Cumulative learnings and conservation implications of a long-term study of the endangered Carnaby's Cockatoo *Calyptorhynchus latirostris*

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ABSTRACT

The endangered Western Australian endemic Carnaby's Cockatoo *Calyptorhynchus latirostris* was studied by Denis Saunders from 1968 to 1996, and by Rick Dawson and Denis Saunders from 2009 to 2016. One breeding population at Coomallo Creek in the northern wheatbelt of Western Australia was studied intensively from 1969 to 1976, and then monitored in early September and November most breeding seasons until 1996. Monitoring resumed in 2009 following the same protocols used from 1977 until 1996, but with at least one extra monitoring visit, usually in January. This long-term research project has: confirmed that what was known as the White-tailed Black Cockatoo *C. baudinii* is two species, Baudin's Cockatoo *C. baudinii* in the forested southwest, and Carnaby's Cockatoo in the wheatbelt, and overlapping the range of Baudin's Cockatoo; demonstrated photographic techniques for identifying banded individuals; proved identification of individuals based on contact calls, and suggested using individual vocal recognition as a method of non-invasive monitoring of endangered bird species; demonstrated the loss of large hollow-bearing trees was greater than replacements were being established; revealed the high rate of loss of hollows in trees still alive; shown that lack of nesting hollows may be limiting breeding; demonstrated the efficacy of artificial hollows; established methods for establishing the timing of egg-laying based on measurements of eggs, and aging of nestlings; developed a method for assessing nestling condition based on body mass; and shown that total rainfall in the first half of autumn is a significant factor in timing of egg-laying. The conservation implications of this half-century of research on Carnaby's Cockatoo are discussed.

Key words: Carnaby's Cockatoo, *Calyptorhynchus latirostris*, long-term ecological studies, hollow nesting, artificial hollows, timing of breeding, nestling condition.

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INTRODUCTION

In January 1968 Denis Saunders (DAS) joined CSIRO Wildlife Research in Western Australia (WA) to study the ecology and behaviour of what was then known as the White-tailed Black Cockatoo *Calyptorhynchus baudinii*, a species endemic to the southwest of WA. At that time the White-tailed Black Cockatoo was recognised as having two forms; the Long-billed White-tailed Black Cockatoo in the forested southwest, and the Short-billed White-tailed Black Cockatoo in the drier region outside the forested region (Forshaw 1969). Little was known about their ecology and behaviour.

The objective of CSIRO's research was to develop methods to minimise the damage the bird caused to commercial apple and pear orchards, and to pine plantations. The bird extracted seed from apples and pears, discarding the rest of the fruit. In some shires with commercial orchards it was a declared pest with a bounty on its bill (Serventy and Whittell 1976). The bird also consumed pine seed, and damaged WA Forests Department pine plantations throughout its range by breaking stems, resulting in bent trees that were unsuitable for sawn timber. The fact that it fed on pine seed was regarded as a benefit to the Forests Department as the bird frequently dropped partially eaten cones from which staff could extract seed to be used for propagating trees for replanting. This saved them the trouble of having to climb trees to harvest cones; a considerable economy for the Department (Perry 1948).

From 1968 until 1977, DAS conducted a detailed ecological and behavioural study on the White-tailed Black Cockatoo during which the species was separated into two taxa (Saunders 1979a), the Long-billed White-

tailed Black Cockatoo, now known as Baudin's Cockatoo *C. baudinii* and the Short-billed White-tailed Black Cockatoo, or Carnaby's Cockatoo *C. latirostris*.

At the beginning of the study it was necessary to decide which of the two forms of White-tailed Black Cockatoo was to be the focus of the research. With the limited resources available, a detailed ecological study could be conducted on only one form, and the decision was made to focus on Carnaby's Cockatoo. There were several reasons for making this choice. The first was that there were several known breeding sites for Carnaby's Cockatoo, but only one site known for Baudin's Cockatoo. The second was that most of the range of Carnaby's Cockatoo was in the area known as the wheatbelt (Figure 1). During the first seven decades of the 20th Century this area was extensively and rapidly cleared of native vegetation to grow cereal crops, particularly wheat, oats and barley, and graze sheep on introduced pastures. In many districts throughout the wheatbelt up to 90% of the original vegetation was removed with the remainder distributed in thousands of small patches. This loss of habitat had major impacts on many species of birds, including Carnaby's Cockatoo (Saunders and Ingram 1995). While the forests of the southwest were being extensively harvested, the impact of harvesting on black cockatoos was not known. Ease of study was the third reason. In the late 1960s it was known that Baudin's Cockatoo nested in the forested southwest with one confirmed nesting hollow over 60m above the ground, whereas Carnaby's Cockatoo nested in the drier regions outside the forested southwest where nesting hollows were much lower, in some cases as low as 3m. The latter hollows could be accessed with aluminium ladders whereas the former required rope ladders, a much more time consuming and dangerous method.

From 1969 to 1996, breeding populations of Carnaby's Cockatoo were studied at various levels of detail at five different locations throughout its range: Coomallo Creek (monitored 1969-1996, 2009-2106) and Three Springs (1974-1980) in the northern wheatbelt; Manmanning (1969-1976) in the central wheatbelt; and Tarwonga and Moornaming (both 1969-1970) in the southern wheatbelt (Saunders 1986) (Figure 1). In 1997 DAS moved to Canberra, and ceased monitoring Carnaby's Cockatoo.

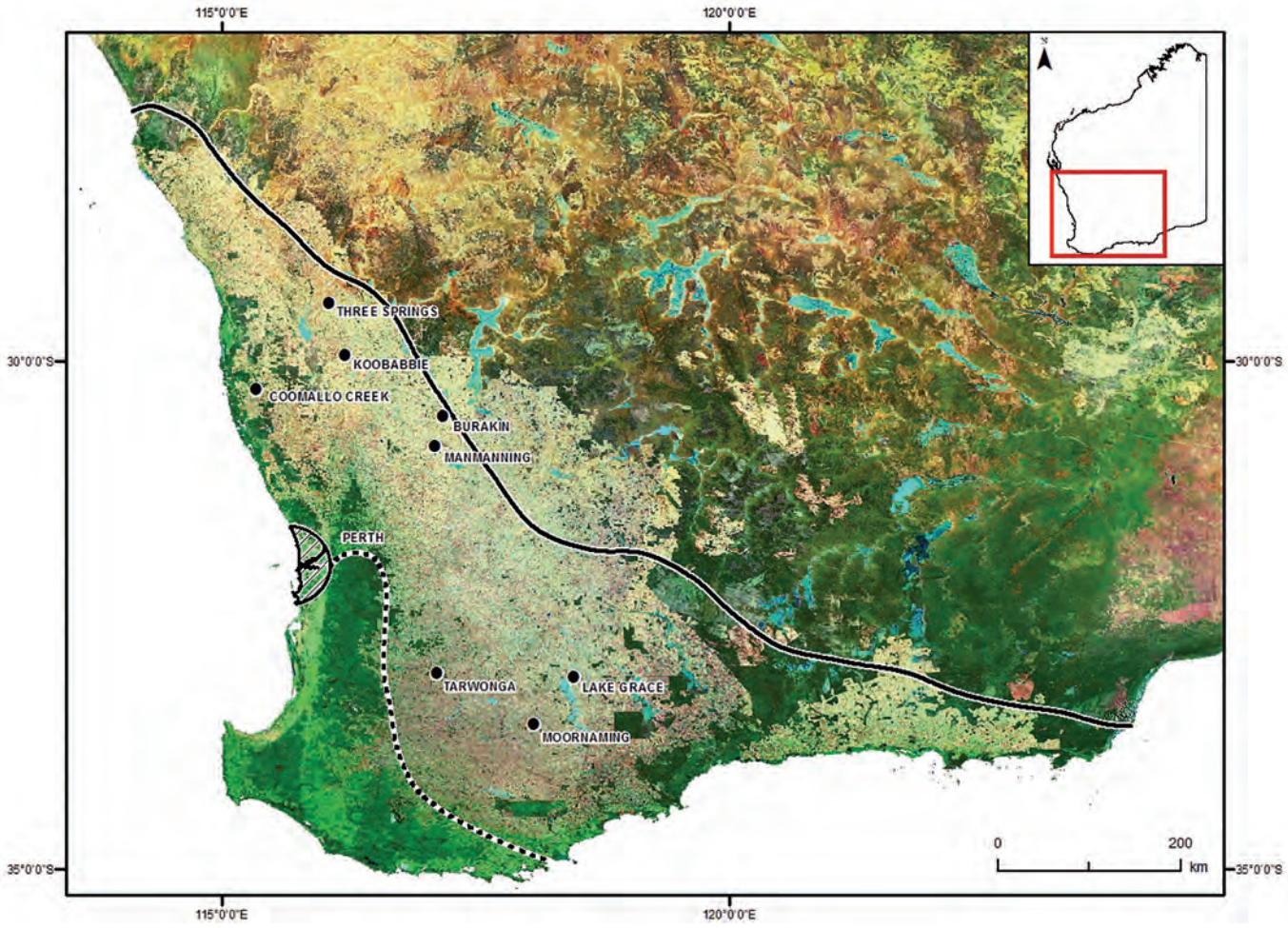

Figure 1. The range of Carnaby's Cockatoo (unbroken line), the range of Baudin's Cockatoo (dotted line) and locations mentioned in the text. Note the extensive clearing of native vegetation (indicted by pale yellow) throughout much of the range of Carnaby's Cockatoo.

In 2008 DAS and RD met at a symposium on the conservation and management of Carnaby's Cockatoo. DAS was then an honorary research fellow with CSIRO in Canberra. RD was a Senior Wildlife Officer with WA Department of Conservation and Land Management with responsibility for protection of WA biota, which included Carnaby's Cockatoo. During that symposium, DAS and RD agreed to visit the Coomallo Creek study area in the cockatoo breeding season of 2009, and use the same monitoring protocols employed by CSIRO from 1981 to 1996. After no monitoring for 13 years, our objective was to establish any change in number of breeding attempts, examine the condition of nestlings, look for any birds banded between 1968 and 1996, and examine the condition of the 206 large hollow-bearing trees found during the research by CSIRO. This collaboration has continued with annual monitoring from 2009 to 2016.

