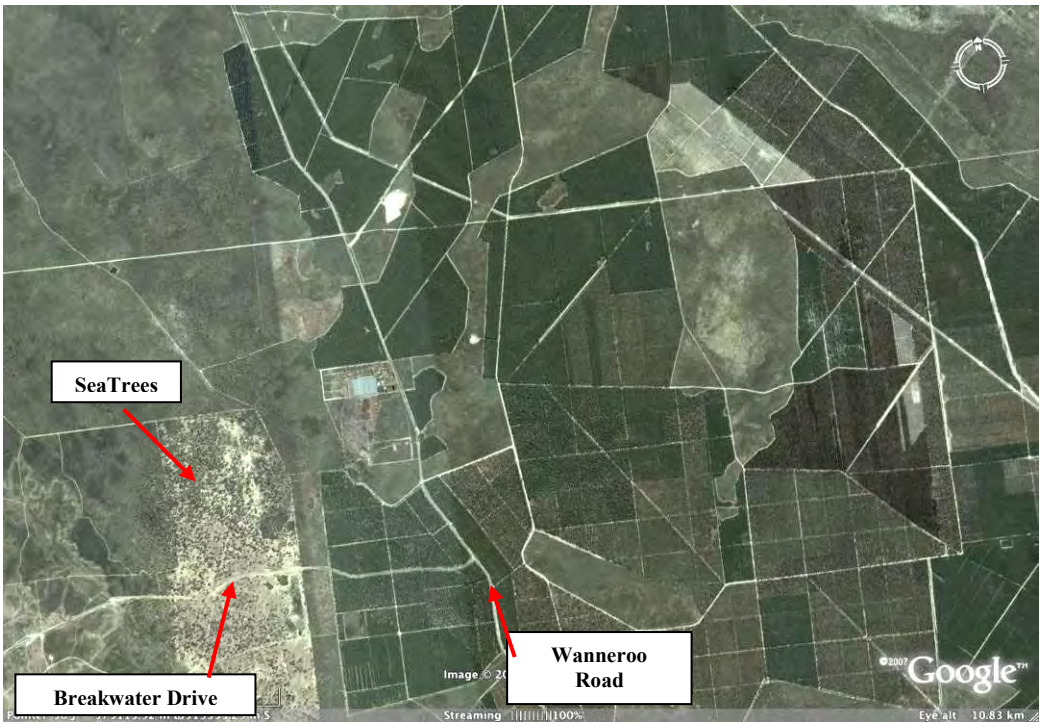


Figure 15: Portion of Boongarra location showing SeaTrees development in relation to Yanchep pine plantation. Building for the SeaTrees development had not been begun at the time of imagery (2007).

Basis for Flock ID & Estimate of Abundance

Best estimate of size: 700
Best count: >650 (30 April 2009); dusk counts: 700 (12 May 2009, 979 (19 May 2009)
Estimated Range: 650 - 850

This flock was consistently observed in association with the SeaTrees development in March and April (Fig 15). The best field observation is a minimum estimate of 650+, which is similar to the first dusk count on 12 May 2009. In April, the flock appears to possess a component (~200) feeding in pine and a larger component (500+) feeding on *Banksia sessilis*. Better February-April counts for this flock would be helpful, as the current estimate may well underestimate the actual number of birds present. In addition, the Boongarra area contains some of the largest and highest quality feeding habitat (pine, *Banksia* woodland, and *Banksia sessilis* thicket) in the GSS area, suggesting that birds may shift into this area as feeding habitats in other areas decline.

Ecology

During March (there are no February observations) this flock appeared to feed in pine and to over-night roost in pine at least occasionally. In late April, the flock appeared to have fragmented with smaller sub-flocks feeding in pine (e.g. $n = 42$, $n = 190 – 230$) and a larger flock of at least 500 birds feeding in *Banksia sessilis* to the west and north of SeaTrees.

The large roost count of 26 May suggests that this may have included ~700 of the _foreign' birds that had occurred within the GSS area during April and May feeding on *Banksia sessilis.* This timing coincides with return of 738 birds to Yanchep National Park, which would appear to be the resident Yanchep flock returning to YNP after roosting at other locations for three weeks (see Yanchep location description), and suggests that the _extra' birds at Boongarra on 26 May were also the _extra' birds observed in dusk counts at YNP during April. Given the movement patter, it would appear that these birds moved into the GSS area from the northern Swan Coastal Plain at the end of March/beginning of April and then return northwards at the end of May (perhaps following a gradient in the availability of *B. sessilis*).

3. Temporal Patterns, Distribution, and Abundance

This section describes the abundance and distribution of Carnaby's Black-Cockatoos within the GSS area, including temporal patterns, estimates of abundance, and habitat use.

A. Limitations of this study

In most cases, 2009 data are only available for the late summer-early autumn period (February-April for field observations and February-June for dusk counts). Thus, the findings presented here are essentially a _snapshot' of the ecology of Carnaby's Black-Cockatoos in the GSS area rather than providing a complete dataset for an entire annual cycle.

B. Daily Patterns

Section 4A describes daily activity patterns for Carnaby's Black-Cockatoos in the GSS area.

C. Spatial and Temporal Patterns in the 2009 Study

The distribution and abundance of Carnaby's Black-Cockatoos in the GSS area varied over the course of the study. In particular, observations suggest that the study period can best be divided into two time periods: a) a *predominantly pine* period in February and March in which most flocks generally foraged in pine, and b) a mixed Dryandra-pine period in which flocks foraged both in Dryandra (i.e. *Banksia sessilis*) thickets and in pine.

1. Pine Period (January – March)

The findings from the 2009 study indicate that, from January through March, Carnaby's Black-Cockatoos in the non-urban portions of the GSS area are concentrated within and adjacent to the pine

plantations, with pine providing the main food source. The distribution of birds during this period appears to be structured around six flocks associated with the Gnangara plantations (Fig 6). In this context ‗associated' means that these flocks tend to occur within or at the periphery of plantations and to feed and roost within the plantation pines at least part of the time. These flocks roost together—or are seen together at dusk—at least occasionally. While other flocks occur within the GSS area, these flocks appear to account for the majority of Carnaby's Black-Cockatoos sighted with the plantations and the non-urban areas more generally. There are two seasonal patterns associated with this period: (a) the return of birds to the GSS area from breeding areas and (b) the maturation of pine cones in January and February. It also appears—based on anecdotal evidence—that some plantations are effectively ‗stripped' of pine by the end of March (or earlier).

The Gnangara and Jandabup flocks are an exception to this general pattern as—while they do feed on pine—much of their foraging activity in these months is focused on habitats outside of the plantation areas, including both natural (e.g. marri, *Banksia* woodland) and anthropogenic (e.g. market gardens) habitats. In this sense, their foraging ecology is a hybrid of that observed in urban areas (small patches of native vegetation, limited amounts of pine) and that of the flocks in the non-urban GSS areas (predominantly pine but other food items in limited amounts).

2. Dryandra - Pine Period (April – May)

In April, the focus on pine begins to break down as large numbers of birds begin to feed on *Banksia sessilis*. The birds feeding on *B. sessilis* include both flocks resident within the GSS area during February-March and birds drawn from other locations, probably from the north of the GSS area. It appears that at least some of the discrete flocks (Boongarra, Yanchep, Neerabup-Nowergup-Carabooda) observed in February-March remain within these locations, but the outside flocks may leave the area.

D. Estimates of Abundance and Trends

This section breaks abundance estimates for the GSS area into two time periods: (a) non-breeding season (February – May) and (b) breeding season (September – December). The other months are transition periods in which birds are moving to and from the GSS area. From roughly mid-December to early February birds are migrating back to the GSS area from breeding sites. Similarly, birds aggregate to move to breeding areas in June, July, and August (particularly the latter two months). It is worth emphasising, however, that birds resident from September to December will also be present in the other months of the year—it is only the population of breeding birds that shifts in and out of the GSS area (although the size of the breeding population may change from year to year). The abundance estimates do include estimates for birds in the urban areas of the GSS, such as provided by Perry (2008). Integration of roost count data from urban areas of the GSS would provide a more comprehensive estimate of the overall abundance of Carnaby's Black-Cockatoos within the GSS area.

Non-Breeding Period (February – May)

Table 7 provides an abundance estimate for the ‗pine period' (February-March). Although birds are likely to be feeding predominantly on pine in January, the abundance estimate covers only February and March as these are the months for which count data are available. In addition, birds are likely to still be moving into the GSS area through early February, meaning the peak abundances for the pine period are not reached until sometime in February.

Table 7: Abundance estimates for Carnaby's Black-Cockatoos in non-urban GSS areas during February-March (pine period) based on 2009 observations. These estimates do include flocks within urban GSS areas.

Location	Minimum	Maximum	Best
Gnangara	325	425	350
Jandabup	380	430	400
Pinjar	370	410	390
Neerabup-Nowergup-Carabooda	230	275	250
*Yanchep**	717	939	800
Boongarra	650	850	700
TOTAL	2672	3329	**2890**

*Yanchep estimate: (a) minimum = mean count for 24 February – 31 March; (b) maximum = mean count for 3-17 February; and (c) best = mean count for 3 February – 31 March

Table 8 provides an abundance estimate for the ‗Dryandra' period (April-May). This estimate must be considered hypothetical as it is based on a number of assumptions and inadequate count data for several locations. The estimate may underestimate the number birds present if (for example) all of the birds from the Jandabup and Pinjar flocks were not present in the ‗Dryandra' flock. Likewise, the estimate may over-estimate the number of birds present if (for example): the ‗foreign' flocks within the Dryandra flock and in the combined Yanchep flock were actually a single ‗foreign' flock of ~550 birds. Nonetheless, the estimate should be considered conservative and suggests that at least 1000 birds were present within the GSS area in April and May that were not present in February and March, i.e. a flock or flocks of 1000+ moved into the GSS area during April and May to feed on *Banksia sessilis*. Thus, the peak annual abundance for the GSS area was probably achieved in April and May, although larger abundances may occur in transitional months as birds aggregate while moving into and out of the GSS area at the end and beginning of the breeding season.

In both abundance scenarios, the abundance of birds appears to follow a north-south gradient that approximates the availability of food. During February and March, the majority of the ‗population' is distributed within or adjacent to the Yanchep plantation and the Pinjar plantation areas north of Old Yanchep Pinjar Road. These plantation areas contain the majority of the pine within the Gnangara-Pinjar-Yanchep plantation system (Figure 2). Similarly, it is likely that 2/3rds of the ‗population'

during April and May were in the Neerabup area and northwards. There are few areas of *Banksia sessilis* thicket in inland areas south of Neerabup, as the Jandabup and Gnangara areas are largely absent of the limestone ridges on which this habitat occurs. There are, however, some patches of *Banksia sessilis* in coastal areas, either as a component of coastal heath vegetation communities or in ridgelines to the east (e.g. in the Burns Beach area) (see further discussion of *Banksia sessilis* as a food source in the Feeding Ecology section).

Table 8: Abundance estimates for Carnaby's Black-Cockatoos in non-urban GSS areas during April - May (Dryandra period) based on 2009 observations. These estimates do include flocks within urban GSS areas.

*flock observed feeding on *Banksia sessilis* in the Neerabup area in April 2009.

Location	Minimum	Maximum	Best	
Gnangara	?	?	130?	*220?*
*Jandabup**	?	?	?	*400?*
*Pinjar**	?	?	?	*390?*
Neerabup-Nowergup-Carabooda	?	?	?	*250?*
_foreign' flock	?	?		*525?*
DRYANDRA* FLOCK	1250	1785	1785	
Yanchep	717	939	800	
'foreign' Yanchep flock	?	?	579?	
COMBINED YANCHEP FLOCK	1252	1507	1379	
Boongarra	650	850	700	
Total _foreign' flocks	Birds not present February-March		[1104]	
TOTAL			**3994**	

Assumptions for this estimate:
1. 130 birds in Gnangara location
2. _Dryandra' flock includes: 220 (Gnangara) + 400 Jandabup + 390 Pinjar + 250 Neerabup-Nowergup-Carabooda + 525 _foreign' flock
3. Combined Yanchep flock: 800 Yanchep + 579 _foreign' flock
4. Dryandra _foreign' flock ≠ Yanchep _foreign' flock
5. Overall abundance estimate (TOTAL) = 130 Gnangara + Dryandra flock + Combined Yanchep flock + Boongarra

Breeding Period (September – December)

Birds are present in the GSS area during the non-breeding period. The resident population during this period would include: (a) non-breeding adults; (b) juveniles (immatures); and (c) a small number of pairs breeding in the GSS area. There would also be more transient flocks moving into the area to feed in Banksia woodland and pine. No studies have attempted to quantify the proportion of individuals that would remain on the Swan Coastal Plain during the breeding period (i.e. the second half of the year). However, as a minimum estimate, about 20-25% of the population might remain in the GSS area during the non-breeding period, suggesting that between 600-1500 birds might be present from August-December. This estimate approximates some of the larger flocks observed during this period (e.g. 600-1000 birds at Burns Beach in 2005 and 620+ birds in the Pinjar plantation in September 2008). Very few birds are observed in urban portions of the GSS area during the non-breeding period (Perry 2008),

suggesting that birds would be concentrated within the non-urban areas. They would likely be feeding within the pine plantations and *Banksia* woodland, with the latter habitat a particular focus for small groups and large aggregations during seasonal peaks in the availability of various *Banksia* species (see Feeding Ecology).

Estimating Abundance

Abundance estimate is problematic for several reasons. Firstly, the abundance of birds within the GSS area is not stable—birds move in and out of the area on a seasonal basis (i.e. twice a year—at the end and the beginning of the breeding season) and in response to changes in food availability. Second, birds are often shifting location, making it difficult to monitor flocks using static site-based counts. Thirdly, the daily activity patterns of birds can make it difficult to account for all the birds present in an area, e.g. not all birds in an area may return to a single roost site and/or water source or return at the same time of day. Finally, counting birds in the field is not straightforward. To obtain accurate counts, birds must be in flight (so as not to be obscured by vegetation) and move in a manner that avoids their being counted twice (e.g. crossing a road or line of trees). Moreover, they must be counted in moving assemblages of up to several hundred birds at a time. These factors emphasise the value of obtaining multiple counts for flocks, training observers in estimation techniques, and retaining skilled observers.

