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Food Resources of Carnaby's Black-Cockatoo (Calyptorhynchus latirostris) in the Gnangara Sustainability Strategy study area

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Gnangara Sustainability Strategy

An across-government initiative

Groundwater – Biodiversity – Land use

FOOD RESOURCES OF CARNABY'S BLACK-COCKATOO (*CALYPTORHYNCHUS LATIROSTRIS*) IN THE GNANGARA SUSTAINABILITY STRATEGY STUDY AREA

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Edith Cowan University & Department of Environment and Conservation

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Report to Forest Products Commission

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Food Resources of Carnaby's Black-Cockatoo (*Calyptorhynchus latirostris*) in the Gnangara Sustainability Strategy study area

Introduction

Carnaby's Black-Cockatoo *Calyptorhynchus latirostris* Carnaby 1948 is an endangered species, endemic to the south-west of Western Australia, and is listed as threatened under State (*Wildlife Conservation Act 1950*) and Commonwealth (*Environment Protection and Biodiversity Conservation Act*) legislation. Since the 1950's, the range of Carnaby's Black-Cockatoo has contracted by more than 30%, the species has disappeared from more than a third of its former breeding range, and the population is estimated to have halved (Garnett and Crowley 2000; Mawson 1995; Saunders and Ingram 1998a,b). Major threatening processes include habitat fragmentation that remove nesting and food resources, illegal trade of birds for the pet industry, and competition for nest hollows with other species (Cale 2003).

The Swan Coastal Plain in Western Australia represents an important foraging area for Carnaby's Black-Cockatoo, with a minimum non-breeding population of at least 4,500 birds visiting the area (Shah 2006). However, an expanding urban population and agricultural development has resulted in the removal of large sections of native vegetation. There has been a major shift in dietary composition from a traditional diet of mostly native seeds and nectar to seeds of pine from plantations (Higgins 1999; Saunders 1980). In particular, the pine plantations in the Gnangara area have been recognised as an important food resource for Carnaby's Black-Cockatoo for over 70 years (Perry 1948; Saunders 1974b).

In the northern Swan Coastal Plain, the underground aquifers are collectively known as the Gnangara Ground Water System and underlie the city of Perth, numerous wetlands, extensive Banksia woodlands and the pine plantations. The declining rainfall and decreasing ground water levels in the northern Swan Coastal Plain has heavily impacted water availability and the ecosystems that depend upon it (Government of Western Australia 2008). A multi-agency taskforce, known cooperatively as the Gnangara

Sustainability Strategy (GSS), was established to plan water and land management uses in the GSS study area. The pine plantations within the GSS study area covered over 23,000 ha and the Forest Products Commission (FPC) are an integral member of the GSS taskforce. The pine plantations in the GSS study area limit ground water recharge and will be harvested without replacement over the next 18 years (Government of Western Australia 2008). The expected clear fall without replacement will potentially lead to a shortage of food for Carnaby's Black-Cockatoo (Cale 2003; Garnett and Crowley 2000). This report aims to review information available on the feeding activities of Carnaby's Black-Cockatoo, and examine the evidence for dependence on pine plantations in the Gnangara Sustainability Strategy study area.

Species Description

Morphological Description

Carnaby's (or Short-billed) Black-Cockatoo is a large cockatoo from an iconic genus of black cockatoos (*Calyptorhynchus*) that are endemic to Australia. Originally considered a subspecies of Baudin's (Long-billed) Black-Cockatoo (*Calyptorhynchus baudinii*), Carnaby's Black-Cockatoo is currently recognised as taxonomically distinct (Saunders 1974a; Christidis and Boles 1994). Carnaby's Black-Cockatoo measures 53 – 58 cm in length, has a wingspan of approximately 110 cm and a mass of 520 – 790 g (Higgins 1999). In body colour, the cockatoos are mostly brownish-black to greyish-black, with creamy white margins on the feathers and broad white panels on the tail feathers (Carnaby 1948). Sexual dimorphism occurs in this species, and the sexes can be distinguished in the following ways: females contain a large creamy-white cheek patch, a light-coloured bill (greyish-white) with a black tip, and a grey to dark-grey eye-ring; males have a comparatively smaller and duller cheek patch, a black or black-grey bill and a pink-red eye-ring (Figure 1).

Figure 1. Carnaby's Black-Cockatoo (*Calyptorhynchus latirostris*) on *Banksia attenuata*. Male on left – note pink-red eye-ring, dark bill and off-white cheek patch. Female on right – note dark eye-ring, pale bill and distinct white cheek patch. Photo credit: L. Valentine.

Distribution and Seasonal Movements

Carnaby's Black-Cockatoo is endemic and widespread throughout the south-west of Western Australia in areas receiving more than 300 mm of mean annual rainfall. Based on the distribution of birds during the breeding season, the total population of Carnaby's Black-Cockatoo has been estimated at between 11,000 and 60,000 birds (Saunders *et al.* 1985), however, the population could number less than 10,000 birds (Mawson and Johnstone 1997).

This species is highly mobile, often gregarious, and typically displays a seasonal migratory pattern that is linked to breeding (Saunders 1980, 1990; Berry 2008). Typically, birds are common in coastal regions in the non-breeding season (January – July) and move inland to the wheatbelt to breed (late July – December; Saunders 1980, 1990; Berry 2008). Breeding mostly occurs in areas receiving 350 – 700 mm of annual rainfall, and the Avon Wheatbelt Bioregion is a prime breeding area (Saunders 1982, 1986, 1990). However, recently Carnaby's Black-Cockatoo have been recorded breeding on the Swan Coastal Plain (Johnstone and Storr 1998). During the breeding season adults nest as solitary pairs

(Higgins 1999; Saunders 1986) in eucalypt woodlands, typically using tree hollows of Wandoo (*Eucalyptus wandoo*) and Salmon gum (*E. salmonophloia*) (Saunders 1982, 1979), and on the coast, Tuart (*E. gomphocephala*) (Johnstone and Storr 1998). Clutch size is between 1 – 2 eggs, although only one chick is successfully reared (Saunders 1982). During the breeding season Carnaby's Black-Cockatoo mainly forages in native vegetation, particularly in proteaceous shrubs in kwongan heathlands. Following breeding, most birds move south and west wards towards the coast, often forming large foraging flocks (Saunders 1974b, 1980).