This research on Carnaby's Cockatoo, focussed on the breeding population at Coomallo Creek, with various ancillary studies conducted at other locations, has been conducted for 48 years. While Coomallo Creek was not monitored every year, monitoring was carried out over 28 years during that period. DAS has been engaged in the study over all years of data collection, and RD has been engaged since 2009. Throughout the study much of the research has had direct conservation and management relevance. The remainder of our paper brings together these products of the research, and demonstrates the benefits of such population studies, provided that the research is published so others may draw on it.

METHODS

In 1968 and 1969 a taxonomic study of the White-tailed Black Cockatoo was undertaken. During the course of this study morphometric data were obtained from 44 cockatoos collected between 1959 and 1967 by Dr Stephen Davies (CSIRO) and 352 collected by DAS throughout the bird's range. In total, 103 Baudin's Cockatoo and 293 Carnaby's Cockatoo were examined (Saunders 1974).

Between 1970 and 1976 contact or "wy-lah" calls of marked individuals were recorded opportunistically at Coomallo Creek and Manmanning, and during a study on the movements of Carnaby's Cockatoo (Saunders 1980, 1983). Recognition of the voice of one individual by another was investigated by general observations, playback experiments, and detailed examination of individual variation in the structure of contact calls displayed on sonograms.

In 1979, 140 clutches of eggs of five species of cockatoo, including Carnaby's Cockatoo, were measured at Burakin, site of a study on Long-billed Corella *Cacatua pastinator pastinator* (Smith and Saunders 1986) (Figure 1) and Three Springs to investigate whether stage of incubation could be established from a single set of measurements based on egg length and maximum diameter, and egg mass. Some clutches were not found until late in incubation, and only one set of measurements was obtained; in other cases up to five egg masses were obtained over the incubation period (Saunders and Smith 1981).

In 1978, all trees in a 15ha patch of Salmon Gum *Eucalyptus salmonophloia* woodland near Three Springs were tagged, and examined to establish their size and condition, and determine how many hollows were available for cockatoos to nest in (Saunders *et al.* 1982). The patch was revisited in 1981, and again in 1997 to examine any changes in number of trees and their condition (Saunders *et al.* 2003).

In 1969 and 1970, breeding populations of Carnaby's Cockatoo were studied at Coomallo Creek, Manmanning, Tarwonga and Moornaming (Figure 1) (Saunders 1986). Visits were made to each area throughout the breeding season, during which searches were made for occupied nesting hollows, their contents noted, and the length of the folded left wing and body mass of nestlings taken. When nestlings were over 21 days old, they were banded with a numbered stainless steel leg band issued by the Australian Bird and Bat Banding Scheme. To study movements of birds from breeding areas, adults were opportunistically trapped on active nest hollows in all four areas and fitted with leg bands.

At the conclusion of the 1970 cockatoo breeding season it was apparent that trying to conduct detailed ecological and behavioural studies in four widely separated areas was not feasible. Accordingly, from 1971 research was concentrated at Coomallo Creek and Manmanning. No further research was conducted at the two southern areas. Coomallo Creek and Manmanning are described in Saunders (1982), and the two southern areas in Saunders (1986). Clearing of native vegetation at Coomallo Creek in the northern wheatbelt only commenced in the early 1960s, and there were still extensive areas of native vegetation in which the cockatoos fed and bred during the period 1969 to 1977. By contrast, the area around Manmanning in the central wheatbelt had less than 10% of native vegetation left at the beginning of the study, and the breeding population was extirpated by 1978 as a result of habitat loss (Saunders 1982). Visits were made to both areas at weekly intervals from the beginning of the breeding season until the last nestlings had fledged. All nestlings were measured each time the hollow was inspected. Adults were trapped and banded as time permitted. Any free-flying banded birds were examined by telescope in order to read their band numbers. Between 1971 and 1976, 172 adult females, 58 adult males and 300 nestlings were also marked with patagial tags with a unique two letter combination.

In addition, between 1974 and 1980, a small breeding population of Carnaby's Cockatoo was monitored at Nereeno Hill, near Three Springs, during research on the ecology of the Red-tailed Black Cockatoo *C. magnificus samueli*.

From 1981 to 1996, the breeding population at Coomallo Creek was monitored each year, involving visits for several days in early September and early November with the exceptions of 1987, 1991, 1992, 1993 and 1995 (Saunders and Ingram 1998). During each visit every known hollow was examined (Figure 2), its contents noted, nestlings measured and banded, adult females trapped and banded opportunistically, and searches made for any hollows not recorded and for banded free-flying birds.

From 2009 until 2016, Coomallo Creek was monitored in early September and November using the same protocols used from 1981 to 1996. In some years an extra visit was made in October to band any nestlings from early in the breeding season that may have fledged by November, and another visit was made in January to band remaining nestlings, and establish breeding success of nesting attempts started later in the season.

On 29th December 2009, during an extremely hot afternoon, a wildfire was ignited by a harvesting machine at Coomallo Creek. The fire, in the southern part of the study area, burnt roughly a fifth of the woodland area, destroying 16 trees with hollows used by Carnaby's Cockatoo, including three with nestlings (Saunders *et al.* 2014a). It also burnt breeding and foraging habitat to the south of the study area. While the fire had a major impact on the affected farming community, and on several conservation areas, it provided a well-timed natural experiment in habitat loss, and its impact on Carnaby's Cockatoo.

The following year, due to an influx of birds displaced by the fire, there was an increase in the number of breeding attempts in the area compared with the previous season. While there were some vacant hollows available, this influx of breeding birds led us to test the hypothesis that hollows were limiting the number of birds breeding in the area, by providing artificial hollows and repairing derelict natural hollows (Figure 3).

Under ideal experimental conditions, artificial hollows would have been installed well before the breeding season began. However, RD was not part of his Department's research division, and could conduct work at Coomallo Creek only when his operational role permitted, or in his own time. Accordingly, in September 2011, several months after egg-laying commenced at Coomallo Creek, 30 artificial hollows were installed throughout the study area, with an initial concentration in the south to replace natural hollows lost in the fire. In August 2013 another 20 artificial hollows were installed. In June 2014, before the commencement of egg-laying, a further 10 artificial hollows were installed, and 19 of the smaller hollows installed in 2011 were replaced with larger artificial hollows. By the commencement of egg-laying at Coomallo Creek in 2014 there were 60 artificial hollows available to the birds. In early September 2015 another two artificial hollows were installed, and a further three in March 2016, bringing the total to 65 artificial hollows and 93 natural hollows available to the birds for the 2016 breeding season.

Figure 2. Denis Saunders at the base of the ladder on the roof of a Landrover, and John Ingram at the top of the ladder (early 1970s) (left). Rick Dawson at the top of the ladder measuring the height of the hollow entrance from the ground (2009). Note the safely harness, now obligatory for all field work involving ladders (right).

RESULTS

Taxonomy

In 1948 Ivan Carnaby, a farmer at Lake Grace in WA's Great Southern Region, published a paper in which he stated that the White-tailed Black Cockatoo that occurred in his district was different from the White-tailed Black Cockatoo found on the coast. He named the coastal bird *Calyptorhynchus baudinii baudinii*, and the one in his district *C. b. latirostris* (Carnaby 1948). He believed that *latirostris* differed from the nominate form in having a shorter, more stout upper bill with which it foraged on the hard woody fruits of *Banksia* and *Hakea*. Carnaby's research was not universally accepted, and needed confirmation. In the 1970s, CSIRO's taxonomic study confirmed that there were two different taxa of black cockatoo with white tail bands in southwestern Australia (Saunders 1974, 1979a; Campbell and Saunders 1976; Adams *et al.* 1984)); one (*baudinii*) with an elongated culmen (mean length 53.0mm, n = 151) in the forested southwest within an area bounded by a line between Perth and Albany and the coast; the other (*latirostris*) with a shorter culmen (44.2mm, n = 373) in the area bounded by a line between the mouth of the Murchison River in the north and east of Esperance in the south and the coast (Figures 1, 4, and 5). The range of *latirostris* overlaps that of *baudinii*. The taxonomic research demonstrated that these were two full species, now known as Carnaby's Cockatoo (*C. latirostris*) and Baudin's Cockatoo (*C. baudinii*).

Research by Johnstone *et al.* (2014) established that Carnaby's Cockatoo should by rights of precedence be named *C. baudinii*. However they pointed out that to change nomenclature at this stage would be disruptive, and argued for the *status quo*. IUCN recently introduced the genus *Zanda* for these species (Birdlife International 2013), but in this paper we retain the nomenclature *Calyptorhynchus latirostris* for Carnaby's Cockatoo and *C. baudinii* for Baudin's Cockatoo because this is the nomenclature followed by the WA Government in its legislation and regulations.

Figure 3. Artificial hollow with a female Carnaby's cockatoo at the entrance (left). Note the wire ladder to allow access to the hollow floor and the wooden post to allow the female something to chew into to provide woodchips for the floor. Rick Dawson repairing a derelict natural hollow with a section of tin to cover the exposed side (right).

