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RESEARCH ARTICLE

Utilization of modified and artificial nests by endemic and introduced parrots on Norfolk Island

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Animals that breed in cavities formed through decay or mechanical damage often face limitations to reproduction due to a shortage of nest sites. Artificial nests are commonly deployed to increase the short-term availability of breeding sites for these species. Often this is an effective approach; however, artificial nests are costly and may be ignored by the target species or inadvertently benefit nontarget species. Here we consider the use of modified natural hollows and artificial nest sites to support endangered Norfolk Island green parrots *Cyanoramphus cookii*. We recorded the characteristics of all modified and artificial nests in the Norfolk Island National Park and used 8 years of nesting data to study nest selection by green parrots and introduced crimson rosellas *Platycercus elegans*. Artificial nests (those lacking a natural base) were never used by green parrots. Nests with thicker walls were more likely to be used by green parrots, but there was no nest site characteristic that predicted frequency of use. Crimson rosella nest use was not predicted by any of the nest characteristics measured. A better understanding of the reasons behind green parrots' avoidance of artificial nests and preference for thicker nest walls is required to inform the future design and management of nest sites. Our study shows that evaluation of how artificial sites are used by the target species is important to maximize the efficacy of conservation efforts.

Key words: artificial nests, competition, nest preferences, parrots, wildlife management, wildlife restoration

Implications for Practice

- Restoring ecosystems to support target species may inadvertently support invasive competitors.
- The efficacy of artificial nest sites should be regularly assessed to ensure benefit to the target species is maximized and support for nontarget species is minimized.
- Simple nest designs with documented success in similar species should be trialed to ensure the most resource-efficient nest design is being used.

Introduction

Many animals, including birds, mammals, reptiles, and amphibians, rely on cavities formed by decay or mechanical damage for shelter and nesting (Gibbons & Lindenmayer 2002; Remm & Lõhmus 2011; Cowan et al. 2021). Many of these cavities, such as tree hollows and rock crevices, take a long time to form and often limit breeding opportunities even in healthy populations. As a result, secondary cavity nesters are particularly vulnerable to the loss of these sites due to habitat destruction (Cornelius et al. 2008; Remm & Lõhmus 2011). Long-term ecological restoration is often unable to fill a short-term deficiency of cavity-based nest sites (Le Roux et al. 2016; Cowan et al. 2021). Therefore, artificial nesting sites are commonly used by wildlife managers to support animals that require hollows, dens, and burrows for breeding (Goldingay & Stevens 2009; Cowan et al. 2021; Stojanovic et al. 2021*a*). For some species, such as the Kangaroo Island glossy black-cockatoo *Calyptorhynchus lathami halmaturinu* (Berris et al. 2018), the provision of artificial nest sites has proved fundamental to population recovery. However, in many cases, considerable challenges face wildlife managers including the cost of deploying and maintaining artificial nests and the difficulty of designing nest installations that are used by the target species alone.

The order *Psittaciformes* has the highest proportion of threatened species among similar sized taxa (Olah et al. 2016) and provides a good case study to explore the challenges of artificial nest provision. More than 70% of parrots are cavity nesters (Olah et al. 2016), and artificial nests are commonly used to support threatened and endangered parrot populations (White et al. 2006; Tatayah et al. 2007; Stojanovic et al. 2021*a*). While

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artificial nest deployments for parrots are often successful (White et al. 2006; Tatayah et al. 2007; Saunders et al. 2020), this is not always the case. For example, artificial nests are sometimes occupied by nontarget species (Stojanovic et al. 2020, 2021*a*) or are not occupied by the target species at all (Lindenmayer et al. 2017; Wimberger et al. 2018). Given the costs associated with the construction and deployment of these nests, designing them with the nesting requirements of the target species in mind is crucial to optimize the use of conservation resources (Stojanovic et al. 2017). However, undertaking detailed studies of the preferences of wild parrots for natural nesting sites is extremely challenging because the threatened species that are typically the focus of such efforts often nest in remote terrain or at low densities, which hinders data collection.

In this study, we explore the efficacy of the modification of naturally formed hollows and construction of artificial nests in the absence of detailed knowledge of the preferred characteristics of natural nests of an endangered parrot. The Norfolk Island green parrot *Cyanoramphus cookii* (hereafter "green parrot") has experienced a significant population decline in recent decades. Since

Figure 1. Examples of nest sites in Norfolk Island National Park with different nest foundations. Clockwise from top left; artificial, tree stump, Ti *Cordyline obtecta* and Ironwood *Nestegis apelata*.

the late 1980s, staff at Norfolk Island National Park have used both modified natural nest sites and wholly artificial nest structures to support green parrot breeding. Artificial nests have been used to compensate for the scarcity of natural breeding hollows due to agricultural land clearance, the felling of mature forest trees, and the invasion of woody weeds (Hill 2002). Modifications made to natural sites aim to prevent predation by introduced rats (*Rattus rattus* and *R. exulans*) and feral cats *Felis catus* (Hill 2002; Ortiz-Catedral et al. 2018). The extent to which these nests fulfill these objectives is yet to be confirmed (Hill 2002).