The Swan Coastal Plain is recognised as a particularly important non-breeding foraging area for the cockatoos, where they often feed in *Banksia* woodlands and *Pinus* plantations (Saunders 1980, 1990). Counts of flocks descending to nocturnal roost sites (of sometimes more than 600 individuals) indicate a seasonal change in density, with the lowest numbers of individuals observed from August to October, presumably while birds move to the wheatbelt to breed (Berry 2008). Previous work has shown that some birds breeding from the Manmanning region tend to spend the non-breeding season in the GSS area, between Perth and the Moore River, with large flocks (several hundreds) frequenting the Yanchep swamp region (Saunders 1980). Historic observations by Perry (1948) indicated that groups of birds between 5,000 – 6,000 individuals were observed foraging in pine plantations around Perth. However, in the late 1970's, Saunders (1980) reported the single largest flock observed contained approximately 1,200 individuals. More recently, Shah (2006) estimated a minimum of 4,510 individual birds on the Swan Coastal Plain during the non-breeding season, based on night-time roost counts (Shah 2006). The northern region of the area covered by Shah (2006) largely overlaps with the GSS boundaries, and consistently contained the largest proportion of sightings of Carnaby's Black-Cockatoo.

Food Resources of Carnaby's Black-Cockatoo

Carnaby's Black-Cockatoo forage on a variety of food items, principally seeds from native and introduced plant species, and occasionally flowers or nectar and insect larvae (Higgins 1999). A review of the literature found that Carnaby's Black-Cockatoo have been observed feeding on components of 73 plant species (Table 1). The majority of these, 59 species from 6 plant families were native to Australia, although 4 are garden species from

outside of the south-west WA region. By far the most specious family consumed were the proteaceous plants, with 16 species of *Banksia*, 19 species *Hakea* and 6 species of *Grevillea* recorded as food items (Table 1). The majority of the remaining native species consumed were *Eucalyptus* or *Corymbia* species from the Myrtaceae family (10 species).

Carnaby's Black-Cockatoo have been predominantly observed foraging on the seeds of 52 native species (Table 1). By far the most common native plant species Carnaby's Black-Cockatoo have been observed foraging upon include the *Banksia* (including *Dryandra* species), *Hakea*, *Grevillea*, *Allocasuarina* and *Eucalyptus* (Carnaby 1948; Saunders 1974a, 1974b, 1980; Higgins 1999). On the Swan Coastal Plain, identified important native food plants include *Banksia attenuata, B. menziesii, B. grandis, B. ilicifolia, B. sessilis, B. prionotes, Corymbia callophyla* and *Eucalyptus marginata* (Saunders 1980; Shah 2006; Weerheim 2008). Indeed, *Banksia* species (especially *B. attenuata*) contributed nearly 50% of native plant foraging records (Figure 2), with an additional 15% of records from Marri *C. calophylla* (Shah 2006).

Figure 2. Male Carnaby's Black-Cockatoo feeding on seeds from *Banksia attenuata*. Photo credit: L. Valentine.

Flowers from 19 species were also recorded as a foraging item. When feeding on flowers, Carnaby's Black-Cockatoo may be foraging on the nectar component or on invertebrates, but this is difficult to confirm, with the exception of *Callistemon viminalis* (Mawson 1995). In addition, on the Swan Coastal Plain, the blossoms from Tuarts *E. gomphocephalla* may also be an important food source (Shah 2006), as well as the flowers of *B. sessilis*. Carnaby's Black-Cockatoo have been observed consuming invertebrates from a number of native plant species (Table 1). The birds have been observed foraging on both braconid wasps and seed-eating weevils (*Alphitopis nivea*) from cones and fruit of *B. attenuata* (Robinson 1965; Scott and Black 1991). Insect larvae may also be taken from the fruit or flowers of other species, such as *B. tricuspis* (e.g. van Leeuwen and Lamont 1996), and Carnaby's Black-Cockatoo crop contents have included the larvae of Cerambycid and Pyralid insects (Saunders 1980). In addition, Carnaby's Black-Cockatoo have been observed stripping the bark from *Acacia saligna* and *Agonis flexuosa*, and may be searching for invertebrates (Shah 2006; Table 1).

The literature review also showed that Carnaby's Black-Cockatoo have been recorded feeding upon 14 introduced plant species (from 12 families), including crop or forestry species such as *Pinus radiata* (Radiata Pine), *P. pinaster* (Maritime Pine) and *Brassica napus* (Canola). Seeds were the target food item of the majority of introduced plant species, with the exception of the garden variety of *Hibiscus*, where flowers were consumed (Table 1; Shah 2006). On the Swan Coastal Plain, Carnaby's Black-Cockatoo are more frequently observed foraging on native plant species, but far greater number of cockatoos are observed feeding in pine plantations (Shah 2006). The pine plantations represent an important food resource for Carnaby's Black-Cockatoo (Saunders 1974b; Saunders 1980; Cale 2003), and the relationship between Carnaby's Black-Cockatoo and the pine plantations is examined in more detail in the following section.

Table 1. Plant species that Carnaby's Black-Cockatoo have been recorded foraging upon. Species nomenclatures are current according to FloraBase November 2008 (see http://florabase.calm.wa.gov.au). References sourced include: [1]Cooper *et al.* 2002; [2]Higgins 1999; [3]Mawson 1995; [4]Perry1948; [5]Robinson 1965; [6]Saunders 1974b; [7]Saunders 1980; [8]Scott and Black 1981; [9]Shah 2006; [10]van Leeuwin and Lamont 1996. Personal observations were made by Dee Stojanovic (D.S.), Jackson Parker (J.P.), Leonie Valentine (L.V.) and Paddy Berry (P.B.).