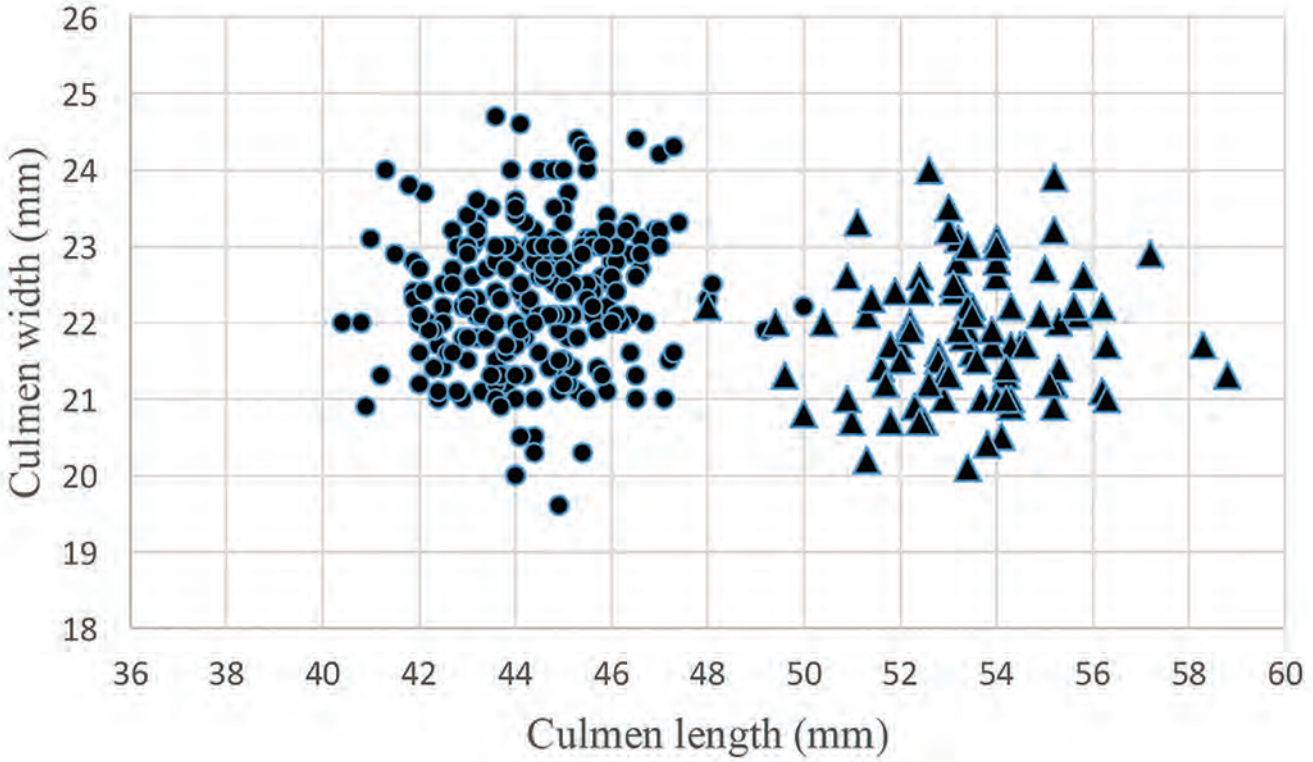

Figure 4. Culmen width (mm) plotted against culmen length (mm) for 240 adult Carnaby's Cockatoo (circles) and 90 Baudin's Cockatoo (triangles), demonstrating the clear separation in bill shape. This is the most obvious morphological difference between the two species.

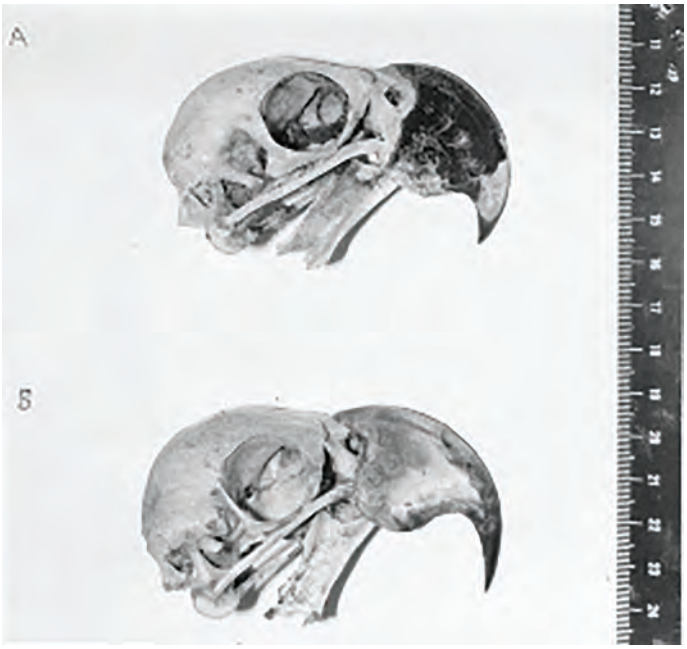

Figure 5. Skull of an adult male Carnaby's Cockatoo (A) and an adult female Baudin's Cockatoo (B) showing the distinctive profiles.

Not surprisingly the vocalisations and diets of the two species differ. C. *baudinii* was responsible for the damage to apple and pear orchards, and C. *latirostris* for damage to pine plantations. There were occasions when both taxa were recorded in mixed flocks, but they were feeding on different plant species (Saunders 1974).

Conservation status of Carnaby's Cockatoo

Over the period 1968 to 1987, CSIRO's research indicated that Carnaby's Cockatoo had declined significantly in abundance and range (Saunders 1990). As a result it was listed: as "Fauna that is rare or likely to become extinct" in Schedule 1 of the Western Australian *Wildlife Conservation Specially Protected Fauna Notice 1996* under the *Wildlife Conservation Act 1950*; as endangered under the Australian Federal Government's *Environment Protection and Biodiversity Conservation Act* 1999; and under IUCN's Red List category and criteria (IUCN 2014). The species was the subject of recovery plans which operated from 2002 to 2012 (Cale 2003), and from 2012 (Department of Environment and Conservation 2012).

Identifying individuals

When undertaking behavioural and ecological studies such as ours it is necessary to be able to recognise individuals. During the course of our research we used several different methods to identify individuals: numbered leg bands; colour bands; and patagial tags (Figure 6). Cockatoos have short tarsi which limit the number of unique colour combinations that can be applied. In addition, the colour attached to bands did not last as long as the birds survived (Saunders *et al.* 2011a). This restricted the identification of individuals because faded colour bands were useless for identification, and the only method left to identify the individual was to read its band number. This involved re-trapping the individual or reading the

Figure 6. Immature female Carnaby's Cockatoo with aluminium patagial tag (FB); it also had a numbered leg band (left). Adult female Carnaby's Cockatoo with a single numbered leg band on the right leg and two colour bands on the left leg, photographed 26 years after the bands were applied (right). Over that time the colour has been stripped from the bands, and the only way to identify the bird is by the numbered band.

band number without trapping. The former was labour intensive and not practicable for population studies, the latter required the assistance of a cooperative bird, a windless day and a steady telescope; these three factors rarely aligned.

Between 1971 and 1976, 172 adult females, 58 adult males and 300 fledglings were marked with patagial tags with a unique two letter combination (Figure 6). These tags proved useful, as individuals could be easily identified using binoculars and telescopes. Unfortunately, they proved detrimental to the birds. Part of the problem was that the predation rate on tagged birds by Wedge-tailed Eagle *Aquila audax* was such that the cockatoos were not surviving long enough to produce sufficient offspring to replace themselves (Saunders 1982). For example, only 101 (59%) of the 172 adult females fitted with patagial tags returned to breed the following year compared with 100% of 12 females fitted with coloured leg bands. This loss of tagged birds was sufficiently concerning for Saunders (1988) to advocate the banning of patagial tags on vulnerable or endangered species.

The recovery and resighting of patagial tags revealed that birds breeding at Coomallo Creek spent the non-breeding season foraging in native vegetation in an area bounded by a line between Coomallo Creek southwest to the coast and north-northwest to the coast (Saunders 1980). Birds from Manmanning spent the non-breeding season on the Swan Coastal Plain feeding on native vegetation in an area bounded by a line between Manmanning southwest to the coast, and in pine plantations to the north of Perth (Saunders 1980). Band recoveries showed that birds from Tarwonga moved northwest towards the coast, but also foraged locally in the non-breeding season. Little is known about movements of birds breeding in the southern wheatbelt, but one band recovery indicated they move to the south coast after breeding (Saunders *et al.* 2011b).

Fortunately, advances in digital cameras have now made reading leg bands relatively easy (Saunders *et al.* 2011a). Since 2009, using cameras we have been able to identify banded females leaving their nest hollows (Figure 6). This allows us to obtain data on demography and breeding success not obtainable during the earlier part of the study (Saunders *et al.* 2016).

In addition, Usher *et al.* (2015) have shown that some individuals have distinctive plumage patterns that are consistent over years. This makes these individuals recognisable without having to trap and band them.

Individuality of voice

Saunders (1983) established that individual Carnaby's Cockatoo recognise each other on the basis of their contact or "wy-lah" call, as do many species of bird with their contact calls (Saunders and Wooller 1988). As Carnaby's Cockatoo mate for the life of their partner (Saunders 1982), individual recognition of voice makes biological sense. For example, a female incubating or brooding young need only leave the nest hollow when she hears her mate return, instead of leaving every time a male flies by calling loudly. Saunders and Wooller (1988) used the idea of individual recognition to demonstrate it was possible to monitor individual Sacred Kingfisher *Halcyon sancta* without trapping them, by building a library of

individual contact calls, and comparing their calls against those in the library to note their presence; a useful technique for monitoring endangered species that should not be trapped. The conservation implications of this are obvious. This method could also be used with Carnaby's Cockatoo to establish whether there are dialects that can be assessed to establish if there are sub-populations of the species throughout its range, and potentially to establish movements to and from breeding areas.

Nesting requirements

The length of Carnaby's Cockatoo research has provided the opportunity to investigate nesting requirements, and assessment of the fate of large hollow-bearing trees. Carnaby's Cockatoo nests in hollows in large eucalypts (Saunders 1979b). Hollows most commonly have a vertical aspect, an entrance of about 270mm, a depth of 1.2m, and a floor diameter of approximately 400mm (Saunders *et al.* 2014a). Saunders (1979b) reported that hollows in Wandoo *E. wandoo* were not as deep or high off the ground as those in Salmon Gum. These differences are related to the different shapes and sizes of the two species of tree, rather than preferences of different breeding populations of the bird.

Saunders *et al.* (1982) examined a 15ha patch of Salmon Gum, York Gum *E. loxophleba* and Red Morrel *E. longicornis* woodland near Three Springs in which several species of cockatoo nested. There were 241 hollows in 173 trees large enough for a cockatoo to nest in. Of these, 17.9% of the trees were rated in good condition in 1978. Condition was based on a scale of 0 = dead to 3 = tree with no signs of dead branches in the crown (Saunders *et al.* 1982). Saunders *et al.* (1982) estimated that it would take at least 130 years for a Salmon Gum to grow to a size to develop a hollow large enough to support a breeding Galah *Cacatua roseicapilla*, the smallest of the cockatoos in the area. Saunders *et al.* (2003) examined the same patch of woodland in 1997 and found that 16.2% were in good condition (Figure 7). Based on the rate of decline in the woodland between 1978 and 1997, by 2125 only 11% of the Salmon Gum in the patch in 1978 would still be alive. Of these only one tree would be rated in good condition. They also reported that there had been no regeneration since 1929 when domestic livestock were introduced to the woodland.