Regardless of the time of year, the most comprehensive and accurate estimates of abundance will come from targeting a 1-2 week window and having small field teams locate flocks, track the flocks to determine where the flocks are over-night roosting, and then conduct counts at dusk and dawn. This would allow the identification of flocks roosting in plantations. Estimates between the second half of February and the first half of March will provide the best estimates of birds associated with pine. In January and early February some birds are likely to still be in transition from breeding, and after the middle of March birds may be starting to feeding on *Banksia sessilis*. Estimates in April and May should identify the large aggregations feeding on *Banksia sessilis*, although it remains uncertain how much annual variability there is in the availability of this food source. Counts in July and August provide an opportunity to count birds as they are aggregating to move back to breeding areas. Finally counts between September and November will indicate the size of the resident population during the breeding period.

Dusk counts also have an important role as they provide a valuable tool for monitoring changes in flock size over time, both within seasons and between years. However, they are best suited for roost sites that are used on a consistent basis over a period of time (e.g. Yanchep National Park, SeaTrees development) and less useful for monitoring flocks that are not consistently associated with particular roost sites. Possible improvements could include: (a) increasing the number of dusk counts at key locations (to increase sample size and count frequency) and (b) developing a more flexible system that would conduct counts at certain locations when birds are known to be roosting in an area for a period of time (if only for a few days). The flock distribution hypothesised in this study provides a framework

for apportioning roost count effort across the GSS area, although further work should be conducted to confirm (or disprove) these distribution patterns.

E. Habitat Use with the Non-Urban GSS Area

Table 9 shows the locations of point samples from flock follows by predominant habitat type (i.e. overall habitat use). 61.4% of point samples were situated within human-modified habitats (pine plantation, market garden, homestead, and other anthropogenic habitat), with more than one-third (37.8%) of samples in pine plantation areas. In contrast, only 34.7% of point samples were located in native vegetation which in our study is mainly remnant patches and not extensive Banksia woodland. These data underestimate the frequency of ‗homestead' habitat use since point sample locations within the SeaTrees development were classified as ‗tuart woodland' although the habitats at this site include houses and other buildings set within native vegetation.

Table 9: Locations of point samples (n = 421) by predominant habitat type. One point sample was split between Pine woodland and Banksia woodland as the predominant habitat type.

Habitat Type	**No. of Point Samples (%)**
Human-Modified	
Pine forest	124 (29.5%)
Pine woodland	34 (8.1%)
Pine plantation – total	159 (37.8%)†
Market garden	37 (8.8%)
Homestead	62 (14.7%)
Other*	2 (0.5%)
TOTAL (Human-modified)	259 (61.5%)
Native Vegetation	
Banksia woodland	27 (6.4%)
Tuart woodland	62 (14.7%)
Other woodland	29 (6.9%)
Dryandra+ thicket	28 (6.7%)
TOTAL (Native Vegetation)	146 (34.7%)
None (in flight)	17 (4.0%)

† Includes: Other (Pine-debris) [*n* = 1]

*Includes: (a) modified landscape (disturbed native vegetation near a quarry) [*n* = 1] and (b) Pine-debris [*n* = 1]

+ *Banksia sessilis*

These findings indicate that the distribution patterns of Carnaby's Black-Cockatoos within the GSS area largely reflect the use of human-modified habitats, particularly during periods in which birds are making intensive use of pine. The findings—and this study more generally—suggest that in the GSS area Carnaby's Black-Cockatoos select habitats at two spatial scales. Firstly, at a landscape-scale, this study demonstrates that a large abundance of Carnaby's Black-Cockatoos birds occurs in an area containing abundant food sources within human-modified habitats. Secondly, at a more localised scale, birds use human-modified habitats more frequently than native vegetation, at least during certain periods. Moreover, although they may feed within native vegetation, which was not extensively surveyed in this study, they will often roost and drink within human-modified landscapes.

4. General Ecology

A. Activity Budgets & Patterns

Daily activity budgets

During daylight hours flocks were generally either resting at roost (_Roost-rest', 37.1% of point samples) or feeding (34.4% of point samples) (Table 10). The rest of their daily activity was devoted to some kind of transition, either between roost sites and other habitats (e.g. drinking or feeding areas) or between feeding patches, with birds in flight (10.1% of point samples) or roosting for short periods of time (_Roost-short', 18.1% of point samples).

Table 10: Frequency of different activity as predominant activity (PDA) for 15-minute point samples during flock follows (total point samples = 421)

Predominant Activity (PDA)	**Number of point samples**
Roostrest*	156 (37.1%)
Feed	145 (34.4%)
Roostshort	76 (18.1%)
Fly	43 (10.1%)
Drink	1 (0.2%)
*includes n = 2 _Roostover-night'	

The low frequency of drinking as a predominant activity is not reflective of the actual frequency of this activity. Drinking bouts for black cockatoos occur at least once a day, but are often brief (typically lasting for only a few minutes) and thus tend not to be well-captured by a 15-minute sampling interval. They may also involve a small number of birds at a time (i.e. the majority of birds present may be short-roosting rather than drinking) and thus be recorded as a supplementary activity for a group. While

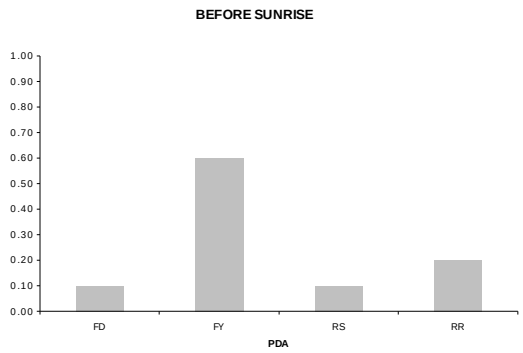
birds often drink just before assuming an over-night roost or just after leaving an over-night roost, drinking also occurred at the conclusion of the morning feeding period and before flocks assumed a day roost. The movement patterns of flocks often appeared to be structured so that they encountered a drink site at some period during the day, and the proximity of drink sites is likely to be a key factor influencing the suitability of roost sites and overall habitat selection.

Daily activity patterns

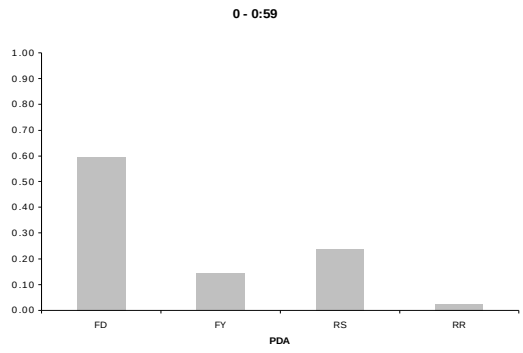
Flocks showed a consistent daily activity pattern. After roosting over-night, they became active just before dawn and moved away from roost sites as soon as light permitted, although they sometimes fed for a time close to the roost. They then moved to feeding habitats generally located within 5km of the roost site, but sometimes travelled further, either directly from the roost site or as _rolling' assemblages of feeding birds. It is likely that they select over-night roost sites so that they are close to where they intend to forage the next day (and to a drink site). However, _nomadic' flocks may occasionally move longer distances and _site-bound' flocks may also be forced to travel longer distances if food sources are depleted closer to their _home' site.

They are active and predominantly feeding (or travelling) for 3-4 hours after dawn, then will roost for several hours during mid-day, before becoming active again (and largely feeding) about 3-4 hours before sunset (Figs 16 and 17). This pattern appears consistent across habitat types, locations, and seasons. As day-length decreases, flocks reduce the amount of time spent day-roosting. So, for example, in February birds would be active from just before 07h00, roosting by 11h00 and then becoming active again between 16h00-17h00. In April, birds would again be active from just before 07h00 and roosting by about 11h00, but would be active earlier in the afternoon (13h00-14h00). Physiological factors may underlie the pattern as the birds conserve energy and reduce water loss by roosting during the hottest part of the day. Predation risk may also be a factor as raptors are mostly active during the middle of the day when thermals permit soaring.

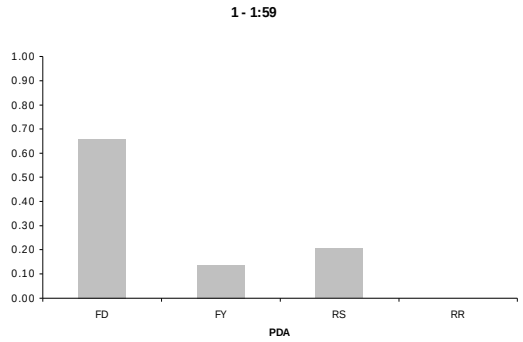
As with most aspects of the ecology of this species, there is also flexibility in their daily activity pattern. In two situations some birds from focal flocks continued to feed through midday: a) some birds ground-feeding on pine (in the shade of the canopy) did not day-roost as other members of the focal flock did and b) some birds from the Jandabup flock continued to feed through midday on ground seed in a fallow market garden while the weather was cool ($\leq$25ºC) and partly overcast.



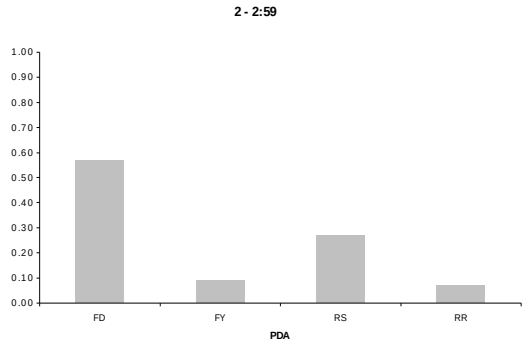
n = 10 point samples



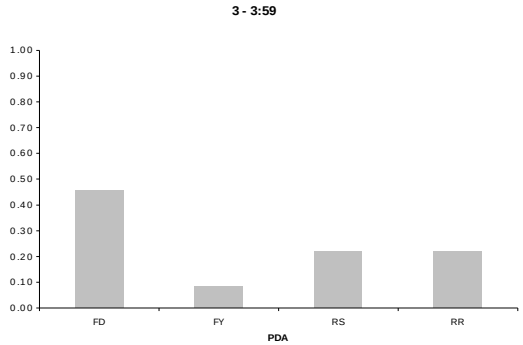
n = 42 point samples



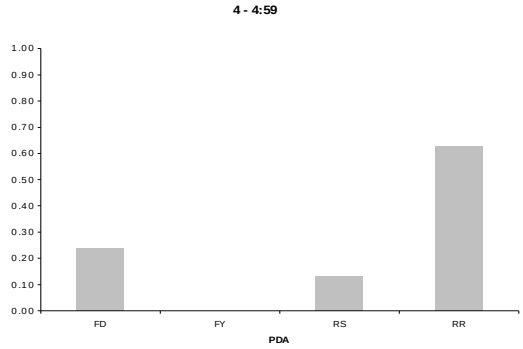
n = 44 point samples



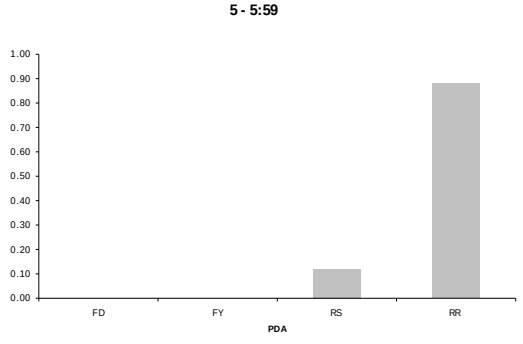
n = 56 point samples



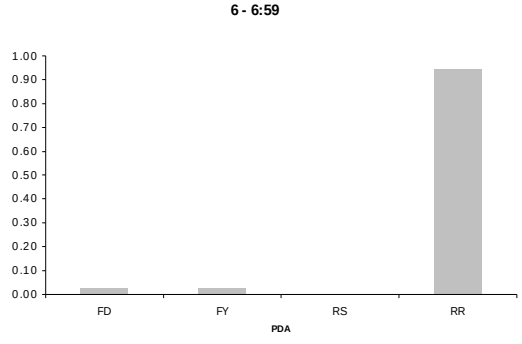
n = 59 point samples [also n = 1 Drink PDA]



n = 46 point samples



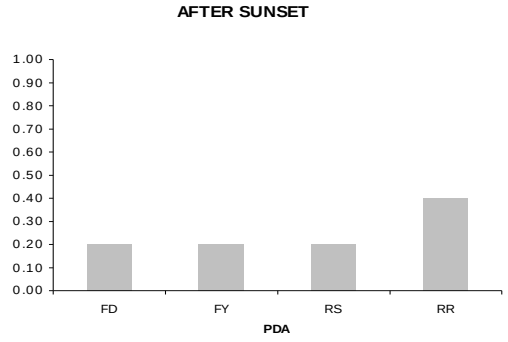
n = 33 point samples



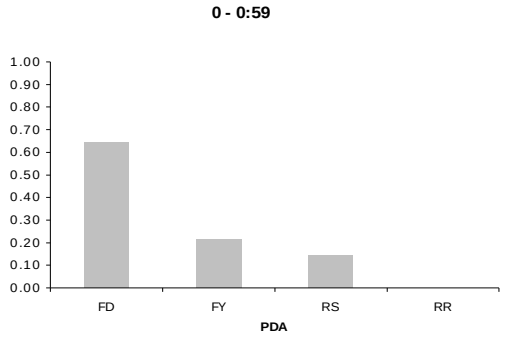
n = 38 point samples

Figure 16: Predominant activities (PDA) as a proportion of point samples (PS) for one hour time intervals from before sunrise to sunrise plus 7 hours

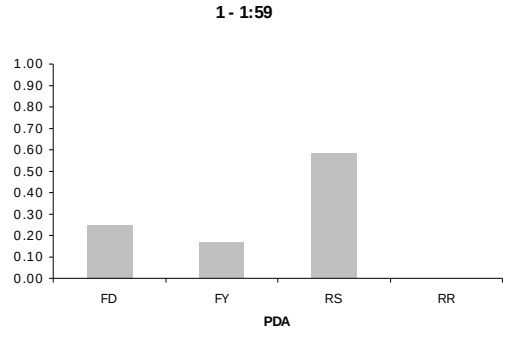
FD = Feed FY = Fly RS = Roostshort RR = Roostrest