Species	Common Name	Part consumed	Reference
	Native Australian Plants		
Family: Casuarinaceae			
Allocasuarina fraseriana	Sheoak	seeds	1, 2, 7
*Casuarina cunninghamiana**	River Sheoak	seeds	J. P. *pers obs*
Family: Mimosaceae			
Acacia saligna	Orange Wattle	bark, invertebrate	9
Family: Moraceae			
*Ficus spp.**	Fig tree	fruit	9
Family: Myrtaceae			
Agonis flexuosa	Peppermint Tree	bark, invertebrate	9
*Callistemon viminalis**	Bottlebrush	nectar	2, 3, 7, 9
Corymbia calophylla	Marri	seed, flower, nectar	2, 5, 6, 7, 9
Corymbia ficifolia	Red Flowering Gum	flower	9
Eucalyptus citriodora	Lemon-scented gum	seed, flower	9
Eucalyptus gomphocephala	Tuart	flower	9
Eucalyptus marginata	Jarrah	seed	2, 6, 7, 9
Eucalyptus salmonophloia	Salmon gum	seed	9
Eucalyptus todtiana	Coastal Blackbutt	seed	2, 7
Eucalyptus wandoo	Wandoo	flower	2, 7
Family: Proteaceae			
Banksia ashbyi	Ashby's Banksia	seed	2, 7
Banksia attenuata	Slender Banksia	seed, flower, invertebrate	2, 4, 6, 7, 8, 9
Banksia fraseri	---	seed, flower	2, 7
Banksia grandis	Bull Banksia	seed, flower	2, 6, 7
Banksia ilicifolia	Holly Banksia	seed	9
Banksia littoralis	Swamp Banksia	seed, flower	2, 7
Banksia menziesii	Firewood Banksia	seed, flower	2, 7, 9
Banksia nivea	Couch Honeypot	seed, flower	2, 6, 7
Banksia nobilis	Golden Dryandra	seed	2, 7
Banksia prionotes	Acorn Banksia	seed	9
Banksia prolata	Tree Banksia	seed	9
Banksia sessilis	Parrot bush	seed, flower	2, 6, 7, 9
Banksia splendida	Shaggy Dryandra	seed, flower	2, 7
Banksia tricuspis	Pine Banksia	seed, flower, invertebrate	10
Banksia undata	Urchin Dryandra	seed, flower	2, 7
Banksia verticillata	Albany Banksia	seed, flower	2, 7
Grevillea armigera	Prickly Toothbrush	seed, flower	2, 7
Grevillea hookeriana	Red Tooth Brushes	seed, flower	2, 7

Grevillea paniculata	Kerosene Bush	seed	2, 7
Grevillea paradoxa	Bottlebrush Grevillea	seed	2, 7
Grevillea petrophiloides	Pink Poker	seed	2, 7
Hakea auriculata	---	seed	2, 7
Hakea circumalata	---	seed	2, 7
Hakea conchifolia	Shell-leaved Hakea	seed	2, 7
Hakea cyclocarpa	Ramshorn	seed	2, 7
Hakea falcata	---	seed	2, 7
Hakea gilbertii	---	seed	2, 7
Hakea incrassata	Golfball Hakea	seed	2, 7
Hakea laurina	Pin-cushion Hakea	seed, flower	9
Hakea lissocarpha	Honeybush	seed	2, 7
Hakea multilineata	Grass leaf Hakea	seed	2,7
Hakea obliqua	Needles and Cork	seed	2, 7
Hakea pandanicarpa	---	seed	2, 7
Hakea prostrata	Harsh Hakea	seed	2, 7
Hakea ruscifolia	Candle Hakea	seed	2, 7
Hakea scoparia	---	seed	2, 7
Hakea sulcata	Furrowed Hakea	seed	2, 7
Hakea trifurcata	Two-leaved Hakea	seed	2, 7
Hakea undulata	Wavy-leaved Hakea	seed	2, 6, 7
Hakea varia	Variable-leaved Hakea	seed	2, 7
Isopogon scabriusculus	---	seed	2, 7
Lambertia multiflora	Many Flowered Honeysuckle	seed, flower	2, 3, 7
*Macadamia integrifolia**	Macadamia	seed	9
Persoonia longifolia	Snottygobble	seed	1
Family:Xanthorrhoeacea			
Xanthorrhoea preissii	Grass tree	seed	9
Introduced Plant or Crop Species			
Family: Altingiaceae			
Liquidamber styraciflua	Liquid Amber	seed	L.V. *pers. obs.*; P.B. *pers. obs.*
Family: Araliaceae			
Schefflera actinophylla	Umbrella Tree	fruit	2, 7
Family: Asteraceae			
Helianthus annuus	Sunflower plants	seed	9
Family: Bignoniaceae			
Jacaranda mimosifolia	Jacaranda	seed	9
Family: Brassicaceae			

Brassica napus	Canola	seed	D.S. *pers. obs*
Raphanus raphanistrum	Wild radish	seed	D.S. *pers. obs.*
Family: Geraniaceae			
Erodium spp.	Wild geranium	seed	D.S. *pers. obs*
Family: Iridaceae			
Romulea rosea	Guildford or Onion Grass	seed	1
Family: *Malvaceae*			
Hibiscus spp.	Hibiscus garden variety	flower	9
Family: Meliaceae			
Melia azedarach	White Cedar	seed	D.S. *pers. obs*
Family: Pinaceae			
Pinus pinaster	Pinaster Pine	seed	2, 4, 7, 9
Pinus radiata	Radiata Pine	seed	2, 4, 7
Family: Polygonaceae			
Emex australis	Doublegee	seed	1, 7
Family: Rosaceae			
Prunus amygdalus	Almond tree	seed	8

* Species is an Australian native, but not indigenous to south-west WA.

