EPA Technical Report: Carnaby's Cockatoo in Environmental Impact Assessment in the Perth and Peel Region

Advice of the Environmental Protection Authority under Section 16(j) of the *Environmental Protection Act 1986*

May 2019

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All images of cockatoos are supplied courtesy of the WA Museum.

Summary

The Perth and Peel regions are experiencing rapid growth and the population is forecast to reach 3.5 million by 2050. This increasing population will put greater pressure on our environment for land and groundwater resources. The Environmental Protection Authority (EPA) is concerned about the cumulative impacts of a growing city, against a backdrop of historical clearing, on Carnaby's cockatoo.

Carnaby's cockatoo is a seasonal visitor to the Swan Coastal Plain, which provides important foraging and roosting habitat during the non-breeding season. It is often encountered during environmental impact assessment (EIA) where its habitat intersects with land proposed for clearing and development. The species and its habitat are threatened by land clearing, invasive species, disease and fire, and increasing proximity to people, impacts potentially exacerbated by climate change.

The species is reliant on the maintenance of resources over multiple bioregions, which adds an extra complexity to its conservation. To address this, mitigation must be applied across the species range. Mitigation measures focused on:

- protection and retention of habitat, including important breeding sites and associated foraging habitat
- management, including habitat restoration and rehabilitation
- reducing adult mortality and increasing breeding rates
- research to better inform environmental impact assessment

will lead to better conservation outcomes for Carnaby's cockatoo, provide more certainty for regulators and industry, and enable more timely assessment.

Scope

This report considers the issues affecting Carnaby's cockatoo *Calyptorhynchus [Zanda] latirostris*, focusing on the Perth and Peel portions of the Swan Coastal Plain region, from Yanchep in the north to Preston Beach in the south (referred to as the Perth-Peel region) (Figure 1), and acknowledging breeding areas in the northern Avon-Wheatbelt and Geraldton Sandplains bioregions, as appropriate (Figure 2).

This report outlines the known threats to Carnaby's cockatoo in the Perth-Peel region, evaluates the risks to the population and suggests priorities for research to inform environmental assessment, management and monitoring.

This report is intended to inform EIA under Part IV of the *Environmental Protection Act 1986* (EP Act). However, the information included in this report is equally relevant to other decision makers, such as those assessing native vegetation clearing permits under Part V of the EP Act.

Figure 1: The Perth and Peel portions of the Swan Coastal Plain, showing the location of the original extent of the Gnangara-Pinjar pine plantation (dark green) and the approximate urban extent (grey). Data sources: IBRA v7 Region 2012, Department of Environment and Energy; Urban boundary, Department of Planning; Gnangara-Pinjar Pine Plantation, Forest Products Commission

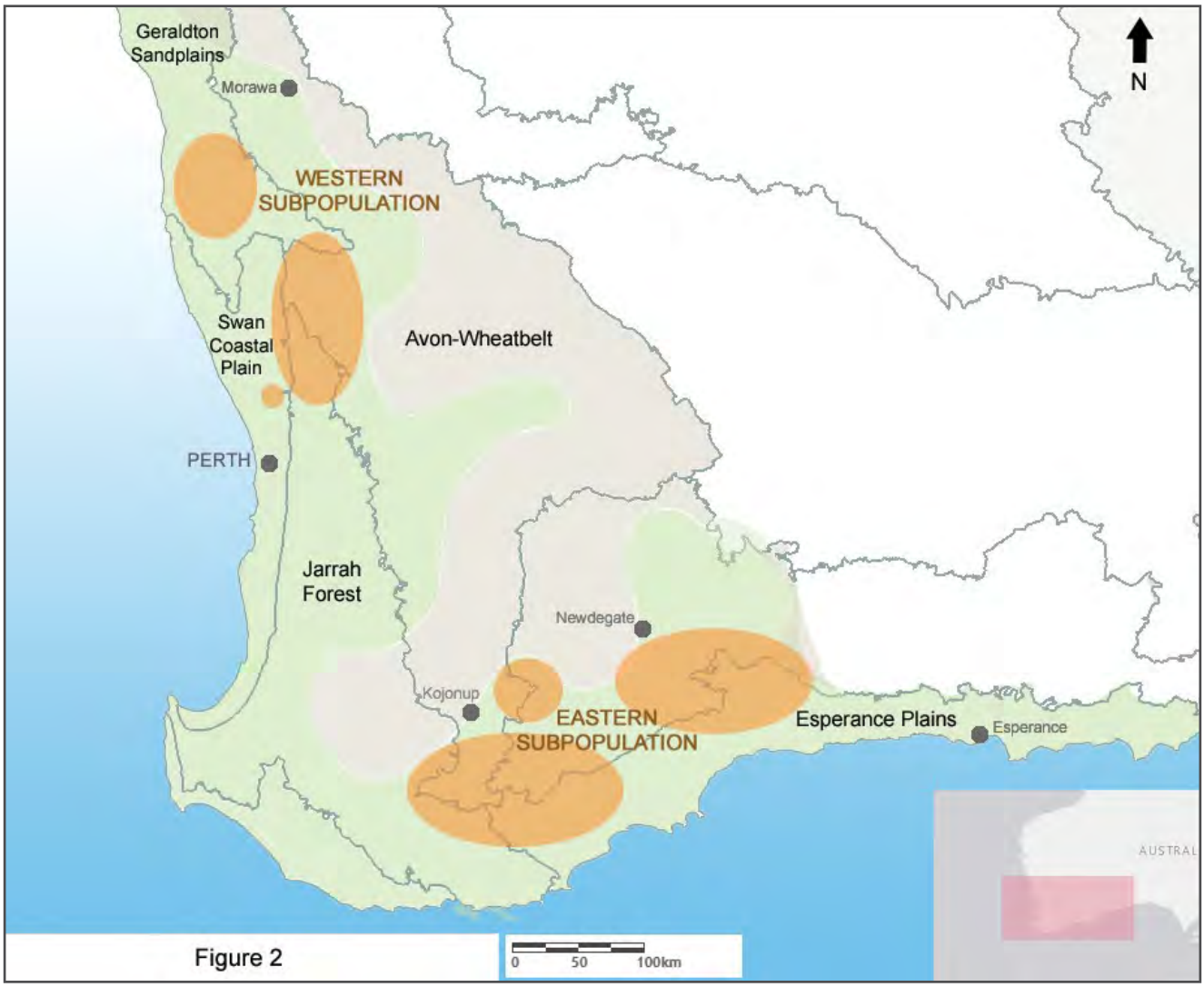

Figure 2: The estimated distribution of Carnaby's cockatoo showing the western and eastern subpopulations, with the former distribution (pre-1987) shaded in grey. Approximate breeding zones are indicated in orange. Indicative distribution is based on Saunders and Ingram, 1987, and contemporary records, as extracted from NatureMap (Birdlife Australia Atlas dataset) and the Atlas of Living Australia, from 2000 to 2018. Data sources: IBRA v7 Region 2012, Department of Environment and Energy

Background

Carnaby's cockatoo is endemic to the south-west of Western Australia (WA). It is the predominant black cockatoo species on the Swan Coastal Plain. The species is an iconic and conspicuous bird, and its conservation attracts a high level of public interest.

General information on the ecology and biology of Carnaby's cockatoo is widely available in the literature, including the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) *Carnaby's Cockatoo Species Profile and Threats Database* (Department of Environment and Energy (DEE), 2016a). Key outcomes of existing research are presented in Appendix 1.