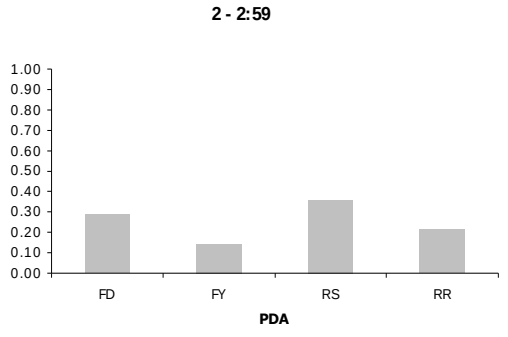
n =5 point samples



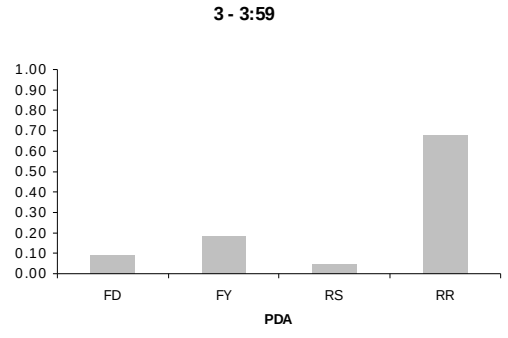
n = 14 point samples



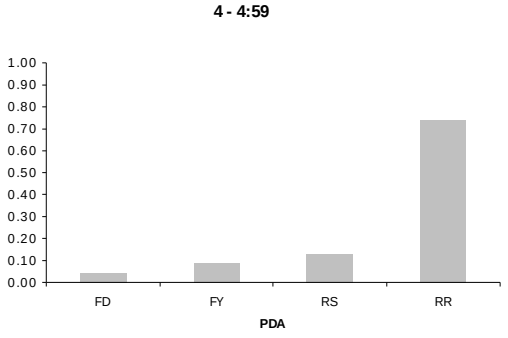
n = 12 point samples



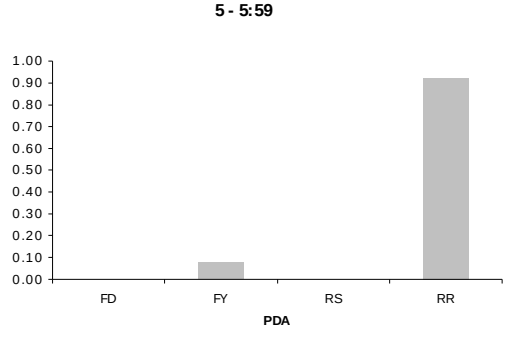
n = 14 point samples



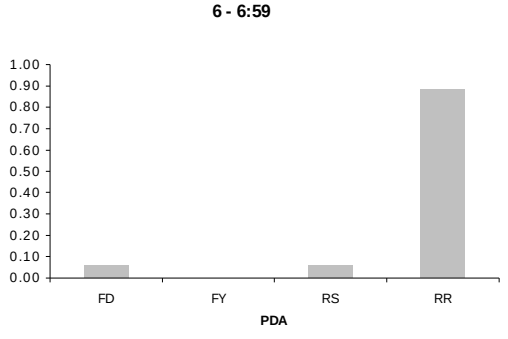
n =22 point samples



n = 23 point samples



n = 13 point samples



n = 34 point samples

Figure 17: Predominant activities (PDA) as a proportion of point samples (PS) for one hour time intervals from after sunset to sunset minus 7 hours

FD = Feed FY = Fly RS = Roostshort RR = Roostrest

B. Water Sources

General Observations

Black cockatoos are obligate drinkers, meaning that they must drink at least once a day to meet physiological demands. There were fourteen observations of drinking in the 2009, with additional observations from Shah (2006) and T. Kirkby (WA Museum, unpublished data) (Table 11). Most drink sites were anthropogenic, but birds also used natural wetlands (Yanchep Swamp in particular). Anthropogenic water sources included livestock troughs, bird baths, artificial ponds, puddles in driveways, dams, and sprinkler/irrigation systems. Although not observed in the GSS area, black cockatoos will also drink from ephemeral natural water sources such as rain puddles (H. Finn, personal observation).

The timing of observations can be classified into four categories: (a) dawn: immediately after leaving the over-night roost; (b) early to mid-morning: after a period of travel and feeding and followed by a further period of feeding; (c) mid- to late morning: just prior to the mid-day roost; and (d) dusk or near-dusk: just prior to assuming the over-night roost. The range of drinking times indicates that there is considerable flexibility in daily activity patterns in terms of when birds will drink.

Influence on Behavioural Ecology

Water is a key influence on the ecology of Carnaby‘s Black-Cockatoos, particularly during the summer when natural water sources may dry up and there is little rainfall. There are few water sources within plantation areas, making the availability of natural and artificial water sources an important daily consideration for flocks. Flock follows suggest that movement patterns to and from roost sites are often structured so that drink sites are encountered and roosts will often be situated near to drink sites.

Table 11: Observations of drinking within the GSS area. From the 2009 GSS study,

Date	Location	Time	Note
5 Feb	Jandabup	0844	Drink site around edge of turf farm; had moved this way after leaving over-night roost in pine to east
6 Feb	Jandabup	0815	Drink site at homestead (in paddock or backyard); at edge of Gnangara plantation; had moved this way after leaving over-night roost in pine to east; continue on feeding
6 Feb	Jandabup	0930	Drink site in semi-natural wetland in suburban area
20 Feb	Pinjar	0850	Probable drink site at boundary between pine and *Banksia* woodland; near campsite for Coastal Walk Trail so may be artificial; had roosted over-night in pine and fed in pine; continue to feed for a little while afterwards then day roost at Anderson Road roost
3 Mar	Yanchep	1930	Drink at Yanchep Swamp (at Yanchep National Park)
6 Mar	Boongarra	0925	Drink at SeaTrees (large birdbath in backyard) after roosting over-night in pine and morning feeding in pine and Banksia woodland to east; day roost afterwards
17 Mar	Gnangara	0705	Drink site at Hammersley Centre across Gnangara Road from over-night roost in pine; continued on to feed in Whiteman park
18 Mar	Jandabup	0830	Drink site at homesteads around Hawkins and Townshend Roads; after over-night roost in

			pine; move west to market garden to feed
18 Mar	Jandabup	0945	Drink from puddle in driveway (after hose ran); near market garden where feeding
19 Mar	Jandabup	1925	Drink from horse trough in paddock across road from market garden where had been feeding; drink in waves of birds before heading east to roost over-night in pine
20 Mar	Jandabup	0725	Drink site at Hawkins Road; drink in homestead after over-night roost in pine and before heading west to feed in market garden
21 Apr	Neerabup	0705	Probable drink in wetland area
24 Apr	Neerabup	1015	Probable drink in same wetland area as 21 April; had over-night roosted in pine, fed in Dryandra thicket and market garden
30 Apr	Boongarra	1020+	Mass (100+ birds attempt to drink) at artificial pond in frontyard at SeaTrees; human disturbance to scare birds away; some birds had been feeding in pines to east but most of flock came from west, probably had been feeding in Dryandra thicket; one other drink site observed also in backyard, appear to be >5 potential drink sites at SeaTrees; birds day roost after

C. Roost Sites

Roosting Habitat Use

The activity state „roost-rest" generally occurred in human-modified habitats rather than in native vegetation (Table 12). This finding probably reflects three factors. Firstly, birds feeding on pine in the morning often chose to day roost in pine trees nearby. Secondly, many areas are largely devoid of native vegetation with tall (endemic) trees (e.g. tuart woodland), both because these habitats have been cleared (e.g. for agriculture, settlement, or silviculture) and because native woodland habitats occur only within a narrow range of soil type and landscape positions within the GSS area and thus have a limited extent within much of the GSS area (particularly in the eastern half). Thirdly, exotic trees on homesteads often provide suitable roosting habitat (e.g. large, well-shaded canopies) and may also be positioned near to natural and artificial water sources.

Characteristics of roosts

Carnaby's Black-Cockatoos roost for extended periods in the middle of the day (day roost) and at night (over-night roost). Table 13 provides a partial list of roost sites in the northern GSS area. Within the GSS area, birds will typically roost (for longer than an hour) only in trees that are at least 15m tall and generally seem to prefer trees that 20m or taller. The tree species used for roosts includes pine, tuart, other native eucalypts, and introduced/exotic species. Pine roosts are generally in stands planted before 1979 (i.e. at least 30 years old). Roost sites in pine seem to be chosen because of their proximity to feeding areas or a drink site. Birds will often feed briefly in the trees at a pine roost site immediately before or immediately after over-night roosting. During day roosts (in both pine and non-pine species) birds often shift roosting positions and sometimes the tree they are roosting in because of changes in sun position, wind strength, and (occasionally) deliberate or inadvertent human disturbance. The presence of soaring raptors can cause flock fly-ups and for flocks to shift to a different roosting location.

The Gnangara and Jandabup flocks will often return to the pine plantation to roost over-night even if they have been feeding off-plantation during the day. The Jandabup flock varies its over-night roost position in pine, while the Gnangara flock consistently roosts in the over-mature pines north of Gnangara Road (see _Flock ecologies' in the Social Ecology section). The site fidelity of the Gnangara flock probably reflects that: a) the pine trees along Gnangara Road are very tall and maintain some cones, b) there are few other areas of very tall pine in the SW corner of the Gnangara plantation; c) the site is close to a drink site at the Hammersley Centre; and d) there are few alternative roosting sites off-plantation that have tall trees.

Availability of roosts

In general, the availability of suitable pine and off-plantation (e.g. Tuart woodland) over-night roost sites currently appears adequate. However, this will change over time as pine is progressively removed and tall Tuarts and other species are lost from private property because of development and senescence. Two examples illustrate this. On the eastern edge of Lake Pinjar birds roost in small stands of introduced species or patches of remnant vegetation that occur on a handful of properties and in tall pine around Regalia Road on-plantation. It would appear likely that many of those trees will not be there in 10-20 years time. Likewise, in 2006 and 2009 the Jandabup flock roosted consistently in pine stands at the eastern edge of Lake Jandabup, some of which were harvested in March-April 2009.

Table 12: Locations of predominant activity _Roost-rest' point samples (n = 156) by habitat type [includes n = 2 _Roost-overnight' point samples]

Habitat Type	No. of Point Samples (%)
Human-modified	
Pine forest	41 (26.3%)
Pine woodland	14 (9.0%)
Pine plantation (total)	55 (35.3%)
Market garden	0
Homestead	41 (26.3%)
TOTAL (Human-modified)	96 (61.5%)
Native Vegetation	
Banksia woodland	3 (1.0%)
Tuart woodland	36 (23.1%)
Other woodland	21 (13.5%)
Dryandra thicket	0
TOTAL (Native Vegetation)	60 (38.5%)

Table 13: Roost sites in northern GSS area. The list is only partial and includes roosts monitored for DEC and roost sites identified in 2009 study. Roosts located in pine tend to be short-term roosts only (with some exceptions).
WS: roost site monitored in 2009 (overseen by W. Stock, ECU)
GP: Gnangara plantation PP: private property PI: Pinjar plantation YP: Yanchep Plantation DEC: conservation reserve/national park DPI: Department of Planning & Infrastructure

No.	Roost Type (ON = over-night; Day = day roost)	Location	Vegetation	Landholder	Note
1	ON	Gnangara Road (along Centre Road -powerline corridor)	pine	GP	used extensively for over-night roosting; birds roost either side of powerline corridor in tall (>25m) pines; to the east pines are within the chainlink fence enclosing the mine site; the area under the pines to the west is a motorcycle recreation area; drink site across Gnangara Road at Hammersley Centre; [WS] is near Gaskell Road
2	Day (possible ON)	Stoney Road	tall eucalypts	PP	small farm with large (introduced eucalypts); large leafy canopy; used extensively as a day roost
3	Day (possible ON)	Lakelands Leisure Village	tall eucalypts	PP	
4	Day (possible ON)	Sydney Road	tall eucalypts	PP	
5	Day (possible ON)	Ross Street	tall eucalypts	PP	
6	Day (possible ON)	west of boundary road	tall eucalypts	PP	will also day roost in pine to east on plantation; drink sites in this general area; large (introduced) eucalypts
7	Day (possible ON)	Hawkins Road North	tall eucalypts	PP	
8	ON	north and south of Amarante Road (west of Quail Road)	pine	GP	birds overnight roost in pines in this general area; drink site in private property just to west of Hawkins North Road (Roost site 7); some of this area harvested March/April 2009
9	Day (possible ON)	South of Lake Maringup	tall eucalypts; tuart	PP	Capron-Maringup-Garden Park Drive-Dundebar Road-Franklin Road area includes several sites with large eucalypts suitable for roosting and proximity to known feeding sites
10	Over-night	East of Silver Road/North of Warbrook	pine	GP	
11	Day (possible ON)	Ziatus-Chitty Road	tall eucalypts	PP	
12	ON	171 Perry Road	tall eucalypts; pine	PP	appears to be main off-plantation over-night roost; large (introduced?) eucalypts with good canopy; also a strip of pine ~400m to south on same property; [WS]
13	ON	Regalia Road-Dasypogon Road area	pine	GP	
14	Day (possible ON)	Waneroo Golf Course	tall eucalypts	PP	
15	Day (possible ON)	Perry Road (Lot 1965)	tall eucalypts	PP	
16	ON	North of Wattle Avenue East	pine	PI	
17	ON	South of Wattle Avenue East	tuart	PP	
18	Day (possible ON)	West of Alf Barbagallo Raceway	tuart	DEC?	

19	Probable ON	Lot 21	tuart	PP	patch of Tuart Woodland in excellent condition; may be part of proposed Neerabup industrial area
20	Day (possible ON)	Wattle Ave West north along Gibbs Road South to Wescoe Road	tall eucalypts; tuart	PP	Tuart woodland and other tall eucalypts; some day roost; possible ON roosts in area; galahs and corellas present; near to large areas of Dryandra thicket (known feeding areas)
21	Over-night	299 Gibbs Road North	tall eucalypts; tuart	PP	galahs & corellas present; [WS]
22	Possible Day/ON roost	Lake Nowergup Reserve	tuart	DEC	
23	Day (possible ON)	Neaves Road	tall eucalypts	PP	
24	Day (possible ON)	Anderson Road	tall eucalypts	PP	large patches of remnant woodland to north and south of Anderson Road; used extensively as day roost
25	Over-night	Old Yanchep-Pinjar Road (South of Wescoe Road)	pine	PI	
26	Over-night	SeaTrees	tuart; tall eucalypts	PP	[WS]
27	Day (possible ON)	Carabooda Road	tall eucalypts; pine	PP	
28	Over-night	Acacia Road	pine	YP	
29	Day (possible ON)	Whiteman Park	tall eucalypts	DPI	
30	Probable day	Ballajura	tall eucalypts	unknown	exact location not determined: but almost certainly day roost in the Ballajura area
31	Over-night	Southern Yanchep planatation	pine	YP	birds roost ON in pine then return to YNP to drink am & evening; travel E-W north of old Y-P road; not all Carnaby's associated with YNP will roost on there (but may day roost)
32	Over-night	Yanchep National Park (east of Wanneroo Road)	pine	DEC	small patch of pine south of Yeal Swamp Road (in Banksia woodland); pine 'islands' provide useful roosting habitat in Banksia woodland [WS]
33	Day/ON	Yanchep National Park	tuart; tall eucalypts	DEC	Multiple roost sites
34		Yanchep Office			[WS]
35		Yanchep Golf Course			[WS]
36	ON	Star Swamp			reserve at North Beach [WS]
37	ON	Bernard Road North/South	tuart	PP	[WS]
38	ON	ECU Lake	pine	ECU	used early in non-breeding season [WS]
39	ON	Conductor Retreat		PP	south of Neaves Road [WS]
40	ON	Carabooda			
41	ON	Neaves Rd			
42	ON	Connolly Golf Course			Joondalup Resort Golf Course
43	ON	Ellen Brook			[WS]

D. Social Ecology

Fission-Fusion

By convention a group of black cockatoos is generally referred to as a ‗flock'. However, a group of birds observed together (e.g. feeding during the day or roosting at night) are not necessarily static or enduring entities. Rather, the social ecology of Carnaby's Black-Cockatoos appears to be complex and dynamic, and birds will aggregate and fragment over varying time periods (i.e. hours, days, weeks). During this study, birds often occurred in discrete aggregations that roosted overnight together and at least occasionally foraged together during the day. However, over-night roosting aggregations often fragmented into smaller foraging groups during the day. This fragmentation may reflect food preference (e.g. pine versus *Banksia* spp.) and resource availability (e.g. the presence of an abundant food source allows large foraging aggregations). In general, the social ecology of Carnaby's Black-Cockatoos can be described as a fission-fusion social structure, in which—over a period of time—birds will form groups (fusion) for particular time periods, activities, and stages in the annual cycle that will eventually fragment (fission).