Carnaby's Black-Cockatoos and Pine Plantations

The Swan Coastal Plain represents an important foraging area for Carnaby's Black-Cockatoo (Shah 2006). However, an expanding urban population and agricultural development has resulted in the loss and/or degradation of large areas of native vegetation. There has been a major shift in dietary composition from a traditional diet of mostly native seeds and nectar (from *Banksia, Dryandra, Eucalyptus, Hakea* and *Allocasuarina*) to seeds of pine from forestry plantations (*Pinus pinaster* and *P. radiata*) (Higgins 1999; Saunders 1980). Pine plantations in the Gnangara area (Gnangara, Pinjar and Yanchep plantations) have been recognised as an important food resource for Carnaby's Black-Cockatoo for over 70 years (Perry 1948; Saunders 1974b). The expected clear felling of the pine plantations over the next 18 years is expected to affect Carnaby's Black-Cockatoo food resources (Cale 2003; Garnett and Crowley 2000).

Pine Plantations as a Source of Food

The pine plantations in the Perth region were first planted in the mid-1920's, however, as pine trees can take 7 years to produce the first cones, it is presumed that Carnaby's Black-Cockatoo did not utilise the food source until the early 1930's (Perry 1948; Saunders 1974b). By the late 1940's, Carnaby's Black-Cockatoos were well-known visitors to the forestry plantations in the Perth region, with some flocks containing estimates of 5 – 6000 individuals (Perry 1948). When foraging in pine plantations, Carnaby's Black-Cockatoos tear the pine cone from the tree, dropping approximately 1/5 to 1/10 of cones (Perry 1948; Saunders 1974b). Holding the cone with one foot, the bird tears the outer bracts off, extracts the seeds beneath, removes the hard seed coating and inner tissue, and finally swallows the white kernel (Perry 1948). Once seeds have been consumed, the bird will discard the pine cone (Figure 3). Typically, a flock of birds will move through the plantation as they forage, starting at the edge of the forest and moving inwards, until all the cones have been stripped from the trees, often returning to feed upon seeds left in the dropped pine cones at a later stage (Perry 1948; Saunders 1974b).

Figure 3: Feeding traces of pine cones discarded from Carnaby's Black-Cockatoos at Gnangara Pine Plantation. Photocredit: L. Valentine.

In the mid to late 1960's a study was conducted by the Division of Wildlife Research, CSIRO to examine the extent of damage to pine plantations in a number of plantations around Perth including the Gnangara plantation (Saunders 1974b). This work showed that Carnaby's Black-Cockatoo were most active in the pine plantations in a seasonal manner, typically moving into the Perth metropolitan pine plantations in January, and departing them in April, May or June (depending on the plantation; Saunders 1974b). In the Somerville plantation, the average monthly total of eaten pine cones varied from 2,500 in March to less than 250 in June. While in the Gnangara Plantation, the monthly average of eaten pine cones was greatest in June (> 1000 eaten cones) and lowest in November (< 250). The mid-year increase in activity in the Gnangara Plantation was attributed to additional flocks moving to Gnangara after stripping the plantation closer to the city (e.g. Somerville; Saunders 1974b). In addition, this study also recorded a higher number of eaten pine cones in areas with trees of 16 – 20 years, possibly because there are more of them than the older trees which have undergone thinning and trimming, producing less cones (Saunders 1974b).

A number of cockatoos were also collected by shooting from the Somerville, Gnangara and Mundaring plantations, and their crop content examined (Saunders 1974b). From the two coastal plantations, Somerville and Gnangara, crop content analyses indicated that 97 – 98% of birds respectively had pine seed as a component of crop content (Saunders 1974b), although *Banksia attenuata* was also an important component (34% at Somerville and 14% at Gnangara). While 86% of birds from the Mundaring plantation in the Perth hills

contained pine seed in their crops, seeds from a number of native species were also observed in crops (Saunders 1974b).

Pine Plantations as Roost Sites

In addition to providing an important food source, the pine plantations may also provide important habitat, particularly in the form of night-time roost sites. Early research indicated large numbers of Carnaby's Black-Cockatoo (> 5000 individuals) frequently utilising pine plantations (Perry 1948), while Saunders (1980) reported large flocks (~ 1000 individuals) using watering points in or around pine plantations. More recently, Shah (2006) emphasised the importance of pine plantations in the daily ecology of Carnaby's Black-Cockatoo. On the Swan Coastal Plain, Carnaby's Black-Cockatoos were most abundant in areas with a high proportion of pine plantations (or areas with native bush), and in the GSS area used the pine plantations for roosting and feeding in the early morning and late afternoon (Shah 2006). In addition, up to 825 birds were observed on one evening at a roost in the Gnangara Pine plantation (Shah 2006). On the Swan Coastal Plain, 8 of the 16 roost sites identified by Shah (2006) consisted of pine trees, with an extra two consisting of a combination of eucalypts and pine.

The Carnaby's Black-Cockatoo show a strong dependence on the pine plantation as a food and roost habitat (Saunders 1980, Shah 2006; Cale 2003). There is evidence to suggest that the usual migratory pattern of Carnaby's Black-Cockatoo is changing, whereby not all birds are returning to the wheatbelt to roost (R. Johnstone *pers. comm.*). Indeed, a roost count at the southern end of Pinjar Pines in the breeding season (early September 2008) recorded over 620 birds (Valentine and Stock, unpublished data).

It is possible that the decrease in available habitat in the wheatbelt is driving a south and west ward shift in the distribution of Carnaby's Black-Cockatoo (Johnstone and Storr 1998). Given that the pine plantations will be cleared over the next 18 years, there may be considerable impacts on the population of Carnaby's Black-Cockatoo (Cale 2003; Garnett and Crowley 2000).