Saunders *et al.* (2014a) examined the fate of 252 hollow-bearing trees used by Carnaby's Cockatoo at Coomallo Creek between 1969 and 2013. One tree had three hollows used by Carnaby's Cockatoo in the same season (Saunders 1982). By 2013, forty per cent of the trees had fallen or been pushed over, burnt deliberately or by wildfire, or had been damaged such that the hollow was no longer suitable for Carnaby's Cockatoo. Over 45 years, this was an average annual loss rate of 0.91%. Based on this rate of loss, only 29% of hollow-bearing trees extant in 2013 were predicted to be standing in 2125. Not all of these would be expected to provide hollows suitable for use by Carnaby's Cockatoo because the hollow may become derelict. There was no indication that replacement hollows were being provided by native vegetation at a sufficient rate to compensate for lost hollow-bearing trees.

Number of breeding attempts annually at Coomallo Creek

In the breeding season of 1996 there were 37 breeding attempts recorded at Coomallo Creek, down from 88 in 1975. In 2009 there were 41 recorded breeding attempts (Saunders *et al.* 2014a), little different from the numbers in the 1990s. Three of the breeding attempts in 2009 were by females banded by CSIRO; one was 19 years old (banded as a nestling), and the other two were at least 19 and 25. Their ages were not known as they were trapped and banded as adults in nest hollows.

In 2010 the number of breeding attempts increased to 49, and in 2011 to 53. This increase was due to an influx of birds displaced by the loss of habitat during the wildfire. After the installation of the first 30 artificial hollows in 2011, there were 75 breeding attempts in 2012; an increase of 41.5%. Interestingly, in the period to 1996 no female less than four years old was recorded breeding (Saunders and Ingram 1998). In 2012, one three-year-old female was seen attempting to breed (Dawson *et al.* 2013). In 2014 and 2015, there were 101 breeding attempts, including several by females in their third year (Saunders *et al.* 2015), and 127 by January 2017; over three times as many as in 2009. Artificial hollows are used successfully by Carnaby's Cockatoo; in 2016 they provided 46.4% of available hollows, yet 59.8% of breeding attempts were made in them (Figure 8).

Aging nestlings, estimation of breeding seasons, and assessment of nestling condition

There are several ways to establish the commencement and length of breeding seasons. The most obvious, and most time-consuming, is to visit the area regularly, check every potential nest site, and establish when eggs are laid. The second is to make fewer visits to the area, use the dimensions and mass of eggs to estimate the stage of incubation, and extrapolate commencement and length of egg-laying (based on estimated earliest and latest laying dates). The third is to use the age of nestlings to extrapolate commencement and length of egg-laying. The latter methods are less time-consuming, and more likely to be employed as monitoring techniques.

Saunders and Smith (1981) examined five species of cockatoo breeding in southwestern Australia, including Carnaby's Cockatoo, and demonstrated that it was

Figure 7. Tree T027 at Three Springs in July 1981 (top left) and in August 1997 (top right). There has been little change in the condition of the tree over 16 years, however there has been extensive thinning of the shrub and tree layers, and marked lack of regeneration of woodland species. Tree 22 at Coomallo Creek in the early 1970s (bottom left) and in September 2009 (bottom right). From 1969 to 2014 the tree had two hollows; both hollows were used by Carnaby's Cockatoo during eight breeding seasons, only one was used by Carnaby's Cockatoo during eleven breeding seasons; both were used by Galah and Carnaby's Cockatoo during two seasons, one by Long-billed Corella during six seasons, and the tree had no cockatoo nests during three seasons. Note the deterioration in the condition of trees in the background in 2009.

Figure 8. 57-day-old nestling in a natural hollow (left) and a 71-day-old nestling in an artificial hollow (right). The wire access ladder and the sacrificial wooden post can be seen on the right of the photograph.

possible to establish the stage of incubation of their eggs based on the length and diameter of the egg, and the mass of the egg. It is possible to estimate the mass at laying by using the formula:

$$M = K_w LB^2$$

Where M is the mass of the egg at laying, K_w is a constant, L is the length and B is the diameter of the egg in centimetres. In the case of the five species of cockatoo examined, the value of K_w was 0.554. Using the calculated fresh egg mass, and the measurements of length, diameter and mass it is possible to establish the age of the egg using the formula:

$$T = [(0.554LB^2) - M_t]/[0.017(0.554LB^2)^{0.650}]$$

Where T the number of days of incubation, and M_t is the known mass of the egg at time T. The expression $(0.554LB^2) - M_t$ represents the change in the mass of the egg from laying to time T, and $0.017(0.554LB^2)^{0.650}$ represents the daily loss in the mass of the egg calculated for an egg of that particular initial mass. Saunders and Smith (1981) used this formula to examine 181 eggs; they found a predicted accuracy of +/- 3 days in 69% of eggs examined.

Saunders and Smith's research on cockatoo eggs was conducted before formal ethics approvals were required for field research on wildlife. While no eggs were broken during the research, and there were no known cases of cockatoos deserting their clutches as a result of the eggs being handled, it is possible now that ethics approval would be not obtained for such an approach to estimate breeding seasons, as this technique involves disturbing females incubating eggs.

However, Saunders (1986) established a method for estimating breeding seasons, and assessing nestling condition without disturbing breeding adults. This involved measuring the length of the folded left wing and body mass of nestlings of known age. These data were used to construct a calibration curve from which it was possible to use the length of the folded left wing to estimate the age of nestlings when their hatching dates were not known. The nestlings' estimated ages were used to establish hatching and laying dates (using an incubation period of 29 days), and required only a single visit to the study area. This aging technique has been recently refined by Saunders *et al.* (2015).

Saunders *et al.* (2015) provided another method for aging nestlings which does not require the bird being handled. They produced a series of photographs, together with descriptions of nestlings illustrating nestlings during each week of the 10+ week nestling period. This method only required the observer to have a clear view of the nestling on the floor of the hollow. This may be done by climbing to the hollow or using a camera on an extension pole. Aging from photographs was used during the breeding season of 2016 when 39 nestlings were aged by observing them in the hollow, and then checked against the age obtained using the length of the folded left wing. Twenty-seven nestlings (69%) were aged to within an estimated +/- 3 days. The method is less accurate when observing nestlings in deep and dark hollows.

Saunders (1986) demonstrated a method for assessing nestling condition based on body mass and estimated age. This method involved measuring the folded left wing and taking the body mass of the nestling, aging it on the length of its folded left wing, and assessing its condition against a graph of body mass for age constructed from measurements of 246 nestlings at Coomallo Creek 1970-1976. Any nestling with a body mass for a particular age of less than 1 standard deviation from the mean mass for that age is most likely in poor condition. Body mass measurements from all nestlings at Manmanning 1969-1976, and for all nestlings at Coomallo Creek in the breeding season of 2016 are shown on Figure 9 in relation to mean body mass for age. Most of the Manmanning nestlings, but few of the Coomallo Creek nestlings were below 1 standard deviation of the mean. Five nestlings (two from Coomallo Creek and three from Manmanning) stand out as being older than 85 days, and in poor condition (Figure 9). The

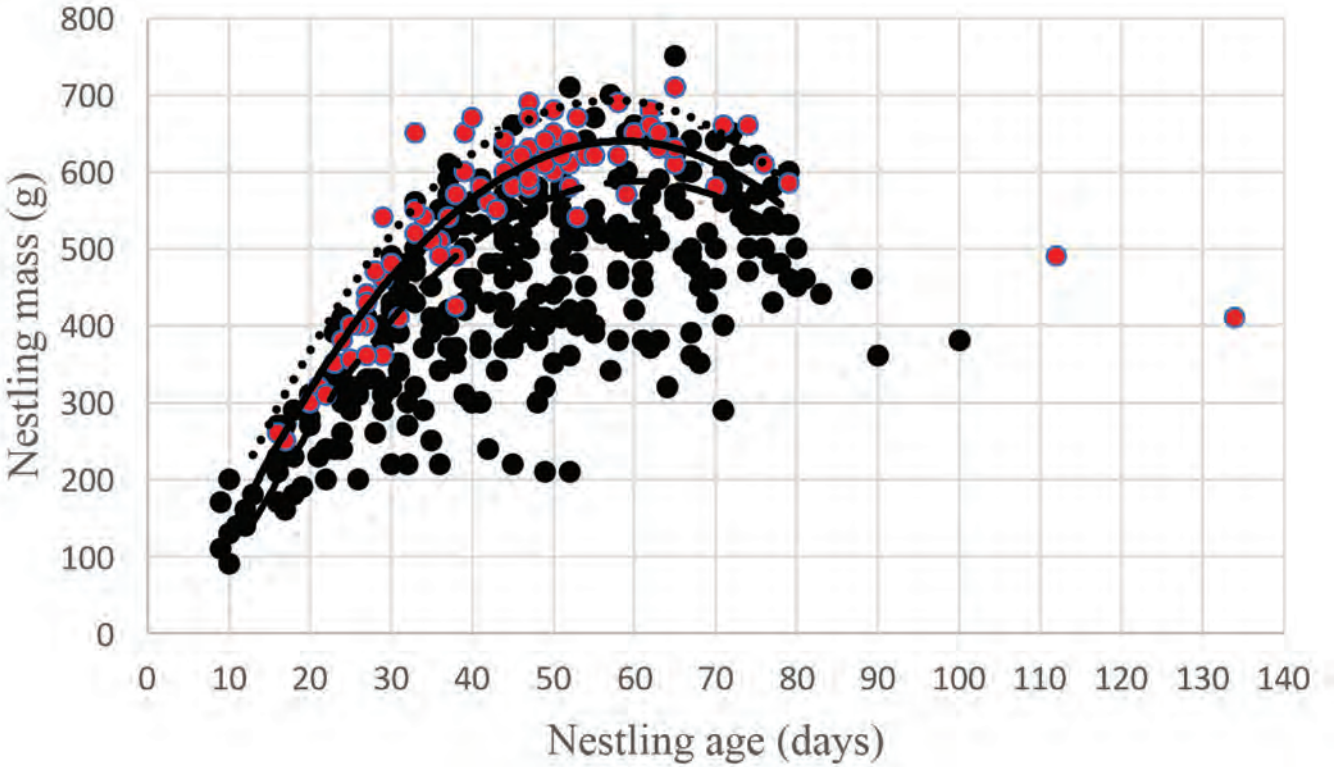

Figure 9. Nestling body mass (g) plotted against nestling age (days) for 302 measurements of nestlings from Manmanning between 1969 and 1976 (black circles) and 90 measurements of nestlings from Coomallo Creek 2016 (red circles). The unbroken line is the mean mass for age for 246 nestlings at Coomallo Creek (1970-1976), and the dotted line and dashed lines represent 1 standard deviation either side of the mean.

normal fledging period for Carnaby's Cockatoo is between 70 and 77 days. Any nestlings remaining in the hollow after 80 days usually have some physical or metabolic defect or are starving, and unlikely to fledge.