Status

Carnaby's cockatoo was once considered vermin because of the damage it caused to commercial orchards and pine plantations (Perry, 1948). However, in 1990 the species was listed by the State, recognising the need for their protection, and federally in 1998. Carnaby's cockatoo is currently listed as Endangered under the *Western Australian Biodiversity Conservation Act 2016* (BC Act) and Endangered under the Commonwealth EPBC Act.

In 2012, the WA Threatened Species Scientific Committee reviewed and recommended retention of the listing of Carnaby's cockatoo based on available data and the recommendation of the 2010 Action Plan for Australian Birds (Garnett et al., 2011), which stated the reasons for listing as *"rapid decline >50% in last three generations (58 years) likely to continue, based on sample counts, areas of occupancy and quality of habitat, nest robbing, disease and competition."*

Distribution

Carnaby's cockatoo occurs widely throughout south-western WA, from the lower Murchison in the north and south to Esperance, and as far east as Forrestania (Storr and Johnstone, 1998).

Clearing in the southern Wheatbelt has resulted in two genetically distinct subpopulations: a western and an eastern (White et al., 2014) (Figure 2). The focus of this report is the western subpopulation, which breeds in the Avon-Wheatbelt, Geraldton Sandplains and Jarrah Forest IBRA bioregions, as far as Morawa in the north, and migrates to the Swan Coastal Plain during the non-breeding season, between January and June. The eastern subpopulation breeds in the southern Wheatbelt region, from Kojonup to Newdegate, and migrates to the south-east coast to the Esperance Plain.

It has been estimated that Carnaby's cockatoo has disappeared from more than one-third of its historical breeding range because of extensive habitat loss in the Avon-Wheatbelt region (Saunders, 1990). Subsequently, the breeding distribution of Carnaby's cockatoo has shifted westward through the Jarrah Forest region, where it now also breeds (Johnstone and Kirkby, 2008a; Storr and Johnstone, 1998).

Population estimates

While no total population census of Carnaby's cockatoo is available, estimates have been made based on long-term monitoring and surveys in the Geraldton Sandplain and Avon-Wheatbelt regions, and existing survey and census data from sites scattered throughout the species range (Garnett et al., 2011).

In 1985, the total population of Carnaby's cockatoo was estimated to be a maximum of 60 000 birds (Saunders et al., 1985; Garnett and Crowley, 2000). Recent population estimates consider the total population to be around 40 000 birds (Department of Parks and Wildlife (DPaW), 2013).

The Perth-Peel region represents just 3.7% of the total mapped distribution of the species, but is estimated to account for about 25% of the greater population (DPaW, 2013). The population in the Perth-Peel region is estimated at about 13 000 birds (Peck et al., 2018).

The numbers of Carnaby's cockatoo utilising the Perth-Peel region vary from year-to-year. The Great Cocky Count – a citizen science project undertaking an annual count on a single day in April each year from 2010 to 2018 - has recorded numbers of roosting cockatoos ranging from 3 912 to 12 465 birds in the Swan Coastal Plain portion of the Greater Perth-Peel Region (Peck et al., 2018). Based on counts between 2010 and 2015, the population of Carnaby's cockatoo on the Perth-Peel Coastal Plain was estimated to be declining by an average of 15% per annum (Byrne et al., 2015). Over the last three years, total counts in the region have increased to 10 919 (2016), 10 248 (2017) and 12 465 (2018), and the trend since 2015 has increased slightly, with the rate of decline revised to 5% per year (Peck et al., 2018).

In 2017, the CSIRO undertook a reanalysis of the 2010 to 2017 Great Cocky Count data, using different analytical assumptions to Peck et al., (2017), and concluded that the Perth-Peel subpopulation of Carnaby's cockatoos was slightly increasing or was at least stable (Cayley et al., 2018). Estimates and trends of population size based on the Great Cocky Count are expected to become more accurate as counts continue (Cayley et al., 2018)

Changes in the counts may be attributable to change over time in survey effort. However, it is not understood how impacts outside of the Perth-Peel region influence the numbers of cockatoos using the region during the non-breeding season. For example, whether an increase in the number of cockatoos in the Perth-Peel region is due to the documented westward shift in the population (Johnstone and Kirkby, 2008a; Storr and Johnstone, 1998), due to habitat loss.

State of knowledge

Over the last 50 years, considerable research has been undertaken on Carnaby's cockatoo by Commonwealth and State government agencies (including the CSIRO, Department of Biodiversity, Conservation and Attractions (DBCA), the WA Museum and Perth Zoo), universities and non-government organisations (including BirdLife Australia).

Since 2000, over 40 research articles and papers have been published on Carnaby's cockatoo. This research has focused on habitat use, foraging behaviour, roost occupancy and movement on the Swan Coastal Plain; and long-term research in the Avon-Wheatbelt and Geraldton Sandplain regions on the breeding ecology, longevity, distribution and migration of the species. In addition, research has been undertaken on developing techniques to increase survival and breeding rates, including the design and installation of artificial nesting hollows.

Based on this literature, there is a sound understanding of distribution, breeding ecology, feeding ecology including nutritional value of foods, habitat requirements, and threats and threating processes; there is some information on migration patterns (see Appendix 1). This research underpins our knowledge of the species throughout its range.

Despite the large amount of research conducted and available information, significant knowledge gaps remain in relation to the ecology of the species and likely impacts of the threatening processes (Table 1).

Table 1: Key knowledge gaps for Carnaby's cockatoo in the Perth-Peel region and research to inform these gaps.

Question	References	Current research
Knowledge gaps that may be addressed in the short-term		
How many Carnaby's cockatoos directly rely on plantation pine habitat?	Cockerill et al. 2013	Ongoing annual census of cockatoos using pine habitat collected by Birdlife Australia Great Cocky Count.
What is the breeding origin of those birds that use the Gnangara-Pinjar pine plantations?	Cockerill et al. 2013	Pine habitat use and movement of cockatoos in the northern Swan Coastal Plain is being investigated by Murdoch University, sponsored by Forest Products Commission (2018). Further investigation required to determine breeding origins of flocks.
How will Carnaby's cockatoo respond to clearing of pine in the Gnangara-Pinjar area? What impacts have occurred from clearing of pine in the Gnangara-Pinjar plantation?	The Department of Premier & Cabinet (DPC) 2015a	The predicted impacts of pine clearing on carrying capacity and estimated minimum abundance were modelled through population viability analysis (Williams et al. 2017), but there is no known on-ground research to verify the assumptions of the model.
What proportion of protected and offset habitat is actually used by Carnaby's cockatoos? How adequate have offset actions been to date?	Richards 2016; Thorn et al. 2018	No current known research
What proportion of habitat is protected or at risk?	Identified in this review	Cumulative risk in Perth-Peel examined through SAPPR (DPC 2015a) and independent review (Whitehead et al. 2017). Proportion of habitat protected addressed in this review.
What is the cause and significance of Carnaby's Hindlimb Paralysis Syndrome?	Vaughan-Higgins et al. 2018	Investigations commenced by Perth Zoo (DBCA) and Murdoch University.