Two examples provide an illustration of this. On 5 February a flock in the Jandabup area (see the description of the Jandabup area later in this section) over-night roosted as a single large aggregation in pines to the west of Silver Road, but then fragmented during a flock ‗fly-up' at dawn, with one group heading to the southwest and another heading to the north. One group was followed to mid-afternoon. The flock apparently re-aggregated later in the day as a similar number of birds was observed at the same location at dawn on 6 February. On 30 April an assemblage of 45 birds from the SeaTrees flock was observed canopy and ground-foraging on pine to the east of Wanneroo Road. At mid-morning this flock flew-up and travelled west to the SeaTrees development, where it joined the bulk of the SeaTrees flock to drink and day roost.

In particular, the YNP ‗flock' could best be characterised as an assemblage of sub-flocks that occasionally aggregate or appear in aggregate (e.g. to day-roost at the park or when drinking at the park). These sub-flocks are likely to over-night in different locations (e.g. some in areas around the park, others in the pine plantations to the east) and to follow different feeding patterns. This is consistent with observations of groups of birds, e.g. leaving the park heading west at first light while others are travelling from the southeast into the area around the swamp at the park 1-2 hours after sunrise; birds travelling to feed to the south and west of the park while others are observed flying to the east into pine.

Site Fidelity

There appear to be two basic flock ‗ecologies' within the GSS study areas: *site-bound* and *nomadic*. There are also likely to be transient flocks that are present for brief periods of time. *Site-bound* flocks

exhibit a reliable association with a particular site (or small handful of sites) to which they consistently return (e.g. daily or a few times a week). The fidelity of flocks to particular sites probably reflects the fact that these sites offer a resource (generally either a water source and/or a roost location) that is otherwise not available within the landscape.

Flocks observed in Gnangara, Yanchep, and Boongarra (at the SeaTrees housing development) appear to follow this pattern, as they consistently returned to three locations [pines directly to the north of Gnangara Road, roost sites and water sources at Yanchep National Park (YNP), and the SeaTrees housing development east of Two Rocks respectively] over the course of the study. In the case of the YNP and SeaTrees flocks, the availability of pine in the Yanchep-Pinjar plantation areas areas permits this ecology, whereas for the Gnangara Road flock, the use of the same over-night roost site may reflect the lack of a suitable alternative over-night roost site (e.g. large trees with a water source near by).

In contrast, nomadic flocks are not strongly bound to any one location but shift location (and thus roost and drink sites) frequently. Some flocks are not tied to a particular roost site but shift their over-night roost location as they move about an area, with over-night roosts (in pine) chosen because of their proximity to feeding areas and drink sites. These flocks are typically resident in an area for a period of time and will over-night roost in the same (or almost the same) location for days to weeks but then move, probably when the local food supply is exhausted. Drink sites appear to be the most consistent ecological features. Examples of nomadic flocks are those occurring around Jandabup, the Neerabup-Nowergup-Carabooda area, and Lake Pinjar. In some areas of the GSS, water is likely to be the main ecological constraint, particularly in summer and in areas away from human settlements and natural wetlands. Thus, even flocks that are flexible in their selection of roost sites may be bound to a limited number of drink sites (especially in summer).

E. Human Interactions

The GSS landscape is not a passive one, but occasionally interacts with Carnaby‘s Black-Cockatoos. Some human aspects of the environment interact directly with birds (e.g. disturbance to roosting flocks, road strikes, fires): Human-related injury or mortality may occur through: illegal shooting, car strikes, entanglement (e.g. in fences, nets, discarded wire), predation by introduced (foxes are already a problem in open GSS landscapes and conversion of pine plantation to parkland could exacerbate this problem) and domestic predators (e.g. predation by cats on birds feeding on the ground), or some form of deliberate harm. There are few data describing rates of injury or mortality from these processes, although shooting and car strikes are known to be important sources of mortality throughout the range of Carnaby‘s Cockatoos. Given the natural history of the species, significant conservation benefits can be achieved by reducing mortality from shooting and by minimising potential interactions with vehicles (e.g. creating road-side buffer zones without potential food sources). Carnaby‘s Black Cockatoos

appear to be relatively tolerant of human presence and are often observed feeding and roosting in close proximity to humans and human activities. Nonetheless, disturbance does occur and may have some adverse effect, particularly if birds are, for example, prevented from using a drink site, roost site, or feeding habitat.

In the 2009 study, disturbance was the main form of interaction between humans and Carnaby's Black-Cockatoos. Humans used cap guns, clanging pots, or other measures to displace roosting, feeding, and drinking birds at the SeaTrees development and the Lakelands Leisure Village. The large size of the flock at the SeaTrees development makes some form of interaction inevitable, as more than 700 birds may aggregate there to feed, drink, day roost, and over-night roost and birds often create a significant amount of noise through the day with contact calls and juvenile pleas. In April, birds also fed in market gardens in the Neerabup area. Personnel reported that the birds began feeding in the market garden at around the beginning of April and did cause damage to crops. Attempts to displace birds with blank cartridges were minimally successful with displaced birds often returning or other birds moving into the market garden a short-time later. The mid-morning period appears to have the highest interaction potential as birds often seemed to feed in the market garden for periods of up to two hours after having fed in other habitats (such as *Banksia sessilis* thickets) and birds generally left the market garden in late morning to assume the day roost. Mitigation mechanisms such as sprinkler systems or air guns would be most effectively deployed during this time.

5. Feeding Ecology and Food Resources

A. General Feeding Ecology

Feeding Activity Patterns

Flocks devoted about a third of their day primarily to feeding (n = 145 predominant activity ‗Feed' of 421 point samples, 34.4%). However, feeding activity was recorded as a supplementary activity in an additional 85 point samples, meaning that some feeding activity occurred more than half the time (n = 230 of 421 point samples, 54.6%). Flocks generally fed most intensively for about three to four hours after sunrise, but also again in the afternoon in the three hours before sunset.

Range of Food Sources

Carnaby's Black-Cockatoos fed on a range of food sources during the 2009 study, including *Pinus* spp., three *Banksia*s (*B. sessilis, B. attenuata, B. prionetes*), *Hakea* spp., marri (*Corymbia callophylla*), insect larvae, market vegetation and fallen seed, orchard fruit or nut (species undetermined), and several unknown food sources on the ground. Birds were most frequently observed consuming pine (44.8% of ‗Feed' point samples), followed by Banksia spp. (not including *B. sessilis*) (20.0%),

vegetation and seed in market gardens (18.3%), and *B. sessilis* (17.8%). Other food items were fed on in less than 10% of point samples. The frequency data are somewhat deceiving as they do not account for the number of birds feeding on a particular food item. For example, it was not uncommon for the majority of a flock to be feeding in one habitat (e.g. pine forest, market garden) and a small number of birds to be feeding on another food source in an adjacent habitat.

Group Size

The mean of the minium estimated number of birds present during PDA ‗Feed' point samples was 117.3±28.1 (n = 145; range: 3-1785). This value is an under-estimate as the size of larger feeding assemblages was often difficult to estimate as many birds were obscured in vegetation.

Habitat Use

Most feeding activity occurred within habitats defined as ‗human-modified' (pine plantations, market gardens, homesteads) (Table 14). These habitats accounted for three-quarters (74.5%) of the habitat types in which ‗Feed' was the predominant activity, with just under half (45.5%) of these in pine plantations. If Dryandra thicket (where birds fed only in April) is not considered, then only 11.3% of ‗Feed' PDA samples occurred in native vegetation habitats.

Variation

The sample of flock follows varies for different locations, limiting the conclusions that can be made about how the feeding ecology of individual flocks varies over time and variation between flocks. The short duration of the study adds an additional limitation. Nonetheless, the findings do suggest several general patterns.

Table 14: Food items consumed during point samples in which ‗Feed' was recorded as the predominant activity (PDA) (*n* = 145) or as a supplementary activity (*n* = 85) (*n* = 230 total ‗Feed' point samples).

Food item eaten	No. point samples food item eaten
Pine (canopy)	81 (35.2%)
Pine (ground)	61 (26.5%)
Pine (total)	103 (44.8%)
Market Garden (ground vegetation or seed)	8 (3.5%)
Market Garden (ground seed - fallow field)	34 (14.8%)
Market Garden (total)	42 (18.3%)
Banksia spp. (canopy)	43 (18.7%)
Banksia spp. (ground)	8 (3.5%)
***Banksia* spp. (total)**	46 (20.0%)
Dryandra (*Banksia sessilis*)	41 (17.8%)
Hakea spp.	11 (4.8%)
Grubbing (observed/probable)	14 (6.1%)
Marri (flower, nectar, insect)	7 (3.0%)
Unknown market fruit/nut (canopy/ground)	3 (1.3%)
Unknown (ground)	12 (5.2%)

Table 15: Locations of predominant activity ‗Feed' point samples (n = 145) by predominant habitat type

Habitat Type	No. of Point Samples (%)
Human-modified	
Pine forest	55 (37.9%)
Pine woodland	11 (7.6%)
Pine plantation (Total)	66 (45.5%)
Market garden	36 (17.1%)
Homestead	5 (3.4%)
Other*	1 (0.7%)
Human-modified (total)	108 (74.5%)
Native Vegetation	
Banksia woodland	12 (8.3%)
Tuart woodland	3 (2.1%)
Other woodland	4 (2.8%)
Dryandra thicket	18 (12.4%)
Native Vegetation (total)	37 (25.5%)
*modified landscape (disturbed native vegetation near a quarry) [*n* = 1]	

B. Pine as a Food Source

Dominance of Pine

Pine was the principal food resource consumed by Carnaby's Black-Cockatoos in this study (Tables 14 & 15), particularly during February and March. This finding is consistent with earlier reports and studies describing the use of plantation pine by Carnaby's Black-Cockatoos in the GSS area and its principal position in their diet (Perry 1948; Davies 1966; Saunders 1974, 1980).

Evidence for pine depletion

Saunders (1974) noted that each year birds tended to completely strip the smaller pine plantations in Perth area, but did not strip the larger Gnangara plantations. Even though the area now covered in pine is larger than that in 1974, anecdotal observations during the 2009 study suggest that there are few areas within the plantations that do not contain pine feeding residues and there are large areas where many trees have few or no standing cones, particularly within the Gnangara and southern Pinjar plantation areas. Although quantitative data is necessary to confirm these observations, they do suggest—particularly when coupled with observations of the foraging behaviour of birds—that in the Gnangara plantation the pine cones available each year are rapidly stripped soon after birds arrive back from breeding areas, causing localised depletion. Evidence of local depletion and the foraging patterns of flocks suggest that areas of local depletion of pine occur, particularly in the Gnangara plantation, which is the most fragmented of the three plantations. The two flocks based around this area spend a greater proportion of their time feeding outside of the pine plantations, even though they will roost in pine on-plantation over-night.

The summer 2009 fire around Yanchep may have caused pine to become depleted for birds feeding out of Yanchep National Park. Thus, in at least some regions of the pine plantations, cones may be largely stripped from trees by the end of March. In addition, as trees may take time to recover from the stripping of cones (Saunders 1974), there may progressively less of a new crop each year, both because more trees have been harvested and because standing trees produce less and less cones. Again, further study is required to confirm these hypotheses, but they do suggest that estimates of the availability of pine do need to reflect spatial (where in the plantations), temporal (pine becomes depleted through the breeding season), and biological (stands of pine may produce fewer pines) considerations.

C. *Banksia sessilis* as a Food Source

Observations in the 2009 study suggest that *Banksia sessilis* is an important food source for Carnaby's Black-Cockatoos in the GSS area, particularly during April and May. Curiously, Saunders (1980) reported only a handful of observations of birds feeding on *Banksia sessilis* and the species was not a

significant component of crop contents. Similarly, Shah (2006) reported only one feeding observation of *Banksia sessilis* in her survey of Carnaby‘s Black-Cockatoos food items on the Swan Coastal Plain. These observations suggest that the importance of *Banksia sessilis* as a food item may have changed since the work of Saunders (1980), possibly because of depletion of other food sources, and that there may be significant inter-annual variability in *Banksia sessilis*, with the species being highly abundant in certain years but less so in others. Alternatively, *Banksia sessilis* habitats may not have been well-surveyed previously. T. Kirkby (WA Museum, unpublished data), for example, recorded abundant *Banksia sessilis* feeding residues in the Eneabba area from 2007-9 and P. Ladd (Murdoch University, unpublished data) observed large numbers of Carnaby‘s Black-Cockatoos feeding on *Banksia sessilis* in the Jurien area in June 2008.

Banksia sessilis is a common under-storey species in many woodland and forest habitats, but can also form extensive thickets up to 5 m tall, particularly in well-drained soils and limestone ridges along the northern Swan Coastal Plain (Marchant 1987, Lamont et al. 1998, others). It ranges from non-serotinous[1] to mildly serotinous and produces a large number of short-lived seeds that are released from fruits in autumn-winter after seed set a few months earlier. Flowers may be present for much of the year and provide an additional food source (nectar and insects) for Carnaby‘s Black-Cockatoos.