Cue for breeding

Carnaby's Cockatoo was known by local Aboriginal people as "the rain bird", and our research confirmed the accuracy of Indigenous knowledge. Between 1969 and 2016, commencement of egg-laying at Coomallo Creek varied from as early as the 2nd week in June (2016) to the 3rd week in August (1976), a difference of 11 weeks. At Manmanning, between 1970 and 1976 there was a four week difference from the 1st (1974) to the last week in August (1970, 1976). The length of these studies enabled modelling to be carried out on the relationship between commencement of egg-laying and rainfall. Saunders *et al.* (2013) found a tight negative relationship between onset of egg-laying and early autumn rainfall for the 24 years of data from Coomallo Creek (1969-2011) and 7 years at Manmanning (1970-1976), with 56% of the variation in commencement date at Coomallo Creek and 59% at Manmanning explained by total rainfall in the first half of autumn. A 100mm increase in rainfall in the first half of autumn was associated with a five-week earlier commencement of egg-laying at Coomallo Creek, and three weeks at Manmanning (Figure 10).

Alison and John Doley collected data on every species of bird occurring each week from mid-1987 to 2016 on *Koobabbie*, their 7,173ha property in the northern wheatbelt of WA (Saunders and Doley 2013). Carnaby's Cockatoo is a regular breeding migrant on *Koobabbie*. The Doleys paid particular attention to the breeding of this species, and throughout this 30-year period made notes on the arrival of the species (Saunders and Doley 2013; Saunders *et al.* 2014b). While they had some breeding records, these were too few to examine commencement of egg-laying in relation to rainfall. Over the 30 years there was a six week difference in arrival dates from the 3rd week in June (1995, 2009, 2010) to the 1st week in August (1987). There was a significant negative relationship between arrival dates and rainfall in the first half of autumn (Figure 11); a 100mm increase in rainfall gave rise to a one week reduction in arrival time.

At Coomallo Creek there was a significant negative correlation between the time eggs were laid and the amount nestling body mass deviated from mean body mass for age (Figure 12). This was demonstrated during the early part of the study (1970-1975), and more recently in 2016. Nestlings produced earlier in the breeding season tend to be heavier than those hatched later in the season.

Female age and breeding failure

The length of the study has permitted examination of breeding failure rates in relation to the age of females. Known failure rates have been used rather than success rates because in some years it has not been possible to establish outcomes for all nesting attempts. Saunders

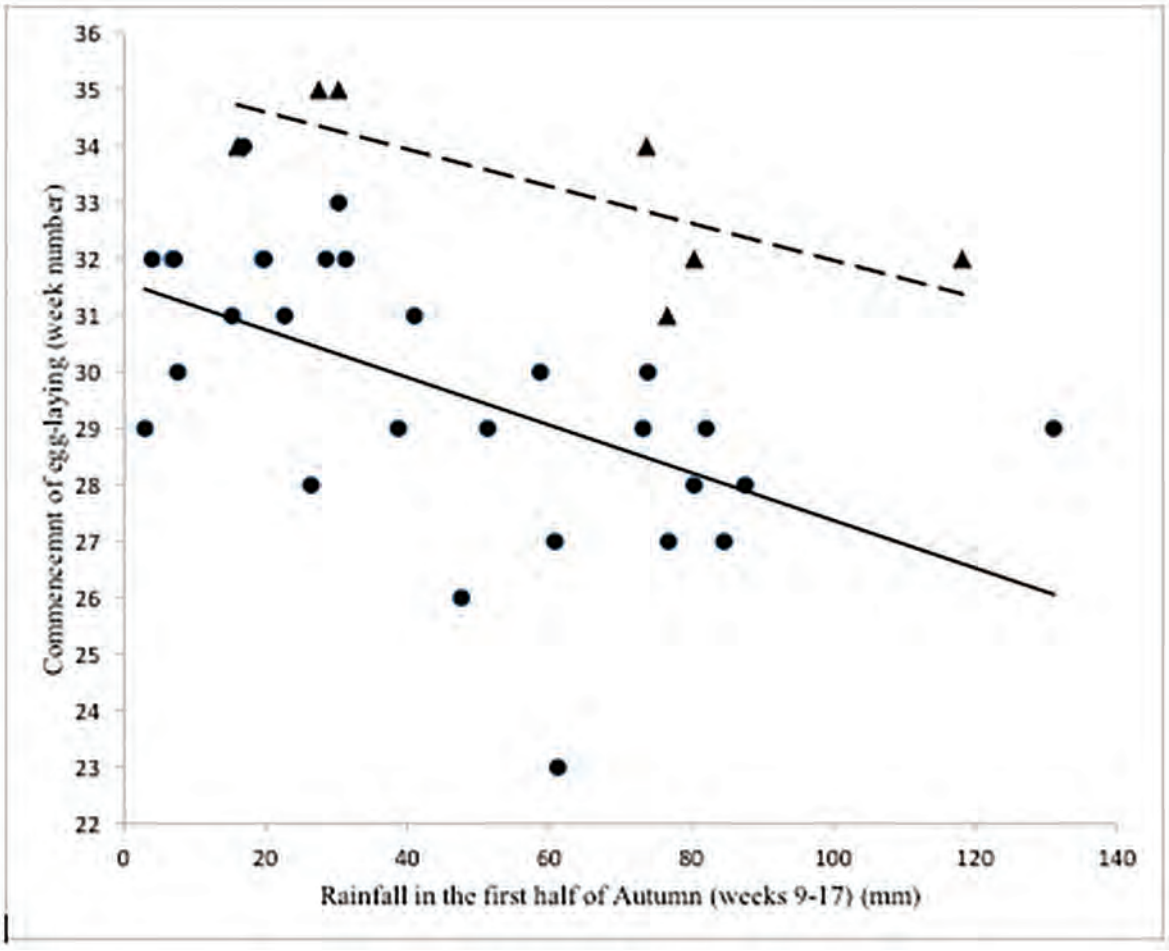

Figure 10. Commencement of egg-laying at Coomallo Creek (1969 – 2016) (circles and line) and Manmanning (1970-1976) (triangles and dashed line) in relation to total rainfall (mm) in the first half of autumn as measured at Badgingarra Research Station.

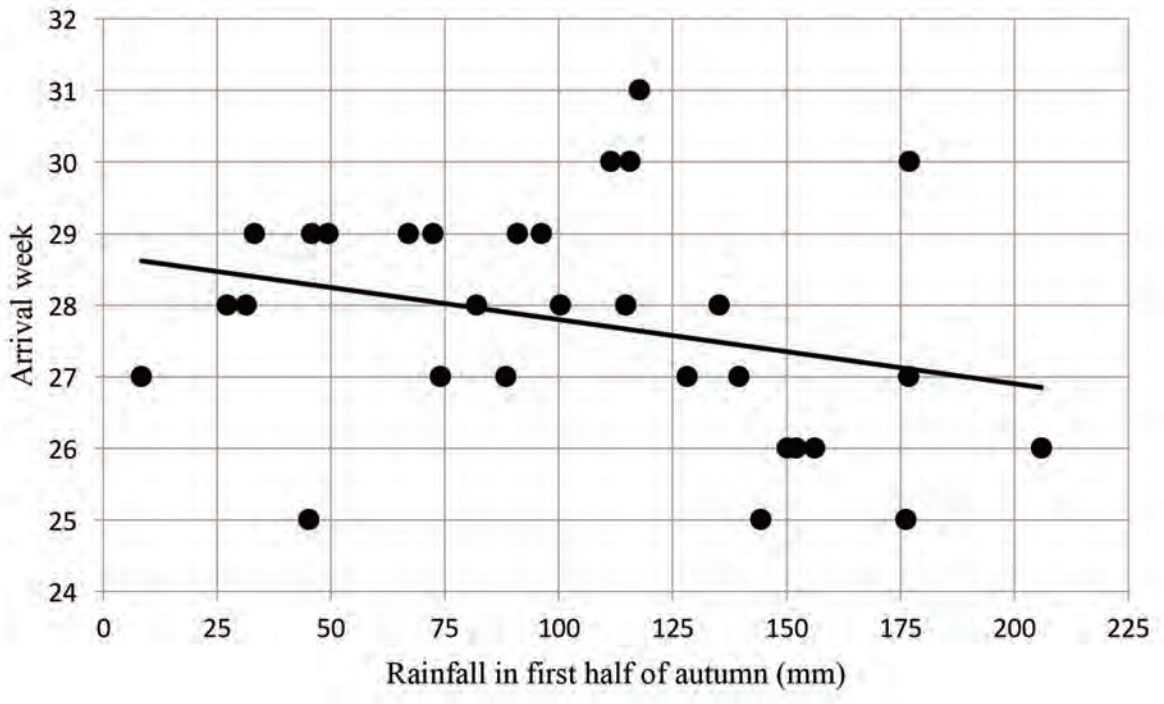

Figure 11. Arrival of Carnaby's Cockatoo at *Koobabbie* (1987 – 2016) in relation to total rainfall (mm) in the first half of autumn as measured at Badgingarra Research Station.

et al. (2016) established that: females in their first two breeding years had failure rates four times that of older, and more experienced females; younger females (4-6 years old) are more likely to nest up to three weeks later than older females (7-27); the oldest females studied were more likely to nest three weeks later than those 10-19; and there was a trend for the oldest females to produce nestlings that were lighter than those of younger females. Despite the length of the study there were few data indicating longevity. One known age female was breeding in her 27th year, and one female of unknown age (banded as an adult) was breeding when she was at least 30 (Saunders *et al.* 2016).