Question	References	Current research
Knowledge gaps that may be addressed in the longer term		
What is the carrying capacity of the remaining foraging habitat on the Swan Coastal Plain? Can Banksia woodland on the northern Swan Coastal Plain continue to support Carnaby's cockatoo once plantation pine habitat is harvested?	Finn et al. 2009; Stock et al. 2013; Valentine et al. 2014	Carrying capacity of foraging habitat (pine and mixed Banksia woodland) in Perth-Peel region estimated through a population viability analysis (Williams et al. 2017)
What factors outside of the Perth-Peel region (food resources, past and future land-use changes, nest hollow abundance and loss) are affecting the population?	Cockerill et al. 2013 DPC 2015a Williams et al. 2017	Ongoing research in breeding areas (Murdoch University, CSIRO, DBCA, WA Museum and Birdlife Australia) and analysis and publication of long-term research in these areas may help to address this knowledge gap.
What factors influence the number of birds using the Perth-Peel region, and are numbers increasing? If so, why?	Identified in this review	No current known research. Analysis of existing long-term data may help to address this knowledge gap.
How does the availability of non-breeding foraging habitat in the Perth-Peel region influence breeding success and juvenile survival in the Avon-Wheatbelt and Geraldton Sandplains regions?	Identified in this review	No current known research
What is the total population size? Is it possible to derive reliable estimates of sub-population size, and if so what are they?	Cockerill et al. 2013; DPC 2015a; Williams et al. 2017	Birdlife Australia CockyWatch program launched in 2018 and extension of the Great Cocky Count into rural areas aim to help to address this knowledge gap.
Knowledge gaps that are unlikely to be addressed in the foreseeable future		
What are the predicted impacts of climate change on population size and health, and habitat?	DPC 2015a	No current known research
What minimum population size is required to maintain viability of the species?	DPC 2015a	No current known research

Key threats and impacts

The threats and impacts to Carnaby's cockatoo are well known (Table 2). The species is primarily threatened by the loss and fragmentation of breeding and foraging habitat as a result of vegetation clearing. This is particularly so on the Swan Coastal Plain and Avon-Wheatbelt regions where extensive historical clearing has occurred.

Table 2: Key threats and contributing actions impacting Carnaby's cockatoo.

Key Threats	Contributing Actions
• Habitat loss (breeding, foraging, roosting) • Habitat fragmentation and degradation • Loss of breeding hollows and nest availability • Mortality of individuals	• Land clearing for: - Agriculture - Urban development - Infrastructure - Forestry - Mining (e.g. Basic Raw Materials) • Historical clearing • Plantation pine harvesting • Fire • Drought • Declining vegetation health including Phytophthora dieback • Aging hollows (hollow degradation) and destruction • Aging population, reduced breeding rates and success • Nest competition (feral bees and native invasive species) • Roost competition • Vehicle strike • Illegal shooting, poisoning and poaching • Disease (e.g. Beak and Feather Disease (BFDV), Avian Polymovirus (APV), Carnaby's Hindlimb Paralysis Syndrome (CHiPs) • Climate change and stochastic natural events

When moving between roosting, water and food resources, Carnaby's cockatoo flocks follow vegetation corridors and actively avoid cleared and open areas, including dense urban areas. Habitat fragmentation increases the distances cockatoos need to travel between resources. Proximity of foraging habitat and water has been demonstrated to be critical to support roosting and breeding sites (Groom, 2015; Le Roux, 2017; Saunders, 1990). Foraging habitat within 7 km of a breeding site is important to adequately support breeding cockatoos (Saunders, 1982; Saunders, 1990). In the Perth-Peel region, individual night roosts need food and water within 6km, with overlapping foraging ranges within 12 km, to support roosting sites and maintain habitat connectivity and movement across the landscape (Le Roux, 2017; Shah, 2006).

Carnaby's cockatoo has been significantly impacted by historical clearing of its habitat for agriculture throughout most of its breeding range during the last century. Broad-scale clearing of native vegetation has resulted in fragmentation of breeding and foraging habitat; and loss of breeding hollows (Saunders and Ingram, 1987); changes in the species distribution (Johnstone and Kirkby 2008a) and genetic partitioning (White et al., 2014); and degradation of vegetation from fire, salinity, groundwater drawdown and grazing.

Increased foraging distances have been linked to poor chick health and lower breeding success rates, leading to abandonment of breeding areas because of a lack of food availability (Saunders, 1982; Saunders, 1990; Saunders et al., 1985; Saunders and Ingram, 1987). For example, Saunders observed that the chicks of adult birds that had to travel greater distances, up to 12 km, to find food, had lower growth rates and fledging success, compared to the chicks of adult birds that had foraging habitat available within 7 km of a nest site (Saunders, 1980; Saunders, 1982). These impacts have had long-term effects that are likely to be contributing to a contemporary downwards population trend.

In the Perth-Peel region, the key threatening process to Carnaby's cockatoo is the clearing of foraging habitat, both native and pine. Actions that contribute to the loss of habitat in the region include urban and infrastructure development, plantation forestry and basic raw material extraction.

Carnaby's cockatoo's most important natural food resource on the Swan Coastal Plain is *Banksia* species (predominantly *B. attenuata, B. menziesii* and *B. sessilis*), and it also feeds frequently on *Corymbia calophylla* (Marri) (Groom et al., 2014). Banksia woodland in the Perth metropolitan area has been reduced to one third of its original extent since European settlement and the remaining portions are fragmented into smaller patches, with the majority (82%) of remnant patches under 10 ha size (DEE, 2016b). The significant clearing and fragmentation of Banksia woodland was recognised by the Commonwealth in 2016 when it listed the *Banksia Woodland on the Swan Coastal Plain* as an Endangered Threatened Ecological Community under the EPBC Act (DEE, 2016b). The importance of Banksia woodland habitat for Carnaby's cockatoo has been demonstrated through foraging studies, which determined that Carnaby's cockatoo exploit all areas of available Banksia food resources on the Swan Coastal Plain (Johnson et al., 2016).

Climate change is likely to exacerbate impacts to Carnaby's cockatoo. The drying climate trend has caused a reduction in the availability of groundwater resources for environmental, social and economic requirements. Reduced rainfall affects the health and seed productivity of Banksia species and increases tree death, leading to a decrease in food availability (DEE, 2016b). An increase in the frequency of stochastic fire and extreme weather events, such as heat waves and severe storms, because of climate change, is likely to result in habitat loss and increase the incidents of mass deaths of individual cockatoos due to exposure (Saunders et al., 2011).

The reduction in habitat, together with fragmentation, has resulted in an increase in the numbers of Carnaby's cockatoo using habitats that intersect with urban areas. This increases the incidents of mortality to individual cockatoos, due to vehicle collision where they fly to the ground to drink from water pools, feed on dropped seeds and nuts on roadsides, or when flying across roads between areas of foraging habitat. The Perth Zoo Veterinary Department receives hundreds of black cockatoos each year with 85 Carnaby's cockatoo admitted for the 2017-18 financial year, of which 21.2% were due to vehicle collision (Data supplied DBCA, 29 August 2018). This figure is likely to be an under-representation of the number that are hit by vehicles because of unreported deaths or injuries.

The urban landscape may also support the species through provision of artificial water sources and roosting resources via planted street trees and residential gardens. However, these resources may be temporary and are not guaranteed.

A relatively recent issue, Carnaby's Hindlimb Paralysis Syndrome (CHiPs mortality), resulting in death or paralysis of affected cockatoos, is thought to be a result of contact with agricultural pesticides or similar products in breeding areas (Vaughan-Higgins et al., 2018). The agent responsible and source of the contamination has not yet been identified and further investigation is required to fully understand the cause and management of this threat.

Plantation pines

Carnaby's cockatoo has adapted to feeding on pines (mostly *Pinus pinaster*), established for forestry throughout the south-west last century, which now form a major part of their diet (Groom et al., 2014; Shah, 2006; Valentine and Stock, 2008).

The introduction of pine plantations to the Perth and Peel region may have influenced the number and distribution of Carnaby's cockatoo (Perry, 1948). This new food resource is likely to have partially counterbalanced the loss of native Banksia woodland foraging habitat in the region, to an unknown degree.