Potential Impacts of Removing Pine Plantations on Carnaby's Black-Cockatoo

The Gnangara Ground Water System is directly recharged by rainfall and supplies approximately 60% of water to Perth (Government of Western Australia 2008). Rainfall levels over the last 30 years have been declining, which has reduced recharge to the aquifer and caused declining groundwater levels (Yesertener 2007). In addition, an increasing population has increased water abstraction levels. The pine plantations in the Gnangara area restrict water recharge into the underground aquifer (Government of Western Australia 2008). Water sustainability is of great concern in the greater Perth region, particularly given the predicted climate change scenarios of continual rainfall decreases. As part of the current groundwater strategy the Gnangara, Pinjar and Yanchep pine plantation will be removed over the next 18 years, most likely without replacement (Government of Western Australia 2008). However, the removal of the pine plantations may lead to a shortage of food for Carnaby's Black-Cockatoo (Cale 2003; Garnett and Crowley 2000).

Energetics of Food Sources – Background

To examine the impacts of pine plantation removal, it is necessary to firstly determine the amount of food that pine plantations provide, as well as the availability of native food resources in the GSS study area. Previous research by Cooper *et al.* (2002) examined the metabolic ecology of Carnaby's Black-Cockatoo, as well as the seed energy content of a number of potential food sources. The basal metabolic rate (BMR) for Carnaby's Black-Cockatoo was 0.86 ± 0.18 $mLO_2g^{-1}h^{-1}$, which was then used to provide an index for field metabolic rate (FMR), which predicts average daily energy requirements of breeding birds, and was estimated to be 726 $kJday^{-1}$ (Cooper *et al*. 2002). The energy requirements of birds can be related to the energy contents provided by food sources, giving estimates on the minimum amount of food required to meet FMR (Cooper *et al.* 2002). The energy content of seeds, and the minimum number of seeds or cones required to meet the FMR of Carnaby's Black-Cockatoo was calculated for a number of native and introduced plant species, with *Banksia attenuata* and *Pinus radiata* providing the highest energetic return per cone (Cooper *et al.* 2002; Table 2).

Table 2. The energy content of seeds, total energy content of cones and the minimum number of cones required to meet the field metabolic rate of Carnaby's Black-Cockatoo for two food species (data extracted from Cooper *et al.* 2002).

Species	Seed energy content ($kJ\ g^{-1}$)	Total energy content ($kJ\ nut^{-1}$)	# of cones day^{-1} (to meet FMR)
Banksia attenuata	22.0	63.9	11
Pinus radiata	25.4	39.4	18

B. attenuata is the principal native food source Carnaby's Black-Cockatoos are observed foraging upon on the Swan Coastal Plain (Shah 2006). Carnaby's Black-Cockatoo have been observed foraging on *P. radiata* in plantations in the Perth hills regions (Saunders 1974b); however, the primary plantation species on the Swan Coastal Plain is *P. pinaster* (J. Parker pers. comm.). Assuming that *P. pinaster* provides similar amounts of energy as *P. radiata*, a single Carnaby's Black-Cockatoo would require more pine than banksia cones per day (Table 2).

Limitations of Data

It is possible to combine the data collected in Cooper *et al.* (2002) with other sources and extrapolate to examine the availability of food resources in pine plantations and native woodlands, and the number of birds an area can **potentially** support. To calculate how many birds are supported by pine plantations and banksia woodlands, additional information is required, including the density of trees per ha (pine: Jackson *pers. comm.*; *B. attenuata*: Bamford and Bamford 2004), the annual cone production (pine: Hopkins and Butcher 1993; Richardson and Cowling 1994; *B. attenuata*: Bamford and Bamford 2004) and the proportion of mature trees producing cones (pine: Hopkins and Butcher 1993). However, a number of caveats are applicable to the data collected by these authors and any extrapolations made regarding food availability for Carnaby's Black-Cockatoo.

Assumptions

The limitations of the data and any estimates regarding food availability for Carnaby's Black-Cockatoo are as follows:

1) The FMR represents the **minimum** amount of food required; and hence the **maximum** number of birds an area can support.
2) Assume 100% assimilation of seeds and no metabolic cost of feeding, and does not take into account differences in handling time of species (Cooper *et al.* 2002);
3) Assume 100% of seeds in each cone are consumed by cockatoos;
4) Assume equal nutritional content of both *P. radiata* and *B. attenuata*.
5) Cockatoos can use all available cones; and, does not take into account the amount of cones that are removed from the tree before they are mature (via bird attack or wind etc);
6) Assume *P. pinaster* provides the same energetic value as *P. radiata*;
7) The density of *B. attenuata* woodland is constant, and does not take into account the variability of banksia woodlands on the Swan Coastal Plain, or the availability of food from other sources in banksia woodlands;
8) 100% of mature *B. attenuata* trees produce cones each year; and, does not take into account variation in productivity due to external effects (e.g. fire regime, Scott and Black 1981; and the possible impacts of *Phytophthora cinnamomi*).
9) The foraging ecology of Carnaby's Black-Cockatoo is not taken into account, including the ability of birds to locate food resources, variability in handling time of food items, or behavioural mechanisms that inhabit food uptake (e.g. accidentally dropping cones).

Food Availability Estimates from the Literature

To calculate how many birds are supported by pine plantations and banksia woodlands, additional information is required, including the average annual cone production and the average number of cone-producing trees per hectare. The following equation is used when calculating the number of birds that could be supported in a hectare of habitat for one day:

Equation 1.

$$X = \frac{\text{energy per cone (kJ cone}^{-1}\text{) * (\# of cones per tree * (\# of trees per ha * proportion producing cones))}}{\text{Field Metabolic Rate (FMR) of Carnaby's Black Cockatoo (kJ day}^{-1}\text{)}}$$

Surprisingly, there is limited information available for either *B. attenuata* or *Pinus* species. Preliminary work on the density and average annual cone production of *B. attenuata* near Jandakot was examined by Bamford and Bamford (2004). At this stage we have no information on the proportion of trees that produce cones annually, nor have we accounted for the possible variation in cone productivity based on fire regimes or other landscape variables (Scott and Black 1981).