In the GSS area, *Banksia sessilis* is only weakly serotinous, and seeds that are set over late spring and early summer are released as soon as the seeds mature and follicles open in March-April, although seeds could be available from February onwards and a summer fire would cause the seed to release earlier (P. Ladd, Murdoch University, personal communication). Rather than having to expend energy extracting seeds from unopened follicles, birds may seek out plants or areas with opening follicles. The degree of serotiny in *Banksia sessilis* also shows a north-south gradient with plants in the northern sections of the Swan Coastal Plain more serotinous than those further south (e.g. around Perth). Thus birds may feed preferentially in newly-burnt areas and in southern areas during late spring/early autumn, and return to feed in northern areas when follicles are more likely to be opening (e.g. late autumn/early winter) earlier (P. Ladd, Murdoch University, personal communication).

Thus, the April-May „Dryandra shift‘ in the GSS area may be reflective of a larger feeding pattern along the northern Swan Coastal Plain based on a north-south serotiny gradient for *Banksia sessilis*. This hypothesis suggests that latitudinal differences in the timing of when *Banksia sessilis* release seeds (as well as burn patterns) allow some flocks of Carnaby‘s Black-Cockatoos to migrate along an optimal availability pathway for *Banksia sessilis*, i.e. to feed in areas just as they are about to release seed and food availability is at its highest. If this hypothesis is correct it would suggest that the „foreign‘ flocks that appeared in early April, fed through April and May, and departed (probably northwards) in late May probably arrived in the GSS area at the beginning of the „peak‘ availability in *Banksia sessilis* and then departed to track similar peaks in *Banksia sessilis* along areas of the Swan

Coastal Plain north of the GSS area. Given the timing of follicle opening on the northern Swan Coastal Plain, *Banksia sessilis* seeds may be particularly important to flocks migrating back to breeding areas in winter.

D. Banksia woodland as a Feeding Habitat

Carnaby's Black-Cockatoos did not make extensive use of Banksia woodland habitats during the course of this study (Table16). Feeding activity tended to involve small numbers of birds and to last only for brief periods. Several factors could account for this. Firstly, observation opportunities may have been limited. Survey effort focused on flocks in and around plantation areas and relatively little time was spent within the eastern and northern margins of the GSS where large areas of Banksia woodland occur. However, extensive remnant patches of Banksia woodland do occur within the area surveyed intensively for this study (e.g. around Lake Pinjar, within and adjacent to plantation areas in the Yanchep and Boongarra areas), and flocks appeared to forage preferentially in pine and (in April) in *Banksia sessilis* thickets rather than in these habitats.

Secondly, use of Banksia woodland habitats may have been more extensive than reflected in the flock follows conducted for this study. For example, both the Gnangara and Jandabup flocks were observed feeding in Banksia woodland habitats. The Gnangara flock, in particular, is likely to have foraged within the Banksia woodland areas south of Gnangara Road and along the eastern margin of the southern sections Gnangara plantation. Flocks in GSS urban areas do feed in Banksia woodland habitats from February-April (these are sometimes the only feeding habitats available to them) and flocks on the Swan Coastal Plain north of the GSS area may also do so. Further data would help evaluate this question.

It is also possible that other feeding habitats and food sources available during this time (e.g. pine, *Banksia sessilis*) provide a better energetic return than Banksia woodland, leading birds to feed disproportionately in habitats that provide a more optimal balance of costs (e.g. energy expended foraging for the food source) and benefits (energy obtained from the food source). Birds may simply prefer food sources (e.g. pine, market garden crops) that provide high returns for energy invested and are thus analogous to _fast food' (Mitchell 2003). Thus, the availability of these food sources could obscure the use of other food items, including species such as *Banksia attenuata.* This appears the most likely scenario and raises the question—if pine were no longer available, would the remnant Banksia woodland habitat provide adequate energetic compensation during the non-breeding season and particularly from January-April? This question gets to the issue of the energetic value of Banksia woodland habitats and how this might vary seasonally.

Seasonal use of Banksia woodland habitats

Several factors suggest that feeding by Carnaby's Black-Cockatoos in Banksia woodland is probably most intensive from mid-winter (June-July) to spring-early summer (November-December). The five main *Banksia* species on the Swan Coastal Plain all flower asynchronously throughout the year (Whelan and Burbidge 1980). Cone maturation times are not known for all species but the cones of *B. attenuata* known to mature from July onwards (with a peak in September/October) (Stock et al. 1991), providing two additional food sources—the seeds within the mature fruit and the insect larvae that often infect the fruiting cones (Scott and Black 1981). Although there is little information on the availability of grubs, they appear to be an important food source and could alter both the desirability of a habitat for Carnaby's Black-Cockatoos (i.e. they may prefer areas with high incidences of grubs) and its energetic value. For example, it is possible that feeding in Banksia woodland may incur greater costs (in terms of time spent foraging and energetic expenditure required to extract food) than in other habitats (pine plantation, *Banksia sessilis* thickets), but the diversity of food sources present within them (including grubs) could provide sufficient benefits to favour foraging there, at least in particular times of the year.

Valentine recorded feeding residue for *Banksia* spp. at Banksia woodland sampling sites surveyed between September-December 2008 (L. Valentine, DEC, unpublished data) (Tables 16 & 17). Two forms of feeding residues were recorded: (a) *flowers* – obvious forms of Carnaby's Black-Cockatoo feeding such as flowers on the ground with clear indications that they had been torn off and (b) *cones* – obvious forms of feeding activity such as cones ripped apart grubbing for weevils and/or follicles damaged from feeding activity (see Valentine and Stock 2008 for indications of feeding activity on cones). The cone feeding residue was also classified as recent or old based on the approximate age of the cone. Most (~70%) sites had cone feeding residues with more than half (~55%) had residues indicating recent feeding on cones of *Banksia attenuata, B. menziesii,* and *B. grandis*.

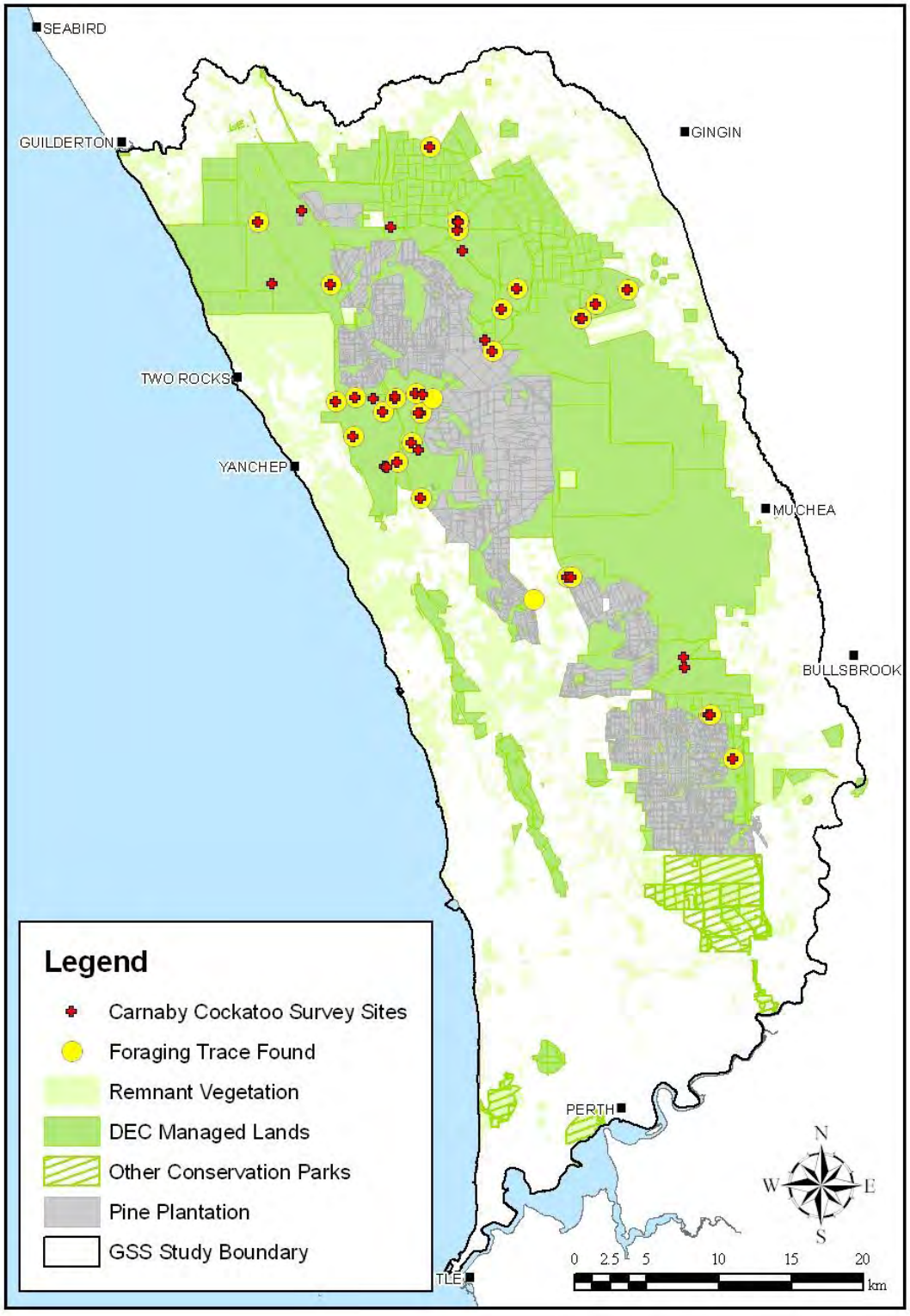


Figure 16: Location of sampling sites for Valentine and Stock (2008) study [L. Valentine, DEC, unpublished data].

Table 16: Observations of Carnaby's Black-Cockatoos feeding on *Banksia* spp. during 2009 study
FF: flock follow number *PS*: No. of point samples feeding on *Banksia* recorded Part/Stage: part of plant and/or phenological stage fed on
Location Codes (see Location Descriptions in Section IV):
GNA: Gnangara JAN: Jandabup PIN: Pinjar NNC: Neerabup-Nowergup-Carabooda YAN: Yanchep BOO: Boongarra

FF	Date	Area	PS	Level	*Banksia* species	Part/Stage	Note
3	4-Feb-09	JAN	2	canopy	*Banksia attenuata*	post-flower cone?	Jandabup flock: some birds feed briefly on *B. attenuata* during movement to WNW after leaving roost site; some birds also feed for a short period on *B. attenuata* in Banksia woodland near pine where flock of 255 ground-forages on pine; possibly feeding on cones but obscured; maximum of 20-30 birds feeding on *Banksia* for <20 minutes
5	5-Feb-09	JAN	3	canopy ground	*Banksia attenuata*	flower stalk flower post-flower cone	Jandabup flock: feeding in large dispersed flock (est. 50-75) through Banksia woodland around west end of Warbrook Road, then south into native vegetation in suburban areas (possibly 120+); also feeding on cones on ground in *Banksia* woodland; fed in Banksia woodland for 30-40 minutes before moving into suburbs; also feed on *Hakea* and other species in suburbs
6	6-Feb-09	JAN	6	canopy ground?	*Banksia attenuata*	flower post-flower cone	Jandabup flock: as with previous two days, flock of 390 leaves over-night roost, heads west, feeds on pine, and then fragments into widely-dispersed foraging assemblage in suburban area with large patches of *Banksia* woodland; birds probably feeding on *Banksia* cones on ground
9	16-Feb-09	PIN	1	canopy	not recorded		Pinjar flock: flock roosting in pine at junction of Wescoe and Old Yanchep Pinjar Road; <40 birds have brief feeding bout in *Banksia* sp. along road-side
10	17-Feb-09	PIN	2	canopy	*Banksia attenuata*	flower post-flower	Pinjar flock: about 30-40 roostshort in Banksia woodland east of Perry Road, with some feeding before heading east
15	20-Feb-09	PIN	1	canopy	not recorded		Pinjar flock: flock of 360+ dispersed and feeding in stands of young pine from over-night roost through to midday roost, in *Banksia* woodland for 10-20 minutes with some feeding and others going to ground out of sight (drink site), then move back into pine
16	3-Mar-09	YAN	1	canopy	*Banksia attenuata*	cone	Yanchep flock: rolling assemblage of 75+ feeding on *Banksia*, *Dryandra* near entrance to National Park

17	4-Mar-09	BOO	7	canopy ground	*Banksia attenuata* *Banksia prionetes*	flower post-flower cone	Boongarra flock: feeding in large assemblage of 500+ within tuart and *Banksia* woodland at SeaTrees development (probably after at least fed in pine earlier); also feeding on *Hakea* and *Dryandra*; birds feed on *B. prionetes* cones on ground (contain grubs?)
18	5-Mar-09	JAN	1	canopy	not recorded		Jandabup flock: first observed in homestead south of Neaves Road (drink?) then fly-up of 430 with portions: a) progressing west; b) moving west and feeding briefly in Banksia woodland south of Neaves Road and others ground-foraging for pine north of Neaves Road
19	6-Mar-09	BOO	7	canopy ground	*Banksia attenuata* *Banksia prionetes*	flower cone	Boongarra flock: 200+ move from over-night roost in pine to feed in pine then some feed in Banksia woodland between pine stands with all of flock in Banksia woodland for ~20 minutes (mostly feeding on *Dryandra* and *Hakea* not *Banksia*) before all return to feed in pine and then move on to SeaTrees where some also feed on *Banksia* including <10 again feeding on *B. prionetes* cones on ground
22	17-Mar-09	GNA	4	canopy ground	*Banksia attenuata*	flower cone	Gnangara flock: flock of 200+ in Banksia woodland at first sight west of Beechboro then fly-up and most of flock flies east; remaining 50+ birds feed on marri flower and *B. attenuata* flower and cone with some feeding on cones on ground
24	18-Mar-09	JAN	7	canopy ground	*Banksia attenuata*	flower cone	Jandabup flock: about 100 birds around Townsend Road, with some (~20-30) feed in Banksia woodland then move west with some feeding in Banksia woodland before reaching fallow market garden where ground-feed on seed there; 5-10 feed on *Banksia attenuata* near market garden for ~15 minutes
25	24-Apr-09	NNC	1	canopy	not recorded		<8 birds briefly feed on *Banksia* sp. near market garden
26	1-May-09	JAN	1	canopy	*Banksia attenuata*		small (n = 6) group of birds in small patch of Banksia woodland with some feeding

Table 17: Sites with Carnaby's Black-Cockatoo feeding residue from *Banksia* spp. during sampling for Valentine and Stock (2008) [L. Valenetine, DEC, unpublished data]. Residues were either: (a) shredded flowers (flower) or (b) cones with evidence of feeding activity (cones). Residues were classified as either: (a) recent or (b) old.