From the early 1900s, Carnaby's cockatoo flocks as large as 2 000 were recorded from the Yanchep area, and were observed feeding in pine plantations (Perry, 1948). Contemporary counts of flocks of over 6 000 Carnaby's cockatoos have been recorded feeding and roosting in the pine plantations in the Gnangara, Wanneroo, Pinjar and Yanchep areas (Finn et al., 2009; Peck et al., 2018; Stock et al., 2013; Storr and Johnstone, 1998) in plantations collectively referred to here as the Gnangara-Pinjar pine plantation.

The original Gnangara-Pinjar pine plantation was 23 000 ha extending over 50 km from Gnangara through to Pinjar, near Yanchep, in the northern Swan Coastal Plain. The plantation has been commercially harvested since 2002 at an average rate of 1 500 ha/year (DPC, 2015b), to reduce pressure on the Gnangara groundwater allocation area and to manage the environmental values, social and economic water requirements for Perth in a drying climate.

Studies of Carnaby's cockatoo foraging behaviour in the Gnangara-Pinjar plantation indicate that all of the available pine is exploited for food, with flocks timing their arrival in the area to coincide with the pine seed maturation from January to June, with abundance peaking in May (Stock et al., 2013). Mature pines have become an important food source as they produce a larger number of seeds over a smaller area and provide a higher calorific content compared to Banksia seeds (Appendix B, Williams et al., 2017). In addition, pine trees provide valuable roosting habitat, which protects flocks during the day from high summer temperatures (Stock et al., 2013).

Even though flocks of Carnaby's cockatoo are regularly counted in the plantation as part of the Great Cocky Count, there is limited understanding of their roosting and foraging behaviour in response to pine clearing activity. For example, once the pines have been removed, it is not known whether Carnaby's cockatoo will increase their reliance on native vegetation in the Perth-Peel region; disperse to forage on alternative habitat outside of the region; or whether mortality rates and breeding success will be affected.

Anecdotal observations, from the DBCA, suggest that Carnaby's cockatoo feed on regenerated pine wildings within the Gnangara-Pinjar plantation, and begin feeding on wildings as soon as the trees are mature enough to produce cones, at about seven to ten years old. However, young pine wildings will not produce the same volume or density of food as mature trees, and cockatoos prefer to forage on older pine 18 to 80 years old (Stock et al., 2013). No quantitative study has been undertaken to document foraging on the pine wildings, and as a result, predicting the significance of the impact of pine clearing on Carnaby's cockatoo is difficult.

There will be a time lag between the harvesting of mature pine trees in the Gnangara-Pinjar plantation and maturation of pine wildings. To reduce the impact of pine clearing, about 800 to 1 500 ha of regenerated pine wildings per year have been retained since 2002. It is proposed that these pine wildings could be actively managed to maximise future foraging options for Carnaby's cockatoo. An additional 2 000 ha of commercial plantation pine, planted since 2012, will provide some foraging habitat until 2029, when they will be harvested.

A population viability analysis (PVA) modelled the relative impacts of clearing the Gnangara-Pinjar plantation on the Perth-Peel subpopulation of Carnaby's cockatoo (Williams et al., 2017). Three scenarios were modelled based on different land use and mitigation options from 2001 to 2050:

- Cessation – immediately (as of 2015) stop further clearing of pine.
- Mitigation – harvesting of plantations to maximise groundwater recharge, but retention of large areas of pine wildings at low densities (40-50 stems/ha) as food for Carnaby's cockatoo.
- Maximum Water – harvesting existing plantations on the Gnangara water mound to maximise groundwater recharge.

Later versions of the PVA (Mitigation 3) tested the effect of measures to increase vital rates (reduced mortality and increased breeding rates) (DBCA, 2017), and the additional mitigation measures recommended in the *Strategic Assessment of the Perth-Peel Region* (SAPPR) (Green Growth Plan) (DPC, 2015a). The revised Mitigation 3 scenario included replacement of pine plantation with about 18 000 ha of pine wildings, retention of 150 ha of existing pine trees (Dick Perry reserve), about 10 000 ha of native Banksia woodland regeneration, avoidance of clearing foraging habitat and roosting sites, creation of conservation reserves, urban forest planting on the Swan Coastal Plain, with additional habitat management in the broader Avon-Wheatbelt breeding range (DPC, 2015a).

Based on the estimated carrying capacity of each scenario, the PVA model projected the likely estimated minimum abundance and mean population size for each of the scenarios, up to 2050 (Williams et al., 2017) (Table 3).

Table 3: Modelled scenarios for the Population Viability Analysis (PVA) showing estimated carrying capacity, minimum abundance and mean population size, based on an initial population size of 8,000 birds (2000).

PVA Modelled Scenarios	Carrying Capacity	Est. Minimum Abundance	Mean Population Size	% Decline in Mean Population Size by 2050
Cessation[1]	9,310	4,278	5,246	34%
Mitigation 2[1]	7,118	3,640	4,344	46%
Mitigation 3[2]	7,587	3,603	4,344	46%
Mitigation 3 with an increase of +1.19% in all vital rates[2]	7,587	4,008	5,220	35%
Maximum Water[1]	5,624	3,012	3,550	56%

The PVA projections identified that clearing of the Gnangara-Pinjar plantation may result in a sudden decline in the abundance and population size of Carnaby's cockatoo in the Perth-Peel region because of a decrease in the available foraging habitat and potential carrying capacity. However, the additional measures in Mitigation 3 have the potential to reduce the severity of decline and enable the population to stabilise at a higher level following decline. The decline may further be reduced through increasing the vital rates by improved breeding success, in areas outside of the Perth-Peel region, and reducing adult mortality. The PVA also indicated that the potential for a sharp population declines because of stochastic bottlenecks in food resources could be averted if the pine clearing rates were reduced each year, spreading the rate of clearing over a longer timeframe and allowing replacement habitat to mature.

1 As extracted from Williams et al 2017.
2 DBCA 2017.

The State Government has committed [11 April 2018] to temporarily slow clearing of the remaining 6 300 ha of mature pines in the Gnangara-Pinjar plantation, from 2 200 ha to 500 ha per year and source pine from alternative locations, until July 2019 when clearing will recommence (Government of Western Australia, 2018a). This delayed clearing is intended to temporarily postpone the predicted population decline until 2023, and provides the opportunity to implement mitigation strategies to help stabilise the population.

Cumulative impacts

Currently, environmental impacts to Carnaby's cockatoo are assessed on a project-by-project basis at the local scale and there is limited knowledge of the cumulative impacts from multiple proposals in the Perth-Peel region.

Population decline and impacts resulting from historical clearing over the last 70 years, combined with ongoing threats of further habitat clearing, disease, mortality and climate change, pose a cumulative risk to Carnaby's cockatoo. The species' migration between the Swan Coastal Plain and breeding areas means the cumulative impacts occur over a temporal and spatial scale, increasing the difficulty for management.

The SAPPR considered a strategic and co-ordinated response to address cumulative impacts to Carnaby's cockatoo in the Perth-Peel region through planning strategies to avoid impacts to habitat, and a strategic approach to address classes of action (i.e. proposed development) that could impact the species. This included the impacts of pine harvesting and the clearing of native vegetation for urban and industrial development, basic raw materials extraction and infrastructure development in the region (DPC, 2015a; DPC, 2015c).

Cumulative impact of the actions included in the SAPPR anticipated there would be about 12% loss of native vegetation foraging habitat and up to 89% of pine foraging habitat on the Swan Coastal Plain (DPC, 2015a). Pine plantations accounted for about 59% of the total foraging habitat intersected by the classes of action. As mitigation, the SAPPR included delivery of a large-scale conservation package across the Perth-Peel and Avon-Wheatbelt region.

In April 2018, the State Government suspended work on SAPPR pending a critical review, which is anticipated to be released in early 2019.