Annual cone production of *P. pinaster* was examined by Hopkins and Butcher (1993) in the Gnangara region, with estimates ranging from 4 – 60 cones per year (average of 20.3 per year) for the Leira strain grown in the area. However, Richardson and Cowling (1994) in South Africa recorded far less cone productivity (average of 6 cones per year). The density of pine plantations varies depending on the stage of plantation production. Typically, in the south-west of WA, pines are initially planted at 1000 stems per ha, and then progressively thinned three times (where half the stems are removed at each thinning phase) prior to clear-fall removal (J. Parker *pers. comm.* 2008).

Bearing in mind the limitations of the data extrapolation (mentioned above), using information sourced from literature, 1 ha of *B. attenuata* woodland could support approximately 196 Carnaby's Black-Cockatoo for one day (Table 3), or just over one bird for a 6 month period. The amount of food available in pine plantations varies depending on the thinning stage, with 1 ha of *P. pinaster* potentially supporting between 62 – 496 birds for one day (Table 3), or just over 2.5 – less than 0.5 birds for 6 months. Based on these estimates, 1 ha of more densely planted pine could support more Carnaby's Black-Cockatoos than 1 ha of *B. attenuata* woodland. Following the second thinning, plantations provide less food resource than *B. attenuata* woodlands, although they are still capable of supporting large number of birds.

Table 3. Estimates of average annual cone production, the proportion of cone-producing tress and density of *Banksia attenuata* and *Pinus pinaster*, including the number of Carnaby's Black-Cockatoo supported in a one hectare area.

Species	Average cones / tree	Proportion producing cones (%)	Average Trees/ha	# of CBC / ha / day[a]	# of CBC / ha / 6 months[a]
Banksia attenuata	6.7[b]	100	332[b]	195.8	1.1
Pinus pinaster	20.3[c]	45[c]	1000[d]	495.8	2.8
			500[d]	247.9	1.4
			250[d]	123.9	0.7
			125[d]	62.0	0.3

[a] Number of cockatoos supported is calculated using Equation 1 above, and is calculated using estimates by Cooper *et al.* (2002; see Table 2), and assuming *P. pinaster* cones provide the same amount of energy as *P. radiata*.

[b] Bamford and Bamford (2004)

[c] Hopkins and Butcher (1993)

[d] Density per thinning stage (J. Parker pers. comm.)

Estimating Food Availability in the GSS study area

The Gnangara, Pinjar and Yanchep Pine Plantations

In late 2007 the three pine plantations (Yanchep, Pinjar and Gnangara) covered approximately 18,000 ha (Government of Western Australia 2008). Current forest management practices involve clear-felling ~ 1,000 ha per annum and thinning ~ 2,500 ha per annum (J. Parker *pers comm.* 2008). Current stocking rates of pine in the plantations are ~ 250 plants / ha, with thinning practices reducing densities to 125 plants / ha (J. Parker *pers comm.* 2008). Given this, it is estimated that by late 2008 / early 2009 there will be approximately 14,500 ha of 250 plants / ha and 2,500 ha of 125 plants / ha; which could provide the minimum requirement of food for a **maximum** of approximately **10,684 birds** for a 6 month period, representing an enormous food resource for Carnaby's Black-Cockatoo.

Although this figure represents an absolute maximum number of birds the area can support, and does not account for foraging ecology of the species, it still represents an enormous food source to Carnaby's Black-Cockatoo. The removal of this food source over the next 18 years is very likely to impact on Carnaby's Black-Cockatoo. As Carnaby's

Black-Cockatoo are able to forage on a wide range of species (see Table 1), it is imperative to examine the availability of alternative food sources in the GSS study area. In particular, it is important to determine the availability of native food sources in areas that will be protected from clearing (e.g. DEC estate), and to examine the influence of landscape features and disturbances on food availability.

Native Remnant Vegetation

Although pine plantations in the Gnangara area have been recognised as an important food resource, Carnaby's Black-Cockatoo have also been recorded feeding on a range of native species (24 species) in the GSS study area (Shah 2006). Indeed, Carnaby's Black-Cockatoo are more frequently observed feeding on native species of plants although, larger numbers of birds are typically observed feeding on pines (Shah 2006). Principal native plant species include seven Banksias, five Eucalypts and three Hakeas. Banksia species accounted for nearly 50% of all native feeding records on the Swan Coastal Plain (Shah 2006). The majority of native feeding records are on the slender Banksia, *Banksia attenuata*, and this species is considered a critical food resource (Shah 2006). However, large amounts of native banksia woodlands have been cleared to make way for urban expansion and agriculture, and only 50% of remnant vegetation remains in the GSS study area (Government of Western Australia 2008).

We examined the availability of food resources provided by remnant vegetation from different vegetation complexes and a range of fuel ages to examine the influence of landscape features and disturbances on potential food resources for Carnaby's Black-Cockatoo. Here, we present a summary of data collected and how this information can be combined with food energetic values to estimate food resource availability in a landscape.

Summary of Methods and Results

We examined a number of sites throughout the GSS study area, in different landforms and from a range of fuel ages. Thirty-two of these sites were located in *Banksia* woodlands in either Bassendean North or Cottesloe North Vegetation Complexes (Heddle *et al.* 1980). Year since last burn (YSLB) of each site was determined using DEC Fuel Age spatial mapping (current at June 2008), with sites placed in one of the following four categories: 0

– 5 YSLB, 6 – 10 YSLB, 11 – 15 YSLB and >15 YSLB. At each site the density of *B. attenuata* was recorded, and, for five individual plants, the number of cones containing unopened follicles was counted (Figure 4). Cones with unopened follicles contain seeds and represent the standing crop of food resource in a habitat. In addition, a number of cones (~ 5) were collected from each study site and examined for foraging traces from Carnaby's Black-Cockatoo (Figure 4). Where foraging trace was clearly present, the number of follicles attacked was also recorded.