Month	**No. sites with feeding residue** (all)	**No. sites with feeding residue** (flower)	**Species**	**Total sites with feeding residue** (cone)	**Species**	**No. sites** (Recent)	**No. sites** (Old)
September	5	1	*B. sessilis*	4	*B. attenuata*	4	
				1	*B. grandis*	1	
October	4			4	*B. attenuata*	4	
November	18	8	*B. menziesii*	18	*B. attenuata*		2
					B. attenuata	6	
					B. menziesii		1
					B. menziesii	8	
					unknown		1
December	3	1	*B. menziesii*	3	*B. attenuata*	1	
Total	30	10		30		24	4
% Total Sites ($n = 43$)	69.8%	23.2%		69.8%		55.8%	9.3%

E. Energetics & Seasonal Variability in Food Sources

Food Sources in the GSS Area

Carnaby's Black-Cockatoos may feed on a range of food sources within the GSS area (Saunders 1980, Shah 2006, Valentine and Stock 2008). Potential food items include: pine; *Banksia attenuata* and other common *Banksia* species (particularly *Banksia menziesii* but also *Banksia prionetes* and others); *Banksia sessilis* (Dryandra); marri (*Corymbia callophylla*), various eucalypts (e.g. tuart, jarrah) and similar species (e.g. *Corymbia fictofolia*); endemic shrubs and bushes (e.g. *Hakea* and *Grevillea* species); non-native species (e.g. *Erodium*, *Liquidambar*); and grubs and insects present within *Banksia* cones, underneath bark, and in other vegetation forms (e.g. flowers). Two points are worth emphasising in this context: a) diversity itself does not necessarily translate into high food availability and b) food sources differ in their ecological value to Carnaby's Black-Cockatoos.

The value of a particular food source will reflect several factors. Firstly, the food sources vary in abundance. Some present in high abundances (pine, *Banksia sessilis*, and the two dominant *Banksia* species on the Swan Coastal Plain—*Banksia attenuata* and *Banksia menziesii*) and thus provide a large biomass of potential food. Others are present at lower abundances and do not provide a significant food source. Secondly, the food sources have different energetic contents and nutritional value, and thus provide different energetic and nutritional benefits relative to the foraging effort required to obtain them (Cooper et al. 2002, Valentine and Stock 2008). Thirdly, they vary in the time of year and length of time that they are available. Some, such as pine, are available year-round although with a seasonal peak (e.g. maturation of pine cones in January and February). Others are ephemeral and available only at particular times. *Banksia sessilis* seeds, for example, show a strong peak in availability in April and May when follicles open and seeds are released. Likewise, nectar from marri flowers is only available during the flowering period (roughly February-April) and is likely to vary from year-to-year given inter-annual variability in marri flowering. Shifts in movement patterns and feeding habitat use reflect this variability (at least for *Banksia sessilis*).

In general, we have a good understanding of the abundance of the main food sources in the GSS area and their energetic value based on plantation inventories, vegetation mapping and sampling, and the energetics work of Cooper et al. (2002). However, we have a much weaker understanding of variability in food sources and how this variability influences food availability for Carnaby's Black-Cockatoos in the GSS area. Further study in this area would improve estimates of the availability of food on an annual and seasonal basis.

Energetic value of Banksia woodland habitats

The previous section suggested the seasonal variability in the availability of food sources within Banksia woodland is an important consideration in determining whether birds could compensate for the loss of pine by switching feeding efforts to Banksia woodland habitats. Estimates of the potential energetic value of Banksia woodland habitats must account for a complex suite of factors, including:

(a) *the range of potential food items available in a stand*

Carnaby's Black-Cockatoos feed on a range of vegetation in Banksia woodland habitats, such as the two dominant *Banksia* species (*B. attenuata* and *B. menziesii*); other *Banksia* species (e.g. *B. prionetes*, *B. ilicifolia*); dryandra (*B. sessilis*); various *Hakea* species. In particular, the current estimates do not include *B. menziesii,* which is the co-dominant *Banksia* species in Banksia woodland habitats on the Swan Coastal Plain (with *B. attenuata*).

(b) *the range of potential food items on a single plant*

Potential food items may include seeds, nectar, and or insect larvae from a plant. Insect larvae (grubs) may be particularly important food source to include in energetic estimates.

(c) *seasonal phenological variation*

These may include differences in timing of flowering and fruit maturation (Stock et al. 1991) and patterns in serotiny (e.g. timing of seed release and processes causing seed release). At least one *Banksia* species is flowering throughout the year, indicating birds can feed on nectar and insects associated with flowers year-round (Whelan and Burbidge 1980; W. Stock, unpublished data). However, only *Banksia attenuata* flowers during much of the summer period. Data on seed availability is limited, as is data on the incidence of weevils both in cones.

(d) *influence of environmental factors on variation in flowering, seed production, and seed release/retention*

Factors such as fire, precipitation, disease may influence these processes.

(e) *long-term implications of climate change*

Climate change may affect the long-term productivity of Banksia woodland habitats.

(f) *foraging ecology of Carnaby's Black-Cockatoos*

Aspects of the behavioural ecology of Carnaby's Black-Cockatoos can affect the extent to which they use the energy that is potentially available within a Banksia woodland habitat. Potential factors include habitat selection, cone handling time, cone discard rate, the extent to which they „deplete' an area in a single feeding bout, and if/how often they will return to areas previously foraged within.

Implications

The complexity of these factors currently limits the precision of estimates of food availability for Banksia woodland habitats. Nonetheless, an understanding of the energetic value of feeding habitats is vital for any analysis of the potential impact of pine removal for several reasons. Firstly, the biomass of birds associated with the GSS area from February-May is likely to be the largest concentration of Carnaby's Black-Cockatoos on the Swan Coastal Plain, and this abundance appears to reflect the availability of both pine and *Banksia sessilis.* Secondly, some evidence suggests that one reason why birds may not feed in remnant patches of Banksia woodland habitats during this period is because of the presence of alternative food sources that are concentrated, abundant, and provide high levels of energetic return food (i.e. pine and *Banksia sessilis*).

Thirdly, it is possible that the current standing crop of pine allows the GSS to supports a larger biomass of birds than the GSS area would otherwise sustain. In other words, could a GSS landscape absent of pine sustain an equivalent biomass of Carnaby‘s Black-Cockatoos to that currently sustained during the non-breeding season? Preliminary estimates of the energetic value of *B. attenuata* habitat suggest that this may be the case (Valentine and Stock 2008). However, this work needs refinement and further exploration. In particular we need to assess the availability of food resources provided by native species throughout the year, especially the January to March period.

F. Foraging Behaviour

Variability and Flexibility

Several observations in this study illustrate the variability of the feeding ecology of Carnaby‘s Black-Cockatoos and their behavioural flexibility:

(a) food use

The six flocks observed in February and March fed on a variety of food sources. The Jandabup flock, for example, fed within pine plantation, market garden, and Banksia woodland habitats (and likely also Dryandra thicket). The flexibility of the Jandabup flock almost certainly reflects the heterogeneity of food sources in the Jandabup area (and probably also the local depletion of pine), but also suggests that flocks may differ in their ability to use different habitats. This may relate both to ‗local knowledge‘ of an area and to how the skills and information needed to exploit new food sources and habitats spread within flocks.

(b) food preference

Flocks or sub-flocks may differ in feeding preference. For example, some birds from both the Yanchep and Boongarra flocks did not ‗switch‘ to feeding on *Banksia sessilis* in April, but continued to feed on pine.

(c) foraging tactics

Some birds appeared to prefer to forage for pine cones on the ground rather than feed on cones in the canopy.

(d) food switching

Birds sometimes switched between food sources within the same foraging bout, e.g. feeding on pine for a period of time and then feeding on other food sources, such as *Banksia and Hakea* species.

Ground Foraging

Both Perry (1948) and Saunders (1974) reported that Carnaby‘s Black-Cockatoos often dropped pine cones to the ground while feeding in the canopy and that dropped cones would often be fed upon at a later time by

birds foraging for cones along the ground. Ground foraging occurred frequently in this study and observations of ground-feeding birds and old residues around them suggest that flocks may initially feed on pine in the canopy and then return to ground forage at a later time (and possibly several times). This suggests, as both Perry (1948) and Saunders (1974) suggested, that ground-foraging indicates the local depletion of pine cones in the canopy (i.e. ‗stripping' of stands), although some birds may ground-forage out of preference for this tactic. Thus, the incidence of ground-foraging could provide an indication of how abundant pine is in the canopy. On several occasions, small ground-foraging parties continued to forage for cones even as other birds had assumed a day roost position. However, these birds almost always remained in the shade of the canopy, suggesting that heat stress (from exposure to the sun) is a factor for birds that are active during the mid-day period in summer. Ground-foraging for *Banksia* cones was also observed. As noted by Saunders (1974), pine cones and *Banksia* cones are structurally analogous, although requiring slightly different techniques to extract seeds. Birds ground-foraging for banksia cones may not have been targeting cones containing seed, but possibly cones containing grubs or other insects.

Influence of food availability on flock size and composition

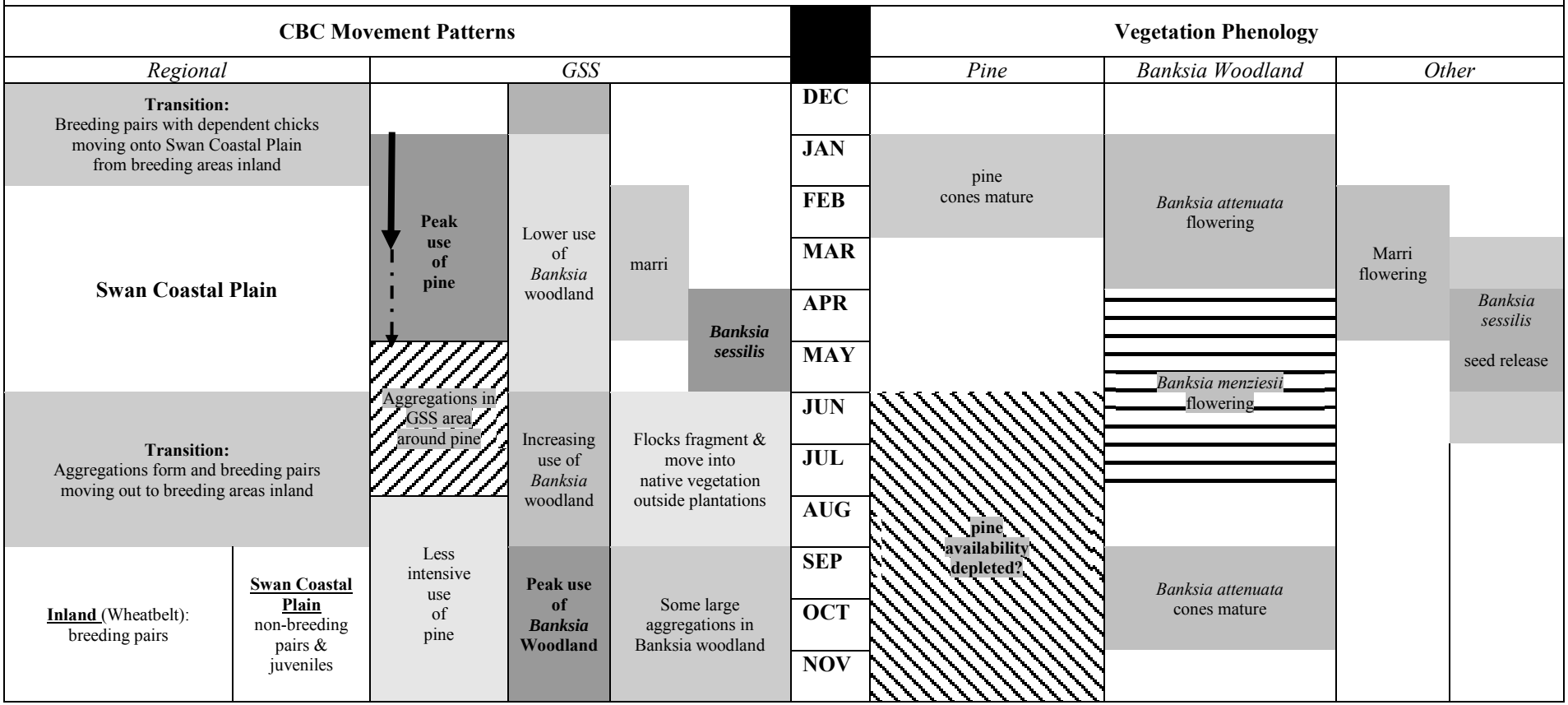
Food availability influences group size in many species. In the 2009 study, food sources appeared to influence both the size and composition of flocks, both on a daily-scale and over a longer time period. Over-night roost flocks often fissioned as they moved off to feeding areas, suggesting that birds shift flocking patterns (group size and composition) in response to the localised availability of food resources, with feeding assemblage sizes decreases as food availability decreases. During February and March (the ‗pine period') most flocks fed on pine, with flocks either roosting over-night in pine or in woodland areas near the plantations, before moving out to feed within the pine plantations during the day. The two largest flocks were associated with the Yanchep and northern Pinjar plantations suggesting that only in these areas is there an adequate abundance of pine to sustain the large biomass of these flocks for several months. While feeding group size varied (see Feeding Ecology next section), the largest pine-feeding groups numbered only a few hundred individuals. In contrast, in April, flocks of more than 1000 birds were observed feeding on *Banksia sessilis* and the flock composition changed significantly, with birds from other areas moving in the Neerabup and Yanchep locations.

6. An Ecological Model for the GSS Area

6. An Ecological Model for the GSS Area

Table 18 provides a conceptual framework for the ecology of Carnaby's Black-Cockatoos in the GSS area, based on observations from the 2009 study and from previous research. The model is provisional but provides an initial framework for understanding the linkage between phenological patterns and the behaviour of Carnaby's Black-Cockatoos.

Table 18: Movement patterns for Carnaby's Black-Cockatoo associated with (non-urban) GSS area and vegetation phenology



PART III
CONSERVATION

1. The Future GSS Landscape

Prior to the 1920s, the GSS area would have been broadly similar to other areas of the Swan coastal plain north of Perth—some areas of human settlement (e.g. farms, towns) interspersed with extensive areas of native vegetation (Tuart and *Banksia* woodland, *Banksia* and *Dryandra* scrub and heath, wetlands). The establishment of some plantations in the Gnangara area in the 1920s (and subsequent expansion) introduced a new and abundant food source that fundamentally altered the ecology of Carnaby's Cockatoos in the region, with large abundances of birds associated seasonally within the plantations from at least the 1940s onwards. This localised abundance of Carnaby's Cockatoos within the Gnangara plantations continued throughout a period of land-clearing in the Wheatbelt that caused many breeding populations to decrease or undergo local extinction. Thus, for the better part of a century Carnaby's Black-Cockatoos have adapted their ecology to the challenges and opportunities of a landscape that provides a mixture of natural and anthropogenic habitats. And, regardless of the outcomes of the Gnangara Sustainability Strategy, they will continue to do so, just as they have adapted to other substantial changes in the landscapes of southwestern Australia.