Other black cockatoos of the south-west

Baudin's cockatoo
Calyptorhynchus baudinii

ENDANGERED (EBPC Act, 1999; BC Act 2016)

Baudin's cockatoo is similar in appearance and behaviour to Carnaby's cockatoo, but differs having a longer thinner bill adapted for feeding on Marri nuts, its primary food source. It is largely restricted to the wet forest regions of the lower south-west region of WA and migrates from south to north in the summer. The species has a more restricted distribution and smaller total population size than Carnaby's, estimated at 15 000 birds.

Baudin's cockatoo has declined greatly in the last 50 years (Johnstone and Kirkby, 2008b), with counts at traditional roosts declining by over 90% since 2009 (Johnstone and Kirkby, 2016). The severe population decline has been recognised by the recent upgrading of its conservation status from Vulnerable to Endangered (Threatened Species Scientific Committee, 2018). Baudin's cockatoo has been demonstrated to be less adaptable than Carnaby's and has a lower fecundity, meaning population growth is slower. It is threatened by loss of nesting habitat as a result of forestry and clearing, competition with bees and other birds for nest hollows, vehicle strikes and illegal shooting by orchardists.

Due to its preferred habitat of denser vegetation, which is located away from populated areas, it has a lower public profile and is more difficult to study than Carnaby's resulting in fewer studies being undertaken on Baudin's. As the species is not easily distinguishable from Carnaby's it is not recorded separately in the Great Cocky Count, as it is likely to be misreported. Baudin's shares a Recovery Plan with the Forest red-tailed black cockatoo, but this plan has not been updated or reviewed since 2008 (DEC, 2008).

Forest red-tailed black cockatoo
Calyptorhynchus banksii naso

VULNERABLE (EPBC Act, 1999; BC Act 2016)

The Forest red-tailed black cockatoo is mostly sedentary and has a traditional range within the Jarrah Forest and Warren bioregions of the south-west, where it breeds. In its natural range, the Forest red-tailed black cockatoo feeds predominately on Jarrah and Marri.

Since 2005, the species has rapidly changed its foraging behaviour to exploit the fruit of exotic Cape Lilac planted throughout the Perth metropolitan area, and the species has expanded its distribution onto the Swan Coastal Plain (Johnstone et al., 2017). Over the last six years, the Great Cocky Count has recorded a significant increase in the number of Forest red-tailed black cockatoos at sites in the Perth-Peel portion of the Swan Coastal Plain, increasing from 601 birds in 2014 to 1,934 birds in 2017 and 4,037 in 2018 (Peck et al., 2018). In addition, the species has been recorded at 23 roost sites where Carnaby's cockatoo has previously been recorded. Despite increases in the number of Forest red-tailed black cockatoos recorded in the Perth-Peel region, there has been a significant decline in breeding success at monitored sites in the northern Jarrah Forest, suggesting that the increase in numbers is not due to breeding success, but that impacts in its natural range are influencing the change in distribution of the species (Johnstone et al., 2017).

The species is threatened by loss of nesting habitat from forestry and clearing in the Jarrah Forest, and changes in food availability caused by a drying climate. As a result, the Forest red-tailed black cockatoo may be becoming more reliant on the Perth-Peel region for foraging and nesting habitat. In addition, like Carnaby's, its incursion into urban areas has increased the incidents of mortality from vehicle strikes. Further information is required to determine the drivers for its change in distribution, the influence of food resources on breeding success, including Cape Lilac, and the significance of the Perth-Peel region to the species and what impact this change will have on Carnaby's cockatoo.

Environmental impact assessment

Impacts to Carnaby's cockatoo are a consideration in environmental impact assessment, at State level under Part IV and Part V of the EP Act and Commonwealth level under the EPBC Act, where proposals and schemes intersect habitat, both native and pine.

The Recovery Plan (DPaW, 2013) and EPBC Act *Referral guidelines for three threatened black cockatoo species* (DSEWPAC, 2012) outline those activities that may have an impact on Carnaby's cockatoo or its habitat. Guidance for proponents on determining the significance of an impact on Carnaby's cockatoo is outlined in the EPBC Act *Referral guidelines for three threatened black cockatoo species* (DSEWPAC, 2012).

As part of the environmental impact assessment process, impacts should first be avoided or minimised, with rehabilitation efforts applied before offsets are considered. Where the residual impacts are determined to be significant, proponents are required to offset the impact (Government of Western Australia, 2011; Government of Western Australia, 2014).

Between 2000 and 2018, the EPA has reported on 41 proposals in the south-west where Carnaby's cockatoo habitat was assessed. Ministerial Statement conditions were set on 13 of those proposals, nine of which included offsets. In addition, the Department of Water and Environmental Regulation (DWER) has applied offset conditions on 107 applications (2009 – 2018) under Part V (EP Act) for the clearing of native vegetation as habitat for Carnaby's cockatoo (Table 4).

Table 4: Offsets under the EP Act for approved clearing of areas supporting Carnaby's cockatoo habitat from 2009 to 2018[1], by IBRA (Interim Biogeographic Regionalisation for Australia) region.

		Number of proposals by process (EP Act 1986)		Offset Area (ha)	
IBRA Region	**Approved Area Cleared (ha)**	**Part IV (EIA)**	**Part V**	**Rehabilitation**	**Land Acquisition**
Swan Coastal Plain	**1,800**	**6**	**56**	**370**	**10,626**
Jarrah Forest	2,090	3	30	85	3,779
Avon-Wheatbelt	**169**	**0**	**11**	**0**	**1,337**
Geraldton Sandplain	1,717	1	4	0	3,942
Esperance Plain	24	0	2	0	273
Warren	10	0	2	5	14
Mallee	72	0	1	0	243
Total (Consolidated)*	**5,806**	**9**	**107**	**420**	**19,148**

Land acquisition is the option most frequently adopted as an offset for Carnaby's cockatoo (Table 4). Between 2009 and July 2018, about 1 800 ha of native vegetation supporting Carnaby's cockatoo habitat was approved to be cleared on the Swan Coastal Plain under the EP Act. To offset this, 10 262 ha of land has been (or will be) acquired and protected, and about 370 ha of habitat will be created, rehabilitated or revegetated to provide new foraging habitat (see Table 4). Overall, about 98% of the total offset area has been for habitat acquisition, with over $5.5 million of offset funds held by the State Government to purchase the land (Government of Western Australia, 2018b).

1 Data sourced from Government of Western Australia (2018b) Offsets Register [Accessed 27 July 2018].

** Totals are consolidated over all proposals that include Carnaby's Cockatoo habitat. Proposals may include one or more regions and may also include habitat values for other black cockatoo species (e.g. Jarrah Forest).*

Proposals with the potential to impact Carnaby's cockatoo habitat are also referred under the Commonwealth EPBC Act. Between 2009 and 2017, 45 parcels of land covering 25 000 ha were purchased, for inclusion in conservation reserves managed by the DBCA, to protect Carnaby's cockatoo throughout its distribution, at a cost of $44.7 million, mainly through offsets under the EPBC Act approvals (Office of the Auditor General, 2017).

This emphasis on land acquisition as an offset is consistent with the actions of the Recovery Plan (DEC, 2013) that emphasises the protection and management of existing habitat over habitat rehabilitation. Although the purchase of land for conservation increases the amount of protected habitat, it does not improve or increase the area of habitat available for cockatoos in the long-term. This point was made in the National Environmental Law Review, which stated that "a net loss of biodiversity will occur if offsets seek only to protect existing, high quality assets, rather than restoring degraded ecosystems and functions" (Briggs, 2013).