While modified and artificial nest sites are credited for saving the species from near extinction (Ortiz-Catedral et al. 2018), building and maintaining them is resource intensive and many have not been used by green parrots or are routinely occupied by introduced competitors. We recorded the characteristics and measurements of all modified and artificial nests on Norfolk Island and used 8 years of nest monitoring data to evaluate the nest preferences of green parrots and their primary introduced competitor, the crimson rosella *Platycercus elegans*. We aimed to identify the physical characteristics that predict whether green parrots and crimson rosellas occupied a nest and the frequency with which they did so over the study period. We discuss our results in context of the aim of conservation management to support recruitment of threatened species while avoiding inadvertently benefitting their competitors.

Methods

Study Area and Species

Norfolk Island is an isolated sub-tropical island located in the southern Pacific Ocean between Australia, New Zealand, and New Caledonia. The Mount Pitt Section of the Norfolk Island National Park (hereafter, "the National Park") comprises 465 ha in the northern half of the island (Hill 2002). It mostly comprises remnant subtropical rainforest; however, some areas are dominated by invasive cherry guava *Psidium cattleyanum* and African olive *Olea europaea* subsp. *cuspidata* (Director of National Parks 2010). The terrain in the National Park mostly consists of ridges and steep gullies, reaching a maximum elevation of 318 m (Director of National Parks 2010).

The Norfolk Island green parrot is one of the largest species of the *Cyanoramphus* genus, at 100 g (Higgins 1999). Green parrots nest year-round, predominantly within 2 m of the ground in decay-formed cavities in the trunks and root systems of trees (Hill 2002). The crimson rosella is native to eastern Australia and slightly larger than the green parrot at 125–140 g (Higgins 1999; Forshaw 2010). The species was introduced to Norfolk Island as a pet bird in the 1800s (Christian 2005) and has since established a wild population on the island (Dutson 2013; Skirrow 2018).

Nest Sites

National Park staff actively manage 71 nest sites within the National Park. Of these, 60 are natural cavities in living and dead trees that have been reinforced with sheet metal and/or cement for structural support and to prevent easy access by nest predators. Most were selected due to observed green parrot nesting behavior at the cavity, and others were chosen because they were thought to be suitable nesting sites (J. Christian 2021, Norfolk Island National Park, personal communication). The 11 artificial nests have been constructed using a variety of materials, including polyvinyl chloride (PVC) piping, wooden planks, wire and cement. [Correction added on 28 January 2022 after first online publication: In subsection "Nest Sites", the last sentence of the first paragraph was corrected.]

Modified and artificial nests are spread throughout the park on the slopes of Mount Pitt, often in clusters of two or three—individual nests within clusters are sometimes less than 15 m

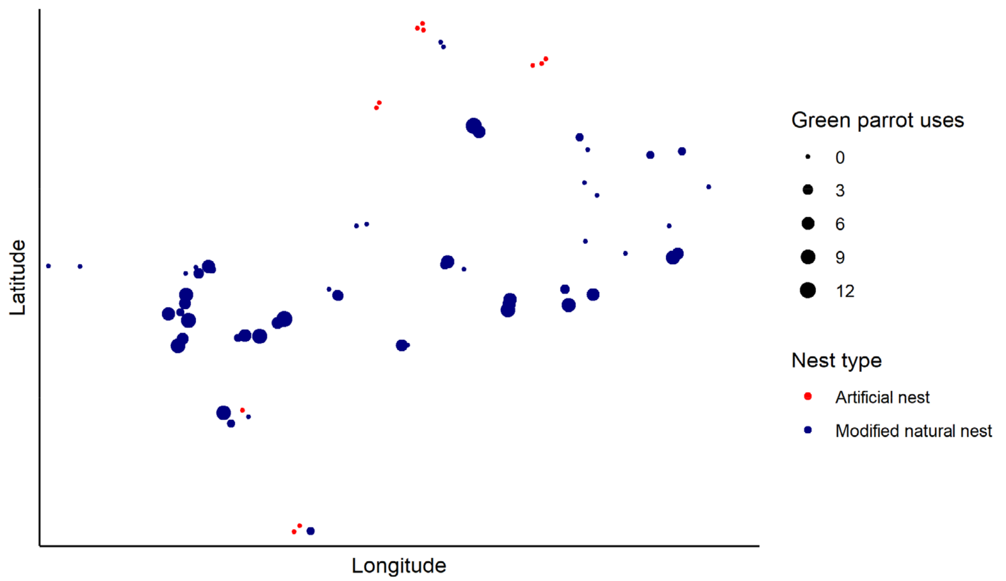

Figure 2. Spatial distribution of nest sites by nest type and number of green parrot uses. Latitude and longitude are not disclosed due to the sensitive nature of nest site locations.

Table 1. Covariates recorded at each nest site. NA indicates that a mean or standard deviation is not applicable due to the type of data collected.