Impacts of urban development on Carnaby's Cockatoo

Breeding populations of Carnaby's Cockatoo from the central wheatbelt move onto the Swan Coastal Plain after breeding, and gather into foraging flocks feeding on pines in large pine plantations and remnant *Banksia* woodland, including plants in suburban gardens (Saunders 1980; Johnston 2013; Stock *et al.* 2013). This foraging population has been declining (Williams *et al.* 2015) as result of clearing pine plantations and remnant *Banksia* woodland for urban development on the Swan Coastal Plain; this clearing will continue (Government of Western Australia 2015). Williams *et al.* (2017) conducted a population viability analysis of Carnaby's Cockatoo frequenting the Swan Coastal Plain. They drew extensively on data generated from the breeding and movement studies referred to above, and on data generated on availability of food resources on the Swan Coastal Plain (Johnston 2013; Stock *et al.* 2013; Valentine *et al.* 2014) to model future population size and extinction risk of Carnaby's Cockatoo under potential land-use scenarios in the rapidly expanding urban region. Population viability analysis was combined with estimates of food resources and a daily ration model to predict the likely future population size that could be supported in the region, and the extinction risk. They found that the most important factor currently limiting population growth for Carnaby's Cockatoo is adult survival rate, whereas

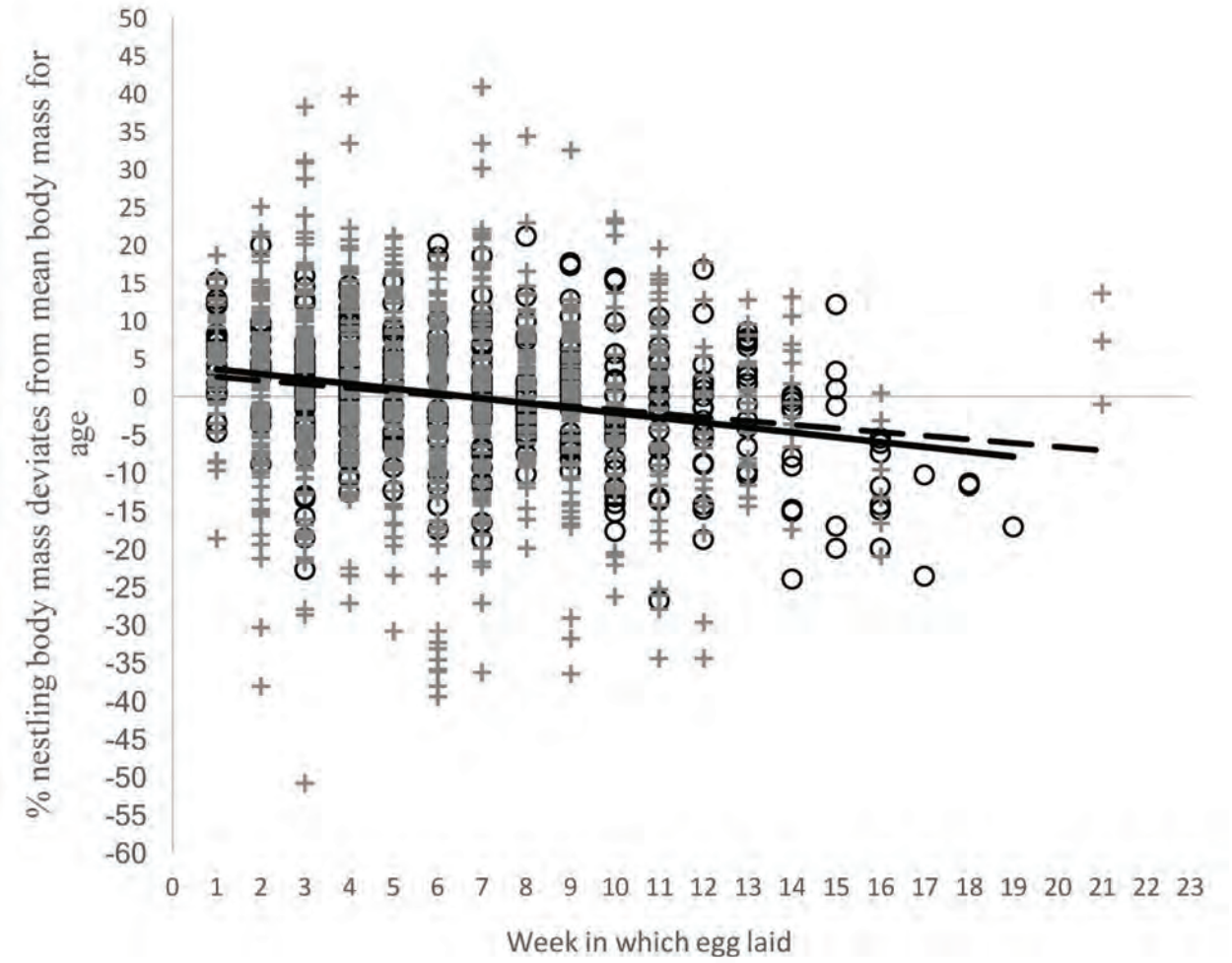

Figure 12. The percentage a nestling's body mass deviates from the mean body mass in relation to the week the nestling's egg is laid after the commencement of egg laying for all nestlings measured in 1970-1975 (1,225 measurements; black circles and line) and 2011-2016 (361 measurements; black crosses and dashed line). Egg-laying commences in week 1. The trend lines are significant ($p<0.001$).

population size is limited by recurring bottlenecks in food availability resulting from a trend of resource depletion combined with large variability in annual seed production.

DISCUSSION

There are two taxa of black cockatoos with white tail bands in southwestern Australia. Both species are listed as endangered, and must be managed separately with different priorities for both management and further research. As a result of the long-term study reported here much is known about Carnaby's Cockatoo, and its conservation needs. In fact, this concentration of research on Carnaby's Cockatoo over the past five decades is perceived to be the reason why little research effort or funds have been directed to Baudin's Cockatoo (Ainsworth 2014). Consequently, little is known about the breeding behaviour of Baudin's Cockatoo, or whether research results from the research on Carnaby's Cockatoo may be applied to management and conservation of Baudin's Cockatoo.

The research on Carnaby's Cockatoo conducted at Coomallo Creek, together with shorter-term studies of four other breeding populations, provided methods for establishing breeding seasons, aging nestlings, and assessing their condition or health. These methods may be applied easily, and should be used to monitor breeding populations throughout the range of the species.

Much is known about the breeding biology of the northern population of Carnaby's Cockatoo, but little is known about the southern population; this should be a priority for management and research.

The research also demonstrated that natural hollows are being lost at a rate that exceeds their natural replacement. Our research was conducted in an area that had been subjected to extensive loss of native vegetation and grazing by domestic livestock (Three Springs), and an area with less extensive clearing of native vegetation, and no grazing by domestic livestock (Coomallo Creek) (Figure 7). The predictions were similar for both areas; loss of large hollow-bearing trees, and little or no replacement. In the light of the extensive loss of native vegetation throughout much of the range of Carnaby's Cockatoo (Figure 1), it is likely these predictions apply widely, indicating urgent attention to revegetation with tree species that would be expected to survive in the region under conditions imposed by climate change, and develop hollows suitable for use by Carnaby's Cockatoo, and for the many other species dependent on hollows for breeding and shelter. As it will take well over a century for a tree to grow large enough to support a hollow suitable for Carnaby's Cockatoo, it is essential in the short-term to renovate derelict natural hollows, and provide artificial hollows suitable for Carnaby's Cockatoo in areas where there are breeding populations of the species. Natural and artificial hollows also require maintenance throughout their service life, with resources dedicated to that work.

As pointed out by Saunders (1982), the breeding population of Carnaby's Cockatoo at Manmanning was extirpated as a result of loss of natural food resources due to excessive clearing of native vegetation. Saunders (1986) pointed out that excessive clearing and loss of food resources was also leading to the decline of the population at Nereeno Hill, near Three Springs. That population has since been extirpated (DAS unpublished data), as were breeding populations at other locations throughout the wheatbelt; for example, Tammin (Saunders and Ingram 1995), Tutanning ((DAS unpublished data), Kellerberrin (DAS unpublished data) and Arrino (Saunders and McAleer 2012). Monitoring of known breeding populations should be conducted with assessment of nestling health to identify areas for revegetation with food species where nestlings are found to be consistently lighter than the mean body mass for Coomallo Creek.

Apart from birds breeding at Coomallo Creek and Manmanning, little is known about the movements of birds from their breeding areas to and from their foraging areas. Research has been conducted on movements since that reported by Saunders (1980), but it has been tracking rehabilitated birds fitted with transmitters (Groom *et al.* 2017). Unfortunately these birds have not been released in areas from which they were taken into captivity. The results of this work provide information on the success or otherwise of rehabilitation, but nothing about the movements of breeding birds from their breeding areas to their non-breeding foraging areas. The generation of information on other breeding populations should be a priority for management; without this information it will be difficult to plan successful conservation, and set realistic targets for management.

Under current predictions of climate change in southwestern Australia, the region is likely to have more exceptionally hot years and more extreme temperatures, with an increase in the number and severity of hot days (CSIRO 2007; Hennessy *et al.* 2008). In the light of these predictions, the timing and length of breeding is critical to the conservation of Carnaby's Cockatoo. Saunders (1982) pointed out that daily change in body mass of nestlings at Manmanning was negatively correlated with ambient temperature. The hotter the temperature, the less body mass accumulated by nestlings. This was attributed to a combination of food shortages, and decrease in foraging time available to the parents. Throughout the range of the species, as the days get longer towards the latter part of the breeding season, they also get hotter. Once the temperature reaches the mid-30s (^{o}C), the birds do not forage, and take shelter in shade until the temperature falls. At Manmanning, where food was limiting (Saunders 1982), and the birds

had exhausted the food supply closer to the nesting area, the adults did not have enough time to commute to available food, obtain enough food for themselves and their offspring, and commute back to their nest hollow; this had major adverse effects on their ability to fledge young successfully.

Southwestern Australia has already experienced extreme temperatures with adverse effects on Carnaby's Cockatoo. In January 2010, 208 Carnaby's Cockatoo were killed by heat stress on an exceptionally hot day (53-55^{0}C) on the south coast (Saunders *et al.* 2011b). This area is sparsely populated, and it is highly likely that many more birds were killed, but not found. More extreme heat days will impact on breeding birds, and limit the time available for foraging. Birds breeding earlier in the season may not be adversely affected, as they may be able to fledge their young, and move them to foraging areas where they can roost close to available food and water, and limit their commuting time. Those breeding later in the season are more likely to be limited by hot days with adverse effects on their reproductive output. Saunders *et al.* (2016) posited that lighter nestlings are less likely to survive to breed than heavier nestlings. They found that younger, and presumably less experienced, females tend to lay later in the breeding season, and produce lighter nestlings than older more experienced females. It is likely that hot days in the latter part of the breeding season are contributing factors to the production of lighter nestlings.