The decreasing availability of suitable land for offsets within the Perth-Peel region, because of the existing highly fragmented landscape, means that purchasing land as an offset is unlikely to be a sustainable long-term strategy, for any species (EPA, 2015). Greater emphasis on rehabilitation and restoration of degraded areas within close proximity of the impacted area would increase or improve the habitat available for Carnaby's cockatoo and enhance local environmental values, acknowledging that these actions will take a long time to provide outcomes.

The EPBC Act *Environmental Offset Policy* (Department of Sustainability, Environment, Water, Population and Communities (DSWEPAC), 2012) includes a provision allowing allocation of up to 10% of 'other compensatory measures' as an indirect offset, which may include research. Research as an offset is rarely applied under the EP Act because it can only be applied for proposals assessed under Part IV. However, the majority of offsets for Carnaby's cockatoo are generated through Part V (Table 4), where research is not an option for an offset.

The application of management and mitigation actions for significant impacts to Carnaby's cockatoo should be consistent with the EPBC Act *Referral Guidelines for Black Cockatoos* (DSEWPAC, 2012). Any offset applied should be relevant to the impact and provide equal value, consistent with the *WA Environmental Offsets Guidelines* (Government of Western Australia, 2014), preferably in the region of the impact. For example, removal of tree hollows, food trees or roost sites should be offset with protection or replacement of habitat that provides the same ecological role e.g. breeding, foraging or roosting habitat.

Research, management and protection

Recovery Plan

The objective of the Carnaby's Cockatoo Recovery Plan is: *"To stop further decline in the distribution and abundance of Carnaby's Cockatoo by protecting the birds throughout their life stages and enhancing habitat critical for survival throughout the breeding range, ensuring that the reproductive capacity of the species remains stable or increases"* (DPaW, 2013).

The six Recovery Plan actions are:

1. Protect and manage important habitat.
2. Undertake regular monitoring.
3. Conduct research to inform management.
4. Manage other impacts.
5. Engage with broader community.
6. Undertake information and communication activities.

The actions are addressed by major research programs, which are coordinated by a recovery team overseen by DBCA and consisting of experts and regulators from government (DBCA, WA Museum, CSIRO), non-government (Birdlife Australia, WWF) and academia, with additional contributions through university research, wildlife rescue and conservation. Maintaining a collaborative and coordinated effort between government and non-government participants is important to achieve the aims of the Recovery Plan. The actions outlined in the Recovery Plan are estimated to cost $7.73 million over ten years.

The effectiveness of the Recovery Plan will be measured against a series of performance criteria, over ten years, ending 2023, and reviewed every five years. The performance criteria are summarised as: no decline in the species area of occupancy; the number of breeding pairs remains stable or increases (over three consecutive years); estimates of the number of adults and proportion of juveniles across the entirety of known roost sites remains stable or increases (over three consecutive years); and the extent of nesting, feeding and night roosting habitat are maintained throughout the species range.

The Recovery Plan is not yet approved under Part 6 of the *Biodiversity Conservation Act 2016* (BC Act, effective 1 January 2019). However, the EPA may have regard to the plan as guidance in considering proposals.

Management

Management can include short-term measures such as those for improving habitat values, and those that increase vital rates by improving breeding success and reducing mortality, and long-term measures that retain and increase habitat (Table 5).

Measures for improving habitat values for Carnaby's cockatoo include increased management and protection of existing habitat from threatening processes (fire, weeds, pests, and diseases), rehabilitation and restoration of degraded or cleared land, and enhancement of habitat, such as the use of artificial hollows.

Increasing the amount of habitat available for cockatoos is only achievable through rehabilitation and restoration of degraded habitat or cleared land (Saunders and Dawson, 2018).

The Recovery Plan acknowledges that "planting of species that support Carnaby's cockatoo is effective over the long-term and encouraged" (DPaW, 2013). While not yet demonstrated at scale, it is considered that rehabilitation for cockatoo foraging habitat is achievable (Brundrett et al., 2018). However, successful rehabilitation requires considerable effort in terms of time, resources and commitment.

For example, rehabilitation of Banksia woodland is estimated to cost between $5 000 to over $70 000 per hectare (Brundrett et al., 2016; Government of Western Australia, 2014; Government of Western Australia, 2009; PGV Environmental, 2014), depending on the methods used, scale, restoration targets and ongoing annual management.

Significant investment is required to achieve an increase in habitat in the long-term because of the time lag between planting and maturation of habitat species. Carnaby's cockatoo has been observed feeding on Banksia at rehabilitated mine sites in the Jarrah Forest within eight years (Lee et al., 2012). After fire, regenerated Banksia woodland may take over 15 years to provide substantial foraging habitat for cockatoos (Johnson et al., 2016; Valentine et al., 2014). Wheatbelt eucalypts may take from 100 to 200 years to produce hollows suitable for breeding (Rose, 1993), representing a significant time lag between loss and replacement of habitat.

Restoration of degraded habitat through active management may be a more achievable strategy to increase the amount or quality of habitat available within a shorter timeframe than rehabilitation of completely cleared habitat. For example, management of Banksia woodland fire regimes may increase the food resources in foraging habitat as the amount of seed produced is highest in long, unburnt woodland between 15 and 30 years since fire, depending on the species (Johnson et al., 2016; Valentine et al., 2014).

Habitat enhancement such as nest hollow repair, nest competitor control (e.g. feral bees), installation of artificial hollows, and improved access to water sources has the potential to increase habitat quality within a short timeframe and at less cost compared to revegetation, provided the existing habitat values in the area are maintained. Appropriate monitoring is required to ensure these measures are implemented effectively and are providing a benefit.

Management actions that increase vital rates, will help to stabilise or improve the population of Carnaby's cockatoo. The PVA found that reducing adult mortality and increasing breeding rates, by 1.19% per year, will result in an increase in the size of the Perth-Peel subpopulation, when implemented in conjunction with actions to increase food supply.

Breeding rates can be improved by increasing breeding participation and fledging success. As an interim measure, artificial hollows have an estimated life of 20 years or more (Groom, 2010). The provision of artificial hollows and repair of existing old hollows has been demonstrated to be successful in increasing breeding success, providing 60% to 97% of the hollows used by Carnaby's cockatoo at some sites in monitored breeding areas (Saunders and Dawson, 2018). However, to be effective artificial hollows need to be appropriately designed, managed to control nest competitors, and be installed in areas that are supported by adequate foraging resources nearby to enable the birds to breed (see DPaW, 2015a and DPaW, 2015b). Programs such as nest box deployment would benefit by being informed by a coordinated landscape approach identifying suitable locations for the installation of artificial nest boxes.

The Perth Zoo Veterinary Department receives about 300 injured black cockatoos annually of which 40% are returned to the wild (DBCA, 2018). For a species that is long-lived, this represents a significant number of adult Carnaby's cockatoo that would otherwise have been lost from the population as they may go on to breed for many more years. To reduce the number of cockatoos requiring treatment, programs are needed to prevent mortality and injury as a result of vehicle collision and illegal shooting, as well as research to reduce mortality caused by disease and toxicity.

Table 5: Summary of management options for impacts to Carnaby's cockatoo.