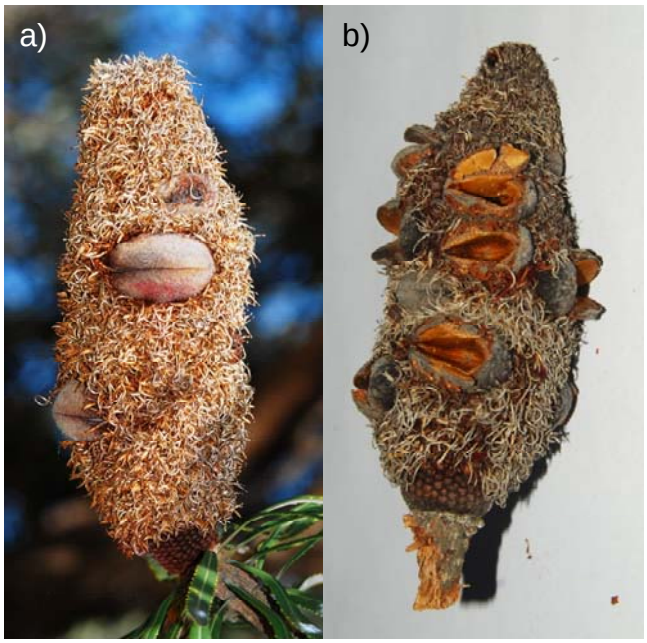

Figure 4. a) Unopened cone of *Banksia attenuata* with closed follicles containing seeds; b) Cone of *B. attenuata* with open follicles and evidence of Carnaby's Black-Cockatoo foraging trace.

Data collected provided the standing crop of food availability per tree, the proportion of trees at a site containing unopened cones and the density of trees per ha for sites from different vegetation complexes and fuel ages (Valentine and Stock, unpublished data). Here, we combine this data with food energetic calculations from Cooper *et al.* (2002; see Table 2) to refine estimates of food resources in *Banksia attenuata* woodland (Table 4).

Food resources clearly vary depending on the type of vegetation complex and year since last burn (Table 4). Bassendean North Vegetation Complex typically provided higher amounts of food resources than Cottesloe North Vegetation Complex (Table 4). The highest amount of food was available on Bassendean North Vegetation Complex with a

fuel age between 11 – 15 years since last burn, while the least amount of food was available at sites in Cottesloe North Vegetation Complex within 5 years of fire (Table 4). Incorporating information on the landform type and year since last burn is clearly important for obtaining more accurate estimates of food availability.

Table 4. Availability of food resources in *Banksia attenuata* woodlands in Bassendean North and Cottesloe North Vegetation Complexes in a range of fire ages in the GSS study area.

Vegetation Complex	Fuel Age (YSLB)	Unopened Cones / Tree[a]	Density (ha)[a]	Proportion containing cones[a]	CBC / ha / 6 months[b]
	0 – 5	8.45	280	0.85	**1.0**
Bassendean	6 – 10	12.4	176	1	**1.1**
North	11 – 15	12	268	0.85	**1.3**
	> 15	5.5	288	0.64	**0.5**
	0 – 5	2.71	200	0.48	**0.1**
Cottesloe	6 – 10	9.58	116	0.9	**0.5**
North	11 – 15	4.04	180	0.84	**0.3**
	> 15	7.35	304	0.9	**0.9**

[a] Valentine and Stock, unpublished data.

[b] Number of cockatoos supported is calculated using Equation 1 above, and is calculated using estimates by Cooper *et al.* (2002; see Table 2), and assuming *P. pinaster* cones provide the same amount of energy as *P. radiata*.

Using DEC spatial layers, the current (as of June 2008) area of each fuel age category within both vegetation complexes that are vested as DEC estate within the GSS study area was calculated (Table 5). The total combined area is approximately 25,000 ha and could provide the minimum requirement of food for a **maximum** of approximately **18,777 birds** for a 6 month period, representing a critical food resource for Carnaby's Black-Cockatoo.

Refining Food Resource Estimates – the Importance of Foraging Ecology & Behaviour

While the estimates above provide a baseline for determining food resources for Carnaby's Black-Cockatoo in the environment, they do not include aspects of foraging ecology or behaviour that may limit the ability of birds to utilise food resources. Incorporating information on foraging ecology or behaviour is essential to provide more accurate

estimates of food resources. For example, in the wheatbelt Carnaby's Black-Cockatoo did not utilise food in habitat patches that were isolated and surrounded by agriculture (Saunders 1977; Saunders 1990). Carnaby's Black-Cockatoo also regularly drop cones that they are handling (Perry 1948; Saunders 1974b), and often do not feed on the entire cone. However, availability of data regarding the foraging ecology or behaviour of Carnaby's Black-Cockatoo is scarce.

Saunders (1974b) estimated that Carnaby's Black-Cockatoo dropped one in ten pine cones prior to feeding, potentially removing this cone from the available food resource. In addition, our observations of foraging trace on *Banksia attenuata* showed that on average, only 29% of a cone was attacked (Valentine and Stock, unpublished data), suggesting that Carnaby's Black-Cockatoo may only be obtaining 29% of the energy available from a cone. Although this information is from a small sample size (n = 71), it provides an indication of how foraging behaviour may limit the availability of food resources, and provides estimates of the 'useable food resources'. We included these two aspects of foraging behaviour to refine initial estimates of food resources (Table 5).

Table 5. Availability of food resources in *Banksia attenuata* woodlands and pine plantations in the GSS study area, incorporating aspects of Carnaby's Black-Cockatoo foraging behaviour.