Our study of the breeding population of Carnaby's Cockatoo at Coomallo Creek has been conducted for nearly half a century. For much of that period, field work has involved at least two people for five days in early September, five days in early November, and two days in January. This is the minimum required to monitor the population; the September work ensures that the nestlings of early breeding attempts are measured and banded, the November work ensures that later breeding attempts are recorded, and the January work allows the results of all, but the very late breeding attempts to be established. In addition, the data collected have been curated, and made available for others to draw on. With results from the study published in over 40 papers in peer-reviewed scientific journals or chapters in peer-reviewed books, the work is readily available for those who need it, and are willing to search the cockatoo literature. The potential problem for this study is one of succession of researchers, others will need to take over conduct of the study from DAS and RD or it will lapse (Figure 13).

What impact has this long-term research on Carnaby's Cockatoo had? The four papers relating to changes in condition of large hollow-bearing trees and the rate of loss of hollows used by the cockatoos (Saunders 1979b; Saunders *et al.* 1982, 2003, 2014a) have been cited 300 times (ResearchGate 4th April 2017), drawing attention to the impacts of extensive loss of breeding habitat on species dependent on hollows for breeding and shelter. Population and demographic data from these studies has been used in conducting population viability analyses of Yellow-tailed Black Cockatoo *Calyptorhynchus funereus* (Fox, J. C. and Brereton, R. 2004 *in litt.*), Palm Cockatoo *Probosciger aterrimus* (Heinsohn *et al.* 2009) and the South-eastern Red-tailed Black Cockatoo *C. banksia graptogyne* (Potts, J. M. 2015 *in litt.*). In addition, the results of the research were used in drafting the Government of Western Australia's (2015) green growth plan for developing the Swan Coastal Plain. By 2031, the city's population is projected to have grown by 35–40% with an estimated population of 3.5 million people by 2056. The draft growth plan includes commitments to: *Improve breeding and associated feeding habitat at known breeding sites in the Wheatbelt of WA which may include fencing and protecting remnants, hollow repair and supplementation, revegetation of food plants and rehabilitation of feeding habitat, and control of nest competitors* and *Improving and supplementing of breeding habitat across the species range through provision of the no less than 700 artificial hollows from Eneabba to Ravensthorpe to address limitations in breeding hollows* (Government of Western Australia 2015). These are direct outcomes of the research and, if applied, will make major contributions to the conservation of the species.

Long-term studies are essential to understanding the ecology and behaviour of our biota, particularly long-lived species. They are essential to studying a range of seasonal conditions and provide more chances of recording stochastic events such as extreme climatic events (Saunders *et al.* 2011b) and bushfires (Saunders *et al.* 2014a). As shown by the research reported here, it may not be necessary to collect data every year. Some research questions only require data collection after decades. For example, the change in condition of the 15ha patch of Salmon Gum woodland near Three Springs was established with three visits in 1978, 1981 and 1997. Others may require more frequent monitoring. For example, the rate of loss of hollows used by Carnaby's Cockatoo at Coomallo Creek was established from data collected in the late 1960s, throughout the 1970s, and then again in the 2000s. These long-term data were also necessary to inform the need for, and placement of, artificial hollows. What is necessary is an individual or individuals committed to maintaining the study over time, and making sure the data are available to others to build on.

The same issues plague a range of the limited long-term ecological studies in Australia. There needs to be a national program that not only maintains a register of all long-term ecological research in Australia, but evaluates each program to decide which are most important to fund, and ensure continuity.

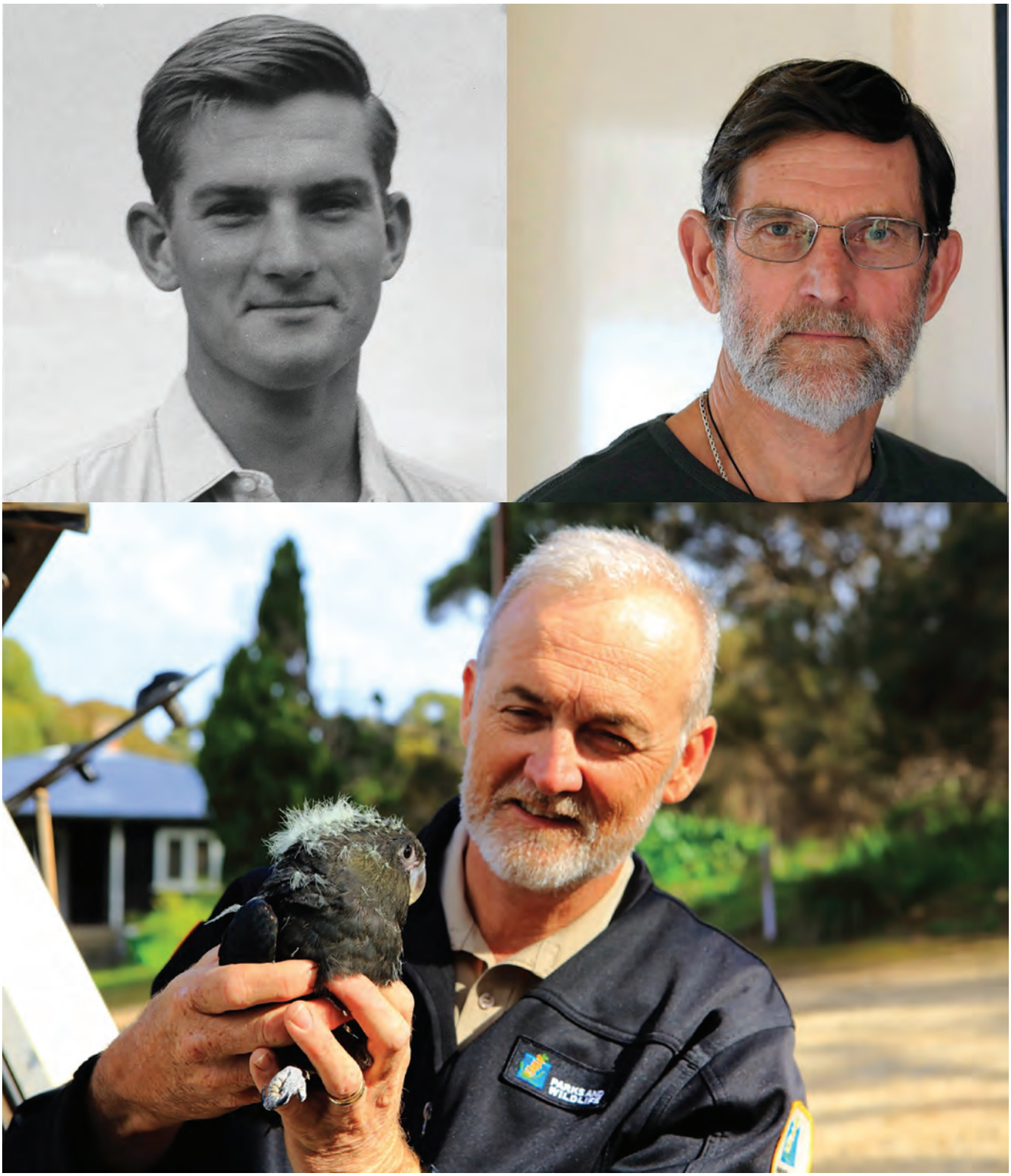

Figure 13. The authors: Denis Saunders in 1968 (top left) and in 2011 (top right), and and Rick Dawson holding a nestling Glossy Black Cockatoo *Calyptorhynchus lathami*.

Acknowledgments

The field work and animal handling reported here were conducted under appropriate ethics and banding approvals; from 1969 to 1996 these were held by staff in CSIRO, and from 2003 by staff in the Western Australian Department of Conservation and Land Management and successor departments. There are many people who contributed to this research over the years. We are grateful to: John Ingram who worked with DAS throughout the period to 1996, the Raffan, Paish, McAlpine, Hayes and Doley families for access to their properties to conduct this research, and for their continued support for the research; the Palm Beach Rotary Club and volunteers who assisted in monitoring, the repair of natural hollows and the installation of artificial hollows; Dr Peter Mawson and Dr Manda Page for support; Amy Mutton who prepared Figure 1; and Professor Stephen Garnett, Dr Dan Lunney, Dr A.O. (Nick) Nicholls PSM, Dr Penny Olsen AM, Professor Harry Recher AM and an anonymous reviewer for constructive criticism of earlier drafts of this paper.

References

Adams, M., Baverstock, P. R., Saunders, D. A., Schodde, R. and Smith, G. T., 1984. Biochemical systematics of the Australian cockatoos (Psittaciformes: Cacatuinae). *Australian Journal of Zoology* **32**: 363-77. https://doi.org/10.1071/ZO9840363

Ainsworth, G. B., 2014. *Valuing Birds: Understanding the Relationship between Social Values and the Conservation of Australian Threatened Avifauna*. PhD Thesis, Charles Darwin University, Darwin.

BirdLife International, 2013. *Zanda latirostris*. The IUCN Red List of Threatened Species 2013: e.T22684733A48062560. https://doi.org/10.2305/IUCN.UK.2013-2.RLTS.T22684733A48062560.en

Cale, B., 2003. Carnaby's Black-Cockatoo (*Calyptorhynchus latirostris*) Recovery Plan. Department of Conservation and Land Management, Wanneroo.

Campbell, N. A. and Saunders, D. A., 1976. Morphological variation in the White-tailed Black Cockatoo, *Calyptorhynchus baudinii*, in Western Australia. *Australian Journal of Zoology* **24**: 589-95. https://doi.org/10.1071/ZO9760589

Carnaby, I. C., 1948. Variation in the White-tailed Black Cockatoo. *The Western Australian Naturalist* **1**(7): 136-139.

CSIRO, 2007. *Climate Change in Australia. Technical Report 2007*. CSIRO and Bureau of Meteorology. http://www.climatechangeinaustralia.gov.au/technial_report.php

Dawson, R., Saunders, D. A., Lipianin, E. and Fossey, M., 2013. Young-age breeding by a female Carnaby's Cockatoo. *The Western Australian Naturalist* **29:** 63-65.

Department of Environment and Conservation, 2012. Carnaby's Cockatoo (*Calyptorhynchus latirostris*) *Recovery Plan. Western Australian Wildlife Management Program No. 52*. Department of Environment and Conservation, Perth, Western Australia: 1-56.

Forshaw, J. M., 1969. *Australian Parrots*. Lansdowne Press, Melbourne.