SHORT-TERM	**Habitat management**	• Feral animal and nest competitor control • Disease and pest control (e.g. Phytophthora and Marri Canker) • Fire management • Fencing • Weed control
	Habitat enhancement	• Natural nest hollow repair • Installation of artificial nest boxes (with long-term management) • Improve access to drinking water near roosts and breeding sites • Urban forest planning for cockatoos
	Increase vital rates	• Rehabilitation of injured cockatoos to wild • Disease and toxicity prevention • Reduce cockatoo road mortality (road signage, speed limits, appropriate verge planting) • Prevent illegal shooting and poaching
LONG-TERM	**Retain and protect habitat**	• Avoidance of important habitat and sites • Minimise native vegetation clearing • Land acquisition of existing important habitat and sites, and accession into parks and reserves
	Rehabilitation and restoration	• Improve succession of natural nest hollows • Increase amount of breeding habitat • Increase amount and quality of foraging habitat
	Population monitoring	• Population trends • Breeding rates and juvenile survival • Health of breeding populations
INFORMATION MANAGEMENT		• Data sharing (including compliance reporting and monitoring) • Habitat modelling • Climatic modelling • Population viability analysis and modelling

In the Perth-Peel region, Carnaby's cockatoo have adapted to the urban environment, utilising non-native species in plantations and residential trees for foraging and roosting. These areas are generally not protected but offer potentially significant resources beyond native habitat. The urban environment can also provide opportunities to supplement foraging habitat through plantings in residential gardens and enhancement of existing parks and reserves. Urban Forest Projects (implemented independently by local governments) designed to address human environmental and social issues associated with living in an urban environment, could also be designed with consideration of Carnaby's cockatoo habitat requirements. Guidelines are required to support these projects to ensure the outcomes for cockatoos align with the Recovery Plan. For example, avoidance of road verges when planting habitat trees, and the use of appropriate food trees that do not attract competitor species, such as corellas. Such guidelines would assist regulators responsible for urban planning.

Protection

Protection of existing habitat and minimising habitat loss will support efforts to increase the population and is important to achieve the success criteria of the Recovery Plan. The EPA considers that the best way to conserve key environmental values is in situ (EPA, 2015).

The complexity of protecting habitat is increased when much of the habitat is located on private land. While 64% of known roosts in the Perth-Peel region intersect with parks or reserves, the remaining roosts are on private land. The majority of confirmed breeding sites (73%) throughout the species range are located on private land (Table 6).

Table 6: Distribution of known Carnaby's cockatoo roosting and breeding sites in Perth-Peel region (PPR) (data courtesy of DBCA 7 September 2018)[2].

Tenure Categories	% White-tailed black cockatoo (WTBC) night roosts within PPR* (No. WTBC roosts)	% Confirmed breeding locations in PPR (No. sites)	% All confirmed breeding locations (No. sites)
Crown Reserves	19% (55)	16% (9)	21% (103)
DBCA Nature Reserves	3% (5)	7% (4)	2% (9)
National Park	7% (14)	0% (0)	2% (10)
DBCA State Forest	26% (51)	14% (8)	2% (9)
Bush Forever (sites overlap with other categories)	16% (31)	0%	0%
Total Parks & Reserves	**64% (125)**	**37% (21)**	**27% (131)**
Private Land	37% (72)	63% (35)	73% (357)
Total	**197**	**56**	**488**

[2] *An undetermined number of roosts are mixed roosts with Carnaby's, Baudin's and/or Red-tailed Black-Cockatoos.*

There are opportunities to increase the protection of Carnaby's cockatoo by giving the most important habitat areas a higher level of tenure security.

The Recovery Plan identifies the importance of mapping habitat to assist in conservation planning, recovery activities and strategic land use planning (DPaW, 2013). The Western Australian Natural Resources Management (NRM) Program funded a project that collated and mapped known and potential critical breeding, roosting and foraging habitat for Carnaby's cockatoo on the Swan Coastal Plain and Jarrah Forest bioregions (Glossop et al., 2011). Geographic information system (GIS) shapefiles and maps are available to regulators and proponents through the Data Toolkit (http://data.wa.gov.au) for use in decision-making.

The opportunity exists to prioritise the selection of sites for protection based on a robust understanding of the habitat requirements of Carnaby's cockatoo, including site use, role and importance within the landscape, such as habitat that maintains connectivity, or supports roosting or breeding locations; or has high value as foraging habitat; or the future value of habitat, such as the presence of mature trees likely to develop potential nest hollows.

Existing datasets from long-term monitoring and research programs offer a valuable resource that could be analysed to underpin the selection of habitat for protection. For example, over ten years of data has been collected through the Great Cocky Count, which could be used to identify important roost sites for priority protection in the Perth-Peel region.

The protection and management of habitat for Carnaby's cockatoo will also benefit other fauna species including other black cockatoo species, flora species, and vegetation communities such as the *Banksia Woodlands of the Swan Coastal Plain* threatened ecological community.

Monitoring

Monitoring programs need to be implemented so that mitigation actions are effective and can be adapted in response to any observed changes in the population.

The long-term datasets from programs, such as the Avon-Wheatbelt studies (DBCA, CSIRO), Cockatoo Care (WA Museum), and the Great Cocky Count, offer the best available baseline to measure changes and detect trends. For example, breeding data collected from over 40 years of research can be used as a historic baseline to monitor nesting success rates and chick health, providing an understanding of the health of the population and habitat condition over successive seasons, with the potential to predict declines (Saunders et al., 2014a; Saunders and Dawson, 2018).

Population monitoring needs to be undertaken across the species range and over consecutive seasons to determine if observed changes are unique to an area or indicative of a broader trend.

The Great Cocky Count can be used to estimate a minimum abundance of cockatoos utilising the Perth-Peel region each year. However, the current analysis and interpretation of results (e.g. Peck et al., 2018) does not consider ecological factors that vary from year to year that may influence the numbers and distribution of Carnaby's cockatoos in the Perth-Peel region. For example, annual changes in the timing and duration of the breeding season, rainfall and food availability may affect the timing and number of Carnaby's cockatoos arriving in the Perth-Peel region. Counts conducted over multiple days or seasonally, and taking account of the variable ecological factors, may allow trends to be measured more accurately and better inform management and mitigation.

Research

Targeted research is critical to reduce uncertainty and inform evidence-based policy, regulation, management and strategic planning.

The suspension of clearing of the Gnangara-Pinjar plantation, to June 2019, provides an opportunity to initiate research to resolve uncertainty regarding the impact of pine removal on Carnaby's cockatoo and test the projections of the PVA, specifically:

1. Determine the how Carnaby's cockatoos are responding to pine clearing, including their distribution, movements and abundance, feeding and roosting requirements.
2. Quantify how Carnaby's cockatoo use pine wildings and native revegetation in the post-pine areas.
3. Determine how reliant Carnaby's cockatoo is on the Gnangara-Pinjar plantations and the availability of alternative foraging resources within and outside the Perth-Peel region (e.g. Midwest pine plantations), including pine wildings.
4. Determine the breeding origin of flocks that utilise the Gnangara-Pinjar plantations.

Outcomes of the above research can be used to inform decision-making regarding the pine harvesting rates, post-pine landscape use and habitat replacement, and future clearing of Carnaby's cockatoo habitat, particularly in the northern Swan Coastal Plain.

Research questions to address key knowledge gaps and inform EIA are identified as:

5. Model habitat characteristics that influence roost and foraging site choice.
6. Identify and prioritize areas for rehabilitation or protection.
7. Determine appropriate buffer sizes around known breeding sites or high use roosts.
8. Make publicly available information for proponents, decision makers and planners, of areas suitable for land use planning, land acquisition and/or rehabilitation offsets.
9. Determine how Carnaby's cockatoo use offset areas.

Further research questions identified in this review to be addressed in the longer-term include:

10. Develop improved techniques at scale for rehabilitation of post-disturbance landscape.
11. Determine how impacts, for example on population size and distribution, in one part of the Carnaby's cockatoo range (e.g. Avon-Wheatbelt) influences other parts of their range (Swan Coastal Plain/ Jarrah Forrest).
12. Investigate how non-breeding foraging habitat influences breeding success and juvenile survival.
13. Model and predict impacts of climate change on Carnaby's cockatoo habitat.