Adaptation, however, does not mean further anthropogenic changes will not have a significant adverse impact. Further, the species has undergone a significant decline and hopes for its recovery rely largely on the preservation of current habitats, as the expense and practical difficulty of landscape revegetation make large-scale habitat restoration unlikely. Thus, the GSS landscape—and particularly the pine plantations—currently forms an integral component of conservation efforts for this species. To what extent a future GSS landscape could support the conservation of the species largely depends on whether that landscape can provide the environmental features required by Carnaby's Black-Cockatoos, in particular, whether it provides feeding habitat capable of supporting 3000+ birds. In order to address these questions, it is first necessary to define what the future GSS landscape will look like and the processes structuring what that landscape will look like (Table 19).

Of these processes, pine removal will almost certainly have the greatest effect, given the importance of pine as a food resource during the non-breeding season and, to a lesser extent, at other times of the year. The next section addresses the potential impact of pine removal and potential responses.

Table 19: Processes that will modify the GSS landscape by 2030

removal of pine	This would occur either through the complete removal of all plantation areas (by 2030) or the establishment of a smaller plantation complex of 10-15 000 ha within the current footprint of the Pinjar and Yanchep plantation areas. The complete removal of pine would eliminate the largest feeding habitat on the Swan Coastal Plain.
establishment of ecological corridors	Proposed corridors will link patches of remnant vegetation within the existing plantation areas. Some restoration activities may occur which would restore vegetation to certain former plantation areas (if not full vegetation communities in all cases). The corridors could create feeding habitat if suitable species are used.
clearing of native vegetation	Clearing of some native vegetation will be required to support development along the NW Corridor and in other areas (e.g. Neerabup industrial area). This would cause localised losses of feeding and roosting habitat.
climate change	Current predictions are that climate change and decreased rainfall patterns will reduce the productivity of Banksia woodland habitats and alter other aspects of the vegetation communities within the GSS area. Continued decline in groundwater levels would also cause changes in vegetation.

2. Pine Removal: Responses and Impacts

A. Impacts

Loss of roosts in pine

Most flocks roost at least part of the time in pine, either during the day after feeding in pine during the morning or at night when some flocks use pine as over-night roosts. Tuart woodland, patches of other woodland, and stands of tall exotic trees are also used as roost sites and would be used more intensively if pine were unavailable for roosting. Many off-plantation roost sites occur on private property, and removal of pine would increase the amount or proportion of habitat occurring on private lands. Habitats on private property do not have the same security as those on DEC lands, and the potential for harmful interactions is higher (e.g. disturbance of roosting flocks) is higher. Probably the greatest problem with losing pine as a roosting habitat is that many areas of the GSS (e.g. Gnangara) do not have many stands of tall, full-canopied trees that could support large (>100 birds) flocks.

Loss of feeding habitat

Removal of pine will have a significant effect, given that this habitat currently sustains about 3000 birds for a period of three months and a smaller abundance through the rest of the year.

B. Responses

Table 20 describes the expected responses of Carnaby's Black-Cockatoos to pine removal.

Adaptive Capacity

The removal of pine will fundamentally alter the ecology of the ~3000 birds now associated with the pine plantations. However, Carnaby's Black-Cockatoos have a flexible behavioural ecology that provides them with some level of adaptive capacity to compensate for the loss of pine. At a regional-scale (northern Swan Coastal Plain), for example, the species appears to have adapted movement, breeding, and residency patterns to broad-scale loss of native vegetation and its conversion to other land uses (Johnstone and Kirkby 2008).

Post-pine ecologies

The ecologies of the Gnangara Road and Jandabup flocks likely provide an indication of what a pine-depleted/pine-absent ecology would look like. Although these flocks continue to rely on pine, both as a food source and as an over-night roost habitat, they now feed frequently outside of the plantation and the majority of their diet is likely to be non-pine food sources. For example, both flocks were observed to over-night roost in pine (often feeding on pine before roosting for the night and after leaving roosting positions at the beginning of the day), they typically travelled off-plantation (often stoping first at drink sites) and then foraged and roosted off-plantation until late in the day. An exception to this is two 2009 Jandabup flocks that ground-fed on fallen pine cones, a behaviour that probably reflects the limited availability of canopy-based cones (Perry 1948, Saunders 1974).

Banksia woodland as a compensatory habitat

Some of the issues associated with Banksia woodland as a compensatory habitat have been addressed in previous sections (e.g. seasonal variability in food availability). An additional problem may arise if birds shift to feed in the extensive Banksia woodland areas at the northern and eastern margins of the GSS area. These areas have few tall trees for roosting (assuming pine is completely removed from existing plantation areas). The availability of water is also an unknown for these areas, and they may lack water sources (especially during summer) because they contain few human settlements. A lack of water and roost trees means that birds might have to travel long distances from roost and/or water sources to feed in these areas.

Temporal Patterns

Current patterns in abundance and in use of pine for feeding suggest that January to March (i.e. the pine period) will be the period in which birds will be most affected by the loss of pine, although the

loss of pine will also affect birds during the second half of the non-breeding season (April-June) and birds resident in the GSS area during the breeding season. In January-March, future abundances will likely be lower than currently as some birds will feed in areas north of the GSS. Birds in the GSS area will feed in other (non-pine) habitats, particularly Banksia woodland areas. In April-May, abundances may be similar or somewhat lower than currently, as birds begin feeding on *Banksia sessilis* in the GSS area.

Table 20: Behavioural responses of Carnaby's Cockatoos to reduction/loss of pine

Response	Note
Flock fragmentation and smaller flock size	The loss of a food source as concentrated as pine will cause some flocks to fragment, either on a daily basis as they depart over-night roosts or on a more permanent basis, as sub-flocks distribute themselves across the landscape in new ways. Those birds that remain near the suburban fringes will likely adopt an ecology similar to that of flocks in urban areas around Perth—small flocks feeding in relatively small patches of remnant vegetation and roosting at a limited number of locations.
Shifts in food use	The absence of pine will force birds to feed on alternative food sources. While in most cases, this will mean feeding on traditional food sources such as *Banksia attenuata,* it is also likely that birds may begin feeding on new food sources or on food sources that they previously used much less.
Changes in habitat use within GSS area	Some birds will feed in the extensive Banksia woodland areas at the northern and eastern margins of the GSS area, as well as other non-pine feeding habitats in other sections of the GSS area.
Changes to daily movement patterns	Birds may have to travel greater distances each day because feeding habitats, roost sites, and water sources are more distant from each other. Pine plantations often provided both feeding and roosting habitats near to water sources. More „rolling" assemblages may occur. These feeding aggregations traverse over large areas feeding for brief periods on small patches of feeding habitat. In contrast, pine is a „dense" food source, meaning that flocks can often remain in one area for the duration of a feeding bout, thus minimising travel associated with foraging.
Changes in roosting patterns	• Flocks will shift to roost sites off-plantation. • Flocks may have shorter residence times at overnight roost sites, i.e. they will move on to another roost sites after exhaust available food in an area. • Flocks will rely more on a small number of roost sites off-plantation. • Flocks will be subject to greater levels of disturbance because many roost sites will be located near settlement areas.
Changes in distribution within northern Swan coastal plain	Some flocks will shift their ranging patterns away from GSS area. Many are likely to shift to feed in areas of remnant native vegetation north of the GSS area. Some birds may also begin to feed in recently-established pine plantations in the Gingin area (R. Johnstone, WA Museum, personal communication).
Changes to activity budgets	Birds may alter activity budgets to accommodate changes in the availability, e.g. by spending longer periods feeding or travelling to/from feeding habitats and less time day-roosting.

C. Significance of Impacts

Are some areas already depleted of pine? What were the effects?

Since 1999, areas harvested of pine within the Gnangara plantations have not be re-planted, which has led to a gradual decline in the amount of standing pine (and available cones), and thus the carrying capacity of the plantations for Carnaby's Black-Cockatoos. The summer 2009 fire around Yanchep may have caused pine to become depleted for birds feeding out of Yanchep National Park. The section of feeding ecology in Part II also discussed some anecdotal observations indicating that at least some areas of the pine plantations have been stripped of cones.

In addition, as trees may take time to recover from the stripping of cones (Saunders 1974), there may progressively less of a new crop each year, both because more trees have been harvested and because standing trees produce less and less cones. Although quantitative data are necessary to confirm these observations, they do suggest—particularly when coupled with observations of the foraging behaviour of birds—that in the Gnangara plantation the pine cones available each year are rapidly stripped soon after birds arrive back from breeding areas, causing localised depletion. Evidence of local depletion and the foraging patterns of flocks suggest that areas of local depletion of pine cones occur, particularly in the Gnangara plantation, which is the most fragmented of the three plantations. The two flocks based around this area spend a greater proportion of their time feeding outside of the pine plantations, even though they will roost in pine on-plantation over-night.

The lack of observation and abundance estimates within the Gnangara plantations during this time period precludes any effort to identify any trends in response to the diminishing availability of pine. However, the longevity of the species would suggest that abundance might not change greatly in the short-term (i.e. $\leq$ ten years), even if the loss of pine had begun to affect demographic parameters such as reproductive success and survivorship. Other measures, particularly aspects of their behavioural ecology, which are measurable and obvious over short time periods may provide more useful indicators of the effect of a reduction or loss of pine as a food source.

Adaptive Capacity and Landscapes

Birds will adapt their behaviour to respond to pine removal. The key questions are whether the alternative habitats in surrounding landscapes will provide sufficient resources to accommodate the ecological requirements of affected birds. As indicated in Table 20, birds will shift their use of habitats within and beyond the GSS area. This raises two questions: (1) Will food availability in non-pine feeding habitats in the GSS area be sufficient to sustain the birds that shift to those habitats? and (2) Will food availability in feeding habitats outside the GSS area be sufficient to sustain the birds that shift to those habitats? Further research is required to address these questions. As discussed in other

sections, there is uncertainty about whether native vegetation habitats could provide sufficient food sources to sustain a large number of birds in the summer (January – March) period. Food availability outside of the GSS area is outside the scope of this report.

Factors Regulating the Size of GSS Populations

A final critical issue for assessing the impact of pine removal is how food availability in the GSS relates to size of the populations in GSS area—are the factors regulating the abundance of these populations associated with GSS area mainly to do with breeding areas (i.e. outside of the GSS area) or are factors during the non-breeding season (i.e. within the GSS area) also important?

Three main factors are likely to regulate the size of breeding populations associated with GSS area: (a) factors associated with breeding areas and reproductive success there (e.g. influence of local food availability on nesting and fledging success); (b) juvenile survivorship (post-fledging survival); and (c) adult mortality rates. In addition, the condition of adult birds during non-breeding season may influence whether they decide to breed in a given year and thus have an indirect effect on reproductive rates. Table 21 discusses how food availability in the GSS area may influence these factors.

General Conclusions

The GSS landscape without pine would be unlikely to sustain the biomass of Carnaby‘s Black-Cockatoos that currently occurs during the first half of non-breeding season (January-March). Carnaby‘s Black-Cockatoos have a strong association with the GSS pine plantations, and utilise the pine plantations as an important source of food and roosting habitat. This report has identified that the pines are most heavily utilised during the early non-breeding season (January-March), and during this period, Carnaby‘s Black-Cockatoo are frequently observed feeding and roosting in pines. In our study, Carnaby‘s spent more time in the pine plantations than the nearby remnant patches of Banksia woodland habitat, indicating a preference for pine plantations. The removal of pine plantation will decrease a reliable available food source that Carnaby‘s Black-Cockatoo have been using since the 1930s. Flocks around the Yanchep and Boongarra areas would likely be most affected by this reduction in food availability because they are both the largest flocks in the the GSS area and currently have the largest crop of standing pine available to them (ie. the Yanchep and northern Pinjar pine plantations)> It is likely that some birds will respond to diminished food availability in the GSS area by moving to other areas, particularly north of the GSS study area where extensive banksia woodlands remain. At this stage there is still considerable uncertainty over the availability of food sources in the Banksia woodland habitat remaining in the GSS study area. Although there is a large contiguous stretch of Banksia woodland to the north and east of the pine plantations (~ 70 000 ha), further research is required to assess whether food sources are available in this habitat throughout the year. Given the lack of information on food supply, a precautionary step for Carnaby‘s Black-Cocaktoo would include the retention of some form of pine plantation.

Table 21: Influence of pine (food) availability on Carnaby's Cockatoos in GSS area

Effect	Note	Effect of reduction in pine availability
Survivorship: dependent chicks	Pine is important for pairs who have returned to the GSS area with a chick that is still at least partially dependent on its parents for food. Pine has several useful characteristics in this regard: a) it is dense, thus minimising the distance that must be moved (unless there are other factors such as water); b) chicks may roost in pine while parents feed; and c) pine itself can be used as a day or over-night roost.	Reduced survivorship
Survivorship: independent juveniles	Given its abundance, year-round availability, and ease of use, pine is likely to be a critical determinant of the survivorship of fledged and independent juveniles (i.e. immature and non-breeding) that may reside in the GSS year-round. Like other species with similar life histories, mortality is often high during the first year post-fledging, often because birds are unable to find adequate food.	Reduced survivorship
Condition of breeding and non-breeding adults	The availability of food during the non-breeding season (~December-January to June-July) influences the condition of breeding pairs that will breed in the second half of the year and also those pairs that will not breed but remain in the GSS area.	Reduced condition likely leading to lower breeding success
Breeding success in GSS area	Some breeding pairs occur in areas of Tuart woodland and they are likely to rely on pine (at least in part) as a food source during breeding periods.	Lower rates of breeding success

3. Risk Assessment Framework

The section provides an initial framework for an environmental risk assessment dealing with the impact of pine removal on Carnaby's Black-Cockatoos. This framework does not constitute a formal risk assessment, bur rather an attempt to identify the issues and information necessary to support one.

Elements of the Risk Assessment Framework

1. Apply the Mitigation Hierarchy

The mitigation hierarchy is a sequence of measures designed to manage impacts from proposed actions (e.g. developments, changes to management). Table 22 provides the elements of the mitigation hierarchy and potential questions arising from their application.