Species	**Category[a]**	**Cones / tree[b]**	**Energy / Cone[c]**	**CBC / ha / 6 months[d]**	**Area in GSS (ha)**	**CBC / 6 months**
Banksia attenuata	BN 0 – 5	7.6	18.5	**0.26**	11535.6[e]	**2955.8**
	BN 6 – 10	11.2		**0.28**	1881.8[e]	**523.3**
	BN 11 – 15	10.8		**0.35**	1429.6[e]	**497.9**
	BN >15	5.0		**0.13**	1822.6[e]	**235.4**
	CN 0 – 5	2.4		**0.03**	4397.5[e]	**145.8**
	CN 6 – 10	8.6		**0.13**	1726.9[e]	**220.1**
	CN 11 – 15	3.6		**0.08**	1330.8[e]	**103.6**
	CN > 15	6.6		**0.26**	873.6[e]	**223.8**
Pinus pinaster	250	18.3	11.4	**0.18**	14500[f]	**2604.2**
	125	18.3		**0.09**	2500[f]	**224.5**

[a] Category: *Banksia attenuata* – Vegetation (BN, Bassendean North; CN, Cottesloe North) and fuel age (YSLB) combination; *Pinus pinaster* – Thinning stage, represented by density per ha (J. Parker *pers. comm.*).
[b] Cones / tree: Valentine and Stock, unpublished data. Incorporates a drop rate of 1 in 10 (Saunders 1974b), and assumes the same drop rate for *B. attenuata* and *P. pinaster*.

[c] Energy / Cone: Represents 29% of the energy per cone originally described by Cooper *et al*. (2002), based on foraging observations (Valentine and Stock, unpublished data) and assumes 29% of cones are consumed for both *B. attenuata* and *P. pinaster*.

[d] Number of cockatoos supported is calculated using Equation 1 above, and is calculated using estimates by Cooper *et al.* (2002; see Table 2), and assuming *P. pinaster* cones provide the same amount of energy as *P. radiate*, and uses data provided in Table 3 and Table 4.

[e] Area of each category within DEC estate within the GSS study area, obtained using DEC fuel age, tenure and remnant vegetation spatial layers (current as of June 2008) and Heddle *et al*. (2002) vegetation complexes.

[f] Area of each thinning stage remaining in GSS pine plantations in late 2008 (J. Parker *pers. comm.*).

By incorporating foraging behaviour data, the estimates on the number of cockatoos an area could support are drastically reduced. If the behavioural data is accurate, it suggests that the three pine plantations in the GSS study area support approximately **2,829 cockatoos**, and the combined Bassendean North and Cottesloe North remnant vegetation in DEC estate support approximately **4,906 cockatoos**. As there is a minimum non-breeding population of at least 4,500 birds that forage in the Perth region (Shah 2006), the combined food resources of the pine plantations and remnant vegetation in the GSS study area represent a critical food resource for this species.

Identifying elements in the landscape that may influence food productivity (e.g. landform type and fire) is crucial for accurate estimates of food resource availability. In addition, incorporating information available on the foraging ecology and behaviour of Carnaby's Black-Cockatoo will provide realistic estimates of the number of birds that an area can support, and highlights the difference between potential 'food availability' in an area and the 'useable food resources'. Additional aspects that should be incorporated into food resource estimates include:

1) Metabolic cost of handling food between species;
2) Metabolic cost of time spent foraging;
3) More accurate estimates of the proportion of available resources that are consumed;
4) Provision of food from other native food sources;
5) Differences in annual productivity of food resources, and the impacts of disturbances on food productivity (e.g. *Phytophthora cinnamomi*).

Summary

Carnaby's Black-Cockatoo is an endangered species, with less than 50% of the original population remaining (Garnett and Crowley 2000). A major threatening process includes habitat fragmentation and the removal of critical feeding resources (Cale 2003). The GSS study area in an important foraging area during the non-breeding season for Carnaby's Black-Cockatoo. Both native banksia woodlands and pine plantations have been recognised as an important food resource (Perry 1948; Saunders 1974b; Saunders 1980). Expanding urban populations and agricultural development has resulted in the removal of approximately 50% of native vegetation in the GSS study area. Within the remnant vegetation, the energetics, occurrence and densities of principal native food sources (e.g. *Banksia attenuata*) is still largely unknown, but varies depending on soil type, vegetation complex and fire history (Heddle *et al.* 1980; Scott and Black 1981; Valentine and Stock unpublished data). In addition, there are a number of limitations with the existing data, and further research is required to accurately estimate the availability of food resources.

The predicted removal without replacement of the pine plantations is expected to impact on Carnaby's Black-Cockatoo (Cale 2003; Garnett and Crowley 2000). The amount of food resources in the GSS pine plantations currently available to Carnaby's Black-Cockatoo is predicted to be able to support over 10,000 birds for a 6 month period (with *a prior* mentioned caveats). If preliminary foraging behaviour data is incorporated, it is likely that the pine plantation will support approximately 2,800 birds for a 6 month period.

Food resources in remnant *Banksia attenuata* habitat in the GSS study area vary depending on the landform and year since last burn (Valentine and Stock, unpublished data). The combined area of Bassendean North and Cottesloe North vegetation complexes (~ 25,000 ha) within DEC estate in the GSS study area could provide the minimum requirement of food for a maximum of approximately 18,500 birds for a 6 month period. However, incorporating preliminary foraging behaviour data reduces this estimate to approximately 4,900 birds for a 6 month period.

The pine plantations provide an enormous food resource for Carnaby's Black-Cockatoos. Regardless of the availability of native food sources, removing this amount of resource will affect Carnaby's Black-Cockatoo in some manner. Assuming the remnant vegetation

provides sufficient food resources for Carnaby's Black-Cockatoos, the birds may simply switch foraging behaviours and diets to principally native species. However, if native food availability is limited, the removal of pine plantations may have greater impacts. Birds may search elsewhere for food during the non-breeding season, possibly switching diets to commercial agricultural crops (e.g. canola), and the populations on the Swan Coastal Plain may dwindle. In addition, if food is limited during the non-breeding season, birds may starve or enter the breeding season in poor condition, which is likely to affect breeding success, and ultimately population growth. Our review and preliminary research reinforces the importance of food resources on the Swan Coastal Plain (from both banksia woodlands and pine plantations), and highlights the urgent need to more accurate research into the availability of food resources and foraging ecology of Carnaby's Black-Cockatoo.

Photo credit: L. Valentine.

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