Consolidating existing datasets and research (published and unpublished) may provide some of the information required to address research questions and knowledge gaps. The outcomes of previous research should be consolidated and data shared to improve decision-making, protection and management.

The five-year review of the Recovery Plan provides the opportunity to adapt the Plan actions in response to changing priorities or questions, such as determining the effectiveness of mitigation measures (e.g. nest box programs, offsets, rehabilitation).

Conclusion

There is considerable knowledge available on the foraging and breeding ecology of Carnaby's cockatoo, which provides a sound understanding of the biological and habitat requirements. However, significant knowledge gaps remain in relation to the ecology of the species and likely impacts of the threatening processes, including carrying capacity of remaining foraging habitat, clearing of Gnangara-Pinjar pine plantation, and the effectiveness of offsets.

Further research is required to better understand cumulative impacts and the interdependency of ecological requirements and impacts between the Swan Coastal Plain and the Avon-Wheatbelt, Geraldton Sandplains and Jarrah Forest breeding regions. For example, understanding how clearing pine foraging habitat in the Perth-Peel region affects breeding success in other regions. Such research and monitoring is critical to determine the effectiveness of offsets (e.g. reserves and rehabilitated areas) and mitigation (e.g. buffers), and to inform decision-making and achieve conservation objectives.

Outcomes of existing research can inform management programs to improve breeding and reduce mortality. Regular review of management programs and the Recovery Plan based on outcomes from new research will enable priorities and actions to be adapted.

The EPA will take a holistic approach when considering proposals that may impact on Carnaby's cockatoo. The information outlined in this report provides context for EIA and should be considered by proponents when preparing schemes and proposals.

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Appendix 1: Literature Review

Research outcome or observation	References
Taxonomy	
Carnaby's cockatoo is recognised as a separate species from Baudin's cockatoo based on the differences in bill morphology and call, and foraging behaviour and distributional differences. However, recent analysis, based on microsatellite data, suggests that there is little genetic difference between the two species.	Johnstone et al. 2014; Saunders 1974; Saunders 1979; White et al. 2011; White et al. 2014
Genetic analysis has determined that large-scale clearing and habitat loss has resulted in recent geographical structuring (genetic drift) into two genetic populations of Carnaby's cockatoo, east and west of the extensively cleared habitat in the southern Wheatbelt.	White et al. 2014
Population	
The total population of Carnaby's cockatoo is currently estimated at 40 000 birds.	DPaW 2013; Garnett et al. 2011
The minimum number of Carnaby's cockatoo counted in the Perth-Peel region between 2010 and 2018 is 3 791 – 12 465 birds.	Peck et al. 2018
Total counts of cockatoos observed at roosts in the Perth-Peel region change from year to year.	Peck et al. 2018; Williams et al. 2016
The Atlas of Australian Birds reported a decline of 46%, between 1977 and 2002, in the northern part of the range.	DPaW 2013; Garnett and Crowley 2000; Garnett et al. 2011
Large-scale clearing in the Wheatbelt in the 1900s has been identified as being responsible for contraction of over one third its former breeding range and reduced breeding success.	Garnett et al. 2011; Johnstone and Kirkby 2010; Saunders et al. 1985; Saunders 1990; Saunders et al. 2014a
The northern population has shifted its distribution westwards and southwards, including breeding on the Swan Coastal Plain, in response to loss of breeding and feeding habitat in the Wheatbelt.	Johnstone and Kirkby 2008; Johnstone and Kirkby 2010; Stock et al. 2013; Storr and Johnstone 1998
Since 2010 a decline in the number of Carnaby's cockatoos roosting at individual sites in the Perth-Peel region has been observed.	Peck et al. 2016; Williams et al. 2016
Foraging	
Carnaby's cockatoo exploit agricultural crops such as canola as a novel food source during nesting periods, in Wheatbelt breeding areas.	Saunders et al. 2014b
Carnaby's cockatoo feed on native (Proteacea mostly *Banskia* spp.) and non-native food sources (mostly pine) during non-breeding periods on the Swan Coastal Plain. Marri and jarrah also form part of the diet in the eastern Swan Coastal Plain and Jarrah Forest. They use a matrix of foraging habitats daily, sometimes feeding on both Banskia and pine in the same foraging area.	Finn et al. 2009; Groom 2011; Groom 2015; Groom et al. 2014; Johnston 2013; Johnston et al. 2016; Shah 2006; Valentine and Stock 2013
Large flocks (~5 000) of Carnaby's cockatoo have been observed feeding in pine plantations since 1948. Large flocks (~3 000 – 6 000 birds) roost in the pine plantations associated with the Gnangara and Wanneroo areas.	Finn et al. 2009; Johnstone and Kirkby 2008a; Peck et al. 2017; Perry 1948; Stock et al. 2013; Valentine and Stock 2013
Carnaby's cockatoo uses a variety of novel watering sources in the metropolitan region including bird baths, roadside puddles, market gardens, and stock troughs, as well as natural features such as lakes and streams.	Groom et al. 2014

Research outcome or observation	References
Roosting	
Flocks show site fidelity to a particular area, but will move between roost trees from day-to-day apparently in response to environmental factors (i.e. distance to food and water, influence of wind and predators).	Berry 2008; Berry and Owen 2009; Berry and Owen 2018; Finn et al. 2009; Groom 2015; Shah 2006
Flocks roost in tall, large trees in the urban landscape, over 8m in height, often relictual native vegetation (e.g. Tuart) or non-native vegetation (e.g. River red gum, Spotted gum, Lemon-scented gum and pine) in residential parks and gardens, including street trees.	Glossop et al. 2011; Groom et al. 2014; Le Roux 2017
Roosts are preferred in close proximity to water (100m – 1km) and within 6km of potential feeding habitat.	Glossop et al. 2011; Le Roux 2017
Carnaby's cockatoo travel approximately 3-13km per day from their roost when foraging on the Swan Coastal Plain.	Cockerill et al. 2013; Groom 2015; Shah 2006
Forest red-tailed black cockatoos have been recorded using roosts previously occupied by Carnaby's cockatoos at sites on the Swan Coastal Plain.	Peck et al. 2016
Breeding	
Carnaby's cockatoo matures at four years old, with an estimated generation time of 15 years. Female Carnaby's cockatoos have been recorded attempting breeding at three years old.	Saunders 1982; Saunders et al. 2016
Egg laying is strongly correlated with rainfall, with earlier breeding in seasons of preceding heavier rainfall.	Saunders et al. 2013, 2014b
Clutches of two eggs are laid, but usually only one chick is reared to fledging age. Two chicks are possible to be reared to fledging when there is adequate food availability.	Saunders 1982; Saunders et al 2014a
Females show nest site fidelity to the area from which they fledged. Females return to the same breeding area each year and will reuse the same hollows, provided the hollow is vacant, otherwise moving to a new hollow nearby.	Saunders 1982; Saunders et al. 2016; Saunders et al. 2018
In the Wheatbelt, Carnaby's nest in hollows with a vertical aspect, 2.5-12m above the ground, an entrance of approximately 27cm (23-30cm), depth of 1.2m (1-2.5m) and a floor diameter of 40cm (for Salmon gum; Wandoo hollows lower and shallower).	Saunders 1979; Saunders et al. 2014c; Storr and Johnstone 1998
Carnaby's cockatoo will successfully use artificial nest hollows and repaired natural hollows.	DEC 2010; Saunders et al. 2014b
Carnaby's cockatoos has been recorded breeding in the Jarrah Forest and using hollows previously used by Forest red-tailed black cockatoos.	Johnstone et al. 2013