Government of Western Australia, 2015. *Perth and Peel Green Growth Plan for 3.5 million*. Department of the Premier and Cabinet, Western Australia.

Groom, C. J., Warren, K. and Mawson, P. R., 2017. Survival and reintegration of rehabilitated Carnaby's Cockatoos *Zanda latirostris* into wild flocks. *Bird Conservation International*. https://doi.org/10.1017/S0959270916000642

Heinsohn, R., Zeriga, T., Murphy, S., Igag, P., Legge, S. and Mack, A.L., 2009. Do Palm Cockatoos (Probosciger aterrimus) have long enough lifespans to support their low reproductive success? *Emu* **109:** 183–191. https://doi.org/10.1071/MU08053

Hennessy, K., Fawcett, R., Kirono D., Mpelasoka, F., Jones, D., Bathols, J., Whetton, P., Stafford Smith, M., Howden, M., Mitchell, C. and Plummer, N., 2008. *An assessment of the impact of climate change on the nature and frequency of exceptional climatic events*. Commonwealth of Australia, Barton, Australian Capital Territory.

IUCN, 2014. The IUCN Red List of Threatened Species. Version 2014.2. http://www.iucnredlist.org (accessed 28 July 2014).

Johnston, T., 2013. Food resource availability for Carnaby's cockatoo *Calyptorhynchus latirostris* on the Swan coastal plain. MSc thesis, Edith Cowan University, Western Australia.

Johnstone, R. E., Fisher, C. and Saunders, D. A., 2014. Case 3658 *Calyptorhynchus baudinii* Lear, 1832: proposed conservation of usage by designation of neotype. *Bulletin of Zoological Nomenclature* **71** (3): 170-178. https://doi.org/10.21805/bzn.v71i3.a16

Perry, D. H., 1948. Black cockatoos and pine plantations. *The Western Australian Naturalist* **1**(7):133-135.

Saunders, D. A., 1974. Subspeciation in the White-tailed Black Cockatoo, *Calyptorhynchus baudinii*, in Western Australia. *Australian Wildlife Research* **1**: 55- 69. https://doi.org/10.1080/00063650009461179

Saunders, D. A., 1979a. Distribution and taxonomy of the White-tailed and Yellow-tailed Black Cockatoos *Calyptorhynchus* spp. **Emu 79**: 215-27. https://doi.org/10.1071/MU9790215

Saunders, D. A., 1979b. The availability of tree hollows for use as nest sites by White-tailed Black Cockatoos. *Australian Wildlife Research* **6**: 205-16. https://doi.org/10.1071/WR9790205

Saunders, D. A., 1980. Food and movements of the short-billed form of the White-tailed Black Cockatoo. *Australian Wildlife Research* 7: 257-69. https://doi.org/10.1071/WR9800257

Saunders, D. A., 1982. The breeding behaviour and biology of the short-billed form of the White-tailed Black Cockatoo *Calyptorhynchus funereus latirostris* Carnaby. *Ibis* **124**: 422-55 https://doi.org/10.1111/j.1474-919X.1982.tb03790.x

Saunders, D. A., 1983. Vocal repertoire and individual vocal recognition in the short-billed form of the White-tailed Back Cockatoo *Calyptorhynchus funereus* Carnaby. *Australian Wildlife Research* **10:** 527-36. https://doi.org/10.1071/WR9830527

Saunders, D. A., 1986. Breeding season, nesting success and nestling growth in the Carnaby's cockatoo *Calyptorhynchus funereus latirostris* over 16 years at Coomallo Creek and a method for assessing the viability of populations in other areas. *Australian Wildlife Research* **13**: 261-73. https://doi.org/10.1071/WR9860261

Saunders, D. A., 1988. Patagial tags: do the benefits for the research worker outweigh the risks to the animal? *Australian Wildlife Research* **15**: 565-9. https://doi.org/10.1071/WR9880565

Saunders, D. A., 1990. Problems of survival in an extensively cultivated landscape: the case of Carnaby's cockatoo *Calyptorhynchus funereus latirostris*. *Biological Conservation* **54**: 277-290. https://doi.org/10.1016/0006-3207(90)90057-V

Saunders, D. A., Dawson, R., Doley, A., Lauri, J., Le Souëf A., Mawson, P. R., Warren, K. and White, N., 2014b. Nature conservation on agricultural land: a case study of the endangered Carnaby's Cockatoo *Calyptorhynchus latirostris* breeding at Koobabbie in the northern wheatbelt of Western Australia. *Nature Conservation* **9**: 19-43. Doi:10.3897/natureconservation.9.8385 https://doi.org/10.3897/natureconservation.9.8385

Saunders, D. A., Dawson, R. and Mawson, P., 2011a. Photographic identification of bands confirms age of breeding Carnaby's Black Cockatoo. *Corella***35**: 52-54.

Saunders, D. A., Dawson, R. and Nicholls, A. O., 2015. Aging nestling Carnaby's cockatoo, *Calyptorhynchus latirostris*, and estimating the timing and length of the breeding season. *Nature Conservation* **12**: 27-42. https://doi.org/10.3897/natureconservation.12.4863

Saunders, D. A., Dawson, R. and Nicholls, A. O., 2016. Breeding failure and nestling body mass as a function of age of breeding females in the endangered Carnaby's Cockatoo, *Calyptorhynchus latirostris*. *Australian Zoologist* **38** (2): 171-182 https://doi.org/10.7882/AZ.2016.032

Saunders, D. A. and Doley, A., 2014. The birds of "Koobabbie" in the northern wheatbelt of Western Australia (1987-2011) and its role in conservation of the region's avifauna. *Pacific Conservation Biology* **19**: 204-232. Complete data set is available DOI: 10.13140/2.1.4122.9766

Saunders, D. A. and Ingram, J. A., 1995. *Birds of Southwestern Australia. An Atlas of Changes in Distribution and Abundance of the Wheatbelt Avifauna*. 295 pp. Surrey Beatty & Sons, Chipping Norton, NSW. ISBN 0 949324 57 4

Saunders, D. A. and Ingram, J. A., 1998. Twenty-eight years of monitoring a breeding population of Carnaby's Cockatoo. *Pacific Conservation Biology* **4**: 261-270. https://doi.org/10.1071/PC980261

Saunders, D. A., Mawson, P. and Dawson, R., 2011b. The impact of two extreme weather events and other causes of death on Carnaby's Black Cockatoo: a promise of things to come for a threatened species? *Pacific Conservation Biology* **17:** 141-148. https://doi.org/10.1071/PC110141

Saunders, D. A., Mawson, P. R. and Dawson, R., 2014a. Use of tree hollows by Carnaby's Cockatoo and the fate of large hollow-bearing trees at Coomallo Creek, Western Australia 1969-2013. *Biological Conservation* **177**: 185-193. doi: 10.1016/j.biocon.2014.07.02

Saunders, D. A. and McAleer, A. J., 2012. The conservation value of private property; a case study of the birds of *Woopenatty* Arrino, in the northern wheatbelt of Western Australia, 1987-2002. *Pacific Conservation Biology* **18**: 164-176. https://doi.org/10.1071/PC130164

Saunders, D. A. and Smith, G. T., 1981. Egg dimensions and egg weight loss during incubation in five species of cockatoo and the use of measurements to determine the stage of incubation of birds' eggs. *Australian Wildlife Research* **8**: 411-9. https://doi.org/10.1071/WR9810411

Saunders, D. A., Smith, G. T., Ingram, J. A. and Forrester, R. I., 2003. Changes in a remnant of salmon gum *Eucalyptus salmonophloia* and York gum *E. loxophleba* woodland, 1978 to 1997. Implications for woodland conservation in the wheat-sheep regions of Australia. *Biological Conservation* **110**: 245-256. https://doi.org/10.1016/S0006-3207(02)00223-9

Saunders, D. A., Smith, G. T. and Rowley, I., 1982. The availability and dimensions of tree hollows that provide nest sites for cockatoos (Psittaciformes) in Western Australia. *Australian Wildlife Research* **9**: 541-56. https://doi.org/10.1071/WR9820541

Saunders, D. A., Wintle, B. A., Mawson, P. R. and Dawson, R., 2013. Egg-laying and rainfall synchrony in an endangered bird species; implications for conservation in a changing climate. *Biological Conservation* **161**: 1-9. https://doi.org/10.1016/j.biocon.2013.02.004

Saunders, D. A. and Wooller, R. D., 1988. Consistent individuality of voice in birds as a management tool. *Emu* **88**: 25-32. https://doi.org/10.1071/MU9880025

Serventy, D. L. and Whittell, H. M., 1976. *Birds of Western Australia. 5th Edition*. University of Western Australia Press, Perth.

Smith, G. T. and Saunders, D. A., 1986. Clutch size and productivity in three sympatric species of cockatoo (Psittaciformes) in the south-west of Western Australia. *Australian Wildlife Research* **13**: 275-85. https://doi.org/10.1071/WR9860275

Stock, W.D., Finn, H., Parker, J. and Dods, K., 2013. Pine as fast food: foraging ecology of an endangered cockatoo in a forestry landscape. *PLoS ONE* **8**, e61145. https://doi.org/10.1371/journal.pone.0061145

Usher, K. M., Groom, C. and Saunders, D. A., 2015. Identification of individual Carnaby's Cockatoos *Calyptorhynchus latirostris* from distinctive plumage markings. *Australian Zoologist* **38**(1): 62-82. https://doi.org/10.7882/AZ.2015.031

Valentine, L.E., Fisher, R., Wilson, B.A., Sonneman, T., Stock, W.D., Fleming, P.A. and Hobbs, R.J., 2014. Time since fire influences food resources for an endangered species, Carnaby's cockatoo, in a fire-prone landscape. Biological Conservation, 175, 1–9. https://doi.org/10.1016/j.biocon.2014.04.006

Williams, M.R., Yates, C.J., Finn, H., Stock, W. and Barrett, G., 2015. Citizen science monitoring reveals a significant, ongoing decline of the endangered Carnaby's black-cockatoo. Oryx, doi:10.1017/S0030605315000320.

Williams, M. R., Yates, C. J., Saunders, D. A., Dawson, R. and Barrett, G. W. 2017. Combined demographic and resource models quantify the effects of potential land-use change on the endangered Carnaby's cockatoo (*Calyptorhynchus latirostris*). *Biological Conservation* **210**: 8-15 doi: http://dx.doi.org/10.1016/j.biocon.2017.03.18