Table 22: Potential mitigation hierarchy for pine removal

Element	Potential Question
1. Avoid	Is it necessary to remove pine?
2. Minimise	Is it possible to leave some pine?
3. Rectify	What measures can be applied to restore feeding habitat?
4. Reduce	How can on-going management be used to best conserve feeding habitat?
5. Offset	What offsets can be applied to compensate for residual impacts (i.e. impacts that cannot be managed through the earlier elements of the hierarchy)?

2. Define the Risk Event(s) and Identify Potential Impacts

Table 26 provides a risk assessment matrix for pine removal. Once the source of risk (pine removal in this case) has been identified, the next step is to identify the risk events associated with this and potential impacts arising from them.

3. Determine the Consequence Rating for Potential Impacts

The next step is to determine the consequence rating for potential impacts using some sort of consequence rating scheme. Generally consequences are considered either with or without mitigation or offset measures in place. Table 25 provides three consequence categories that could be applied in this context. The consequences descriptions for protected fauna individuals and populations were developed by H. Finn and provide an example of consequence descriptions that could be applied in assessing the impact of pine removal. The specific predictors frame the impact in terms of the risk of population decline. A _biologically significant impact' is an effect that could influence population viability. For example:

> —...*a measurable impact on a population and/or its habitat which could reasonably be expected to affect the population's finite rate of increase (λ) or its stability, and as a result influence the population's viability*" (USFWS)

4. Determine the Likelihood Rating for Potential Impacts

Table 23 provides likelihood descriptions drawn from the risk assessment literature.

Table 23: Likelihood descriptions for risk assessment

Value	Descriptor	**Description** AS/NZS 4360 and HB 203:2006 (modified)
5	*Almost Certain*	Expected to occur in most circumstances during the life cycle of the proposed action
4	*Likely*	Will probably occur in most normal circumstances during the life cycle of the proposed action
3	*Possible*	Could occur at some time during the life cycle of the proposed action
2	*Unlikely*	Not expected to occur during the life cycle of the proposed action
1	*Rare*	Occur only under exceptional circumstances during the life cycle of the proposed action

5. Determine the Risk Severity Rating Using a Risk Severity Matrix

Table 24 provides a risk severity matrix. The Risk Severity is determined by multiplying the Consequence Rating by the Likelihood Rating.

Table 24: Risk Severity Matrix

Low	**Medium**	**High**	**Unacceptable**
1 to 4	5 to 10	12 to 16	20 to 25

Table 25: Consequence descriptions for risk assessment

Value	Description AS/NZS 4360 and HB 203:2006	Generic Descriptors - Natural Environment* Impact on ecosystem &/or specific species or communities, recovery, remediation	Specific Descriptors – Fauna (Individuals) Impact on Protected Fauna Individuals	Specific Descriptors - Fauna (Populations) Impact on Protected Fauna Populations
5	**Catastrophic**	Massive impacts with significant remediation required Irreversible alteration to ecosystem functioning Long term environmental recovery that may take decades or longer	Behaviour, physiology, and well-being severely (or mortally) affected with individual reproductive success greatly reduced or ceased	Effects initiate substantial population decline; possible mass mortality
4	**Major**	Major impacts with considerable remediation required Major alteration to ecosystem Recovery period measured in years to decades	Behaviour, physiology, and well-being substantially affected with reduction in individual reproductive success	Effects are biologically significant with key demographic parameters adversely affected; population in slow/moderate decline
3	**Moderate**	Moderate impacts with some management required Moderate alteration to ecosystems Recovery period measured in months to years	Behaviour, physiology, and well-being affected to a degree that individual reproductive success is reduced	Effects detectable for demographic factors at population-level but not biologically significant to unless effect is sustained
2	**Minor**	Minor impacts with minimal management required Minor alteration to ecosystems, not affecting function Recovery period measured in weeks to months	Behaviour, physiology, and well-being affected to a degree that minimally influences individual reproductive success	Effects potentially observable at population-level but insufficient to be biologically significant
1	**Insignificant**	Negligible impact with no management required No alteration to ecosystems	Behaviour, physiology, and well-being barely or weakly affected	Effects not observable at population-level; no effect of biological significance

*DEC (2008) *Guide to preparing a Works Approval and Licence Application Document [DRAFT]*. DEC Industry Regulation, Environmental Regulation Division. October, 2008. (Based on *AS/NZS 4360:2004 Risk Management* and *Environmental Risk Management Handbook Standards Australia HB 203: 2006*) [Used with permission from Oceanica Pty Ltd]

Table 26: Risk assessment table for pine removal

Source / Cause of Risk	Risk Event	Potential Impact	Likelihood	Consequence	Risk Rating	Key Management or Mitigation Actions
Removal of pine	Removal of food resource (pine cones) reduces food availability for Carnaby's Black-Cockatoos	**Individual** 1. Reduced survivorship: dependent chicks 2. Reduced survivorship: independent juveniles 3. Reduced survivorship: adults 4. Reduced condition: breeding/non-breeding adults 5. Reduced breeding success in Gnangara area **Population** 1. Reduction in carrying capacity (Gnangara area) 2. Decline in local abundance (Gnangara area) 3. Decline (or lack of recovery) in breeding populations associated with Gnangara area	**For example:** **4** (Likely) - **5** (Almost Certain)	**For example:** **3** (Moderate) - **4** (Major)	**For example:** **12** (High) - **15** (High) - **16** (High) - **20** (Unacceptable)	Management actions to reduce impact **For example:** 1. Retention of portion of existing pine plantation 2. Restoration of native vegetation food sources 3. Planting of pine stands or strips
Removal of pine	Removal of roosting resource (pine trees) reduces availability of over-night roost sites for Carnaby's Black-Cockatoos	Roost in sub-optimal roost sites Increased human-wildlife conflict Greater travel time and energetic expenditure Flock fragmentation	**For example:** **4** (Likely) - **5** (Almost Certain)	**For example:** **2** (Minor) - **3** (Moderate)	**For example:** **8** (Medium) - **10** (Medium) - **12** (High) - **15** (High)	Management actions to reduce impact **For example:** 1. Retention of portion of existing pine plantation 2. Restoration of native vegetation to provide roost trees 3. Planting of pine stands or strips to provide roost trees (e.g. near areas of native vegetation 4. Conservation covenants with private land-holders 5. Public education programs

4. Assessment Under the EPBC

Table 27 lists the EPBC significant impact criteria for species listed as Endangered and discusses the extent to which the criteria might apply to the impact of pine removal on Carnaby's Black-Cockatoos. Impacts considered as likely to have a significant impact constitute a controlled action under the EPBC. Referral to DEWHA would be appropriate for this action because the proposed removal of feeding habitat currently totalling over 15 000 ha suggests the potential for a significant impact as defined under the EPBC.

The assessment process for the action should consider that pine in the GSS plantations functions as a food source in the same way as native plants do, and the loss of pine feeding habitat will have an impact that is equivalent to the loss of an area of native vegetation of similar size and quality. The status of pine as analogous to that of native vegetation is also supported by the length of time (three-quarters of a century) that the Perth pine plantations have provided feeding habitat for Carnaby's Black-Cockatoo. The pine plantations have provided a remarkably dependable and abundant food source during a period of considerable instability and decline for this species. The assessment process should also follow the mitigation hierarchy and clearly identify measures that could be used to avoid, minimise, reduce, and rectify impacts. Full pine removal will have a large residual impact that needs to be identified and—to the extent possible—offset, in accordance with the principles contained within the draft Commonwealth environmental offsets policy (and also within the State offsets policy).

There is also a need for consistency in how this impact is assessed. Previous assessments have established the expectation (and possible precedent) that almost any loss of potential feeding habitat on the Swan Coastal Plan is concerning. Reasoning *a priori* that birds will compensate for the loss of pine habitat by switching to native vegetation is clearly inconsistent with the view—established in previous assessments and draft recommendations—that feeding habitat is limited and loss of feeding areas should be avoided wherever possible. The action should be assessed for what it is—a substantial loss of feeding habitat that will affect several thousand birds.

Table 27: Carnaby's Cockatoo EPBC „significant action" assessment

Under the EPBC an action will be considered likely to have a significant impact on a critically endangered or endangered species if there is a real chance or possibility that it will cause these outcomes:

EPBC Criteria	Impact	Comment
Lead to a long-term decrease in the size of a population?	possible	Some breeding populations associated with the GSS area could experience population declines as a consequence of reduced food availability. This could occur if, for example, juvenile survivorship was largely contingent on the availability of pine.
Reduce the area of occupancy of the species?	no	Birds will still utilise the GSS area.
Fragment an existing population into two or more populations?	no	Population structuring is likely to occur, but involves populations at breeding areas.
Adversely affect habitat critical to the survival of a species?	?	Feeding habitat on the Swan Coastal Plain has not been listed as „significant habitat" under the EPBC. It would be difficult to argue that GSS pine plantations are critical to the survival of the species in the short-term, given the current total population size (40 000+) and the presence of populations associated the breadth of the Swan Coastal Plain and the southern coast.
Disrupt the breeding cycle of a population?	no	Pine removal will not affect feeding habitat for breeding birds, although a small number of birds are thought to breed in the GSS area.
Modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline?	possible	Some breeding populations associated with the GSS area could experience population declines as a consequence of reduced food availability. This could occur if, for example, juvenile survivorship was largely contingent on the availability of pine. If so, then this would cause an overall species decline.
Result in invasive species that are harmful to a critically endangered or endangered species becoming established in the endangered or critically endangered species' habitat?	possible	Creation of parkland habitat to replace pine plantation could lead to a much higher incidence of fox predation.
Introduce disease that may cause the species to decline?	no	N/A
Interfere with the recovery of the species?	yes	The removal of such a substantial feeding habitat certainly reduces the likelihood that breeding populations in the GSS area would recover.

5. Habitat Management

Landscape Management

Management efforts for Carnaby‘s Black-Cockatoos should aim to retain and, where possible, restore habitat in the GSS area. Retention of a pine plantation in the GSS area would provide the best conservation outcome for this species. Pine removal will remove high-quality feeding habitat and thus will almost certainly have a detrimental effect, although the degree of impact remains uncertain. There is also considerable uncertainty as to whether other feeding habitats would adequately compensate for the loss of pine. Ideally, retention of pine as a feeding habitat resource could be achieved while also achieving other environmental and land use objectives. Beneficial outcomes could be also be achieved by facilitating the establishment of pine plantations in other areas of the Swan Coastal Plain.

Banksia woodland and *Banksia sessilis* thickets are the two most important native vegetation feeding habitats, emphasising the need to protect these habitats within the GSS area (e.g. limit clearing of these habitats) and manage them effectively (e.g. apply appropriate fire regimes). It is also essential to provide stands of pine or other tall trees (e.g. eucalypts) to provide roosting habitat near areas of Banksia woodland particularly at the northern and eastern margins of GSS. Removal of pine will leave little roosting habitat near these areas and the provision of potential roost trees would enhance suitability of these habitats. Water sources may also be limiting, suggesting the possibility of creating artificial water points or wetlands.

Offsets can involve both the creation of feeding habitats through revegetation and the protection of existing habitats. However, where habitats are protected they should be demonstrably under threat. An example of a candidate offset area is the native vegetation in lot 200 (located near the Neerabup industrial area), a landscape that contains both Tuart woodland in good condition and large areas of Dryandra thicket. This area is currently classified as „industrial‘ under the current Perth Metropolitan Planning Scheme.

Restoration of Shrub/Bush Food Sources

Full restoration of Banksia woodland habitats is expensive and logistically difficult, and thus may prove impractical for all but small areas. However, some restoration can be achieved if restoration activities focus on creating feeding habitat rather than the reestablishment of complete native vegetation communities. In other words, feeding habitat can be restored at relatively low cost and logistical outlay if revegetation aims to create a habitat that is simplistic in composition but nonetheless functional in providing food sources. In certain cases, restored habitats could be established involving a hybrid habitat containing both native and non-native (e.g. pine) plant species. At a landscape-scale, feeding habitat can be restored by establishing a matrix of feeding habitats that collectively are: (a) *abundant* (i.e. restore a large biomass of food to the landscape); (b) *redundant* – (i.e. there is sufficient

redundancy in species used to compensate for restoration failure in some species and restoration sites); and (c) *omnibundant* – (i.e. There is sufficient overlap in the availability of food sources to compensate for annual and seasonal variation and ensure that at least one food source is available at all times of the year).

On-going research suggests that feeding habitat can be restored with seven years. At Boddington Gold Mine in the eastern jarrah forest, Carnaby's Black-Cockatoos feed intensively on regenerating native vegetation in mine-site rehabilitation areas as early as six (and possibly five) years after planting (J. Lee, Murdoch University, unpublished data). Initial sampling has found feeding residues for several *Banksia* species and *Hakea* species, findings that are also supported by consistent observations of flocks of feeding within rehabilitation areas. These findings suggest that rehabilitation areas at an early successional stage (i.e. not yet dominated by canopy-forming trees) can provide a functional feeding habitat within a short period of time.

Many of the food sources used by Carnaby's Black-Cockatoos are in fact well-suited to the environment that would be left after pine is removed. Many of the _Dryandras', for example, are among the first species to re-colonise disturbed areas, as are some *Hakea* species. Thus, feeding habitat could be restored at relatively low cost and minimal logistical outlay by establishing vegetation complexes consisting of species such as *Banksia sessilis* and certain *Hakea* species. These complexes could also serve as vegetated corridors linking areas of remnant vegetation (see the network of ecological corridors proposed in Brown et al. 2009). The addition of non-native species such as pine and *Erodium* would further enhance the value of these areas as feeding habitat. Although there may be some resistance to these restoration concepts (and particularly to the idea of using non-natives), the reality is that without the application of alternative revegetation approaches many areas will simply be left to convert to weed-dominated grassland of little to no functional value.

Pine as Restoration Vegetation

Individual pine trees, strips of pine, and stands of pine could be used as a restoration technique, particularly if planted at low densities and positioned within areas where groundwater sources are at depths > 15m and areas with low significance as aquifer recharge areas. Such _patches' of pine would provide both feeding and roosting habitat. The provision of pine roosts may be particularly valuable in areas where large trees are otherwise absent, such as the areas of Banksia woodland at the northern and eastern margins of the GSS area. Planting pines at low stand densities encourages greater canopy volume. While increasing canopy cover also increases use of water by pine, trees with larger canopies are much better producers of cones than trees with small canopies, i.e. the amount of cones a tree produces increases disproportionately with canopy volume. Thus disproportionate gains in per-tree food availability can be achieved by allowing greater canopy volumes even if the standing biomass of a pine stand is reduced.

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