Covariate	*Description*	*Justification*	*Mean/Factor Levels*	*Std. Dev.*
Location	Latitude and longitude	To check for spatial autocorrelation	NA	NA
Years	Number of years (up to 2020) which the nest was available for occupancy	To control for any bias due to the number of years on record	6.9 years	0.5 years
Nest type	The structural base used for the nest Four-level factor: artificial, live tree, Ti *Cordyline obtecta*, tree stump	Little is understood about the role of nest foundations on nest selection in parrots. *Cordyline obtecta* was selected as its own category due to its distinct structure when compared to other trees used for green parrot nesting	Artificial (11), live tree (25), Cordyline (9), stump (26)	NA
Hollow aspect	Four-level factor: north, south, east, west	Ardia et al. (2006), White et al. (2006)	North (18), east (17), south (16), west (20)	NA
Vegetation community	The predominant vegetation community within 10 m of the site. Four-level factor; palm (*Rhopalostylis baueri*), pine (*Araucaria heterophylla*), hardwood forest, cherry guava (*Psidium cattleyanum*)	Mänd et al. (2005), Renton et al. (2015)	Palm (23), pine (13), hardwood (21), guava (14)	NA
Diameter at breast height	Diameter at breast height of nesting tree	Renton et al. (2015), Stojanovic et al. (2021*b*)	37.2 cm	14.8 cm
Canopy cover	Canopy cover calculated from photos taken at the base of each nest site. Canopy pixels were counted using *Adobe Photoshop*, an adaptation of the method described by Stewart et al. (2007)	White et al. (2006)	87.4%	4.1%
Entrance height	Distance of the bottom lip of the hollow entrance from the ground below	Saunders et al. (1982), Renton et al. (2015)	130.5 cm	41.9 cm
Chamber depth	Distance from the bottom lip of the entrance to the nest floor	Saunders et al. (1982), Renton et al. (2015)	94.2 cm	28.1 cm
Floor diameter	Maximum diameter of the chamber floor	Renton et al. (2015)	33.2 cm	11.8 cm
Entrance min.	Minimum diameter of the entrance hole	Renton et al. (2015), Valera et al. (2019)	6.5 cm	1.2 cm
Entrance max.	Maximum diameter of the hollow entrance	Renton et al. (2015), Valera et al. (2019)	17.5 cm	5.8 cm
Wall width	Approximate thickness of the hollow walls. Calculated as the mean of the wall width at the entrance and trapdoor	May affect nest microclimate (McComb & Noble 1981; Wiebe 2001)	5.2 cm	2.4 cm

apart. The spatial distribution of nest sites is shown in Figure 2. All nests have a single entrance hole and a metal trapdoor (for direct access to the nest), but they vary widely in overall dimensions and appearance (Fig. 1).

Data Collection

In April and May 2021, we recorded site-level characteristics and the structural characteristics of nests themselves (Table 1). We measured variables known to influence the attractiveness of nesting sites for parrots, and others that we suspected could influence the likelihood that a nest might be utilized in our study system. We used 8 years of National Park monitoring data (2013–2020) to determine whether each nest had been occupied by either green parrots or crimson rosellas and, if so, the total number of nesting records over the study period. Each nest was checked monthly by staff, and more regularly when occupied. As green parrots nest year-round, a nest may be used more than once in a calendar year. Monthly checks were used to determine which observations represented a new nesting event rather than a continued nest. We considered a nest "used" if a bird had been observed sitting inside it. We did not model nest success as the data do not provide sufficient detail for daily survival rates to be calculated and not all factors of interest could be modeled. As 11% of nests were established during the monitoring period, we also recorded the number of years in which they were available for occupancy during the study period.

Statistical Analysis

We performed all statistical analysis in R v4.0.3 (R Core Team 2020). We fitted generalized linear models (glms) to four different response variables: green parrot occupancy, number of times nest was used by green parrots, crimson rosella occupancy, and number of times nest was used by crimson rosellas. We used a binomial error structure for the binary (yes/no) occupancy response and a negative binomial error structure for the number of nest uses, from the package *MASS* v7.3-54 (Ripley et al. 2013). The distribution test from the package *performance* v0.7.2 (Lüdecke et al. 2021) indicated the negative binomial error structure was better suited to number of nest uses than a Poisson error structure. We created saturated models for each response variable, with all covariates in Table 1 except location. Due to multicollinearity, we removed dominant vegetation from the model. We modeled this covariate as a univariate predictor to ensure a significant relationship was not overlooked. Nest type was removed from both green parrot models because no nesting attempts were recorded in artificial nests (and therefore effects were inestimable for this variable). Crimson rosella occupancy and number of uses were included as predictor variables in the models for green parrot occupancy and number of uses, respectively, to explore any interaction between the two species at nests. We ensured there was minimal residual spatial autocorrelation in the saturated models by plotting spline correlograms with the package *ncf* v1.2.9 (Bjornstad 2020). We dredged each saturated model using the package *MuMin* v1.43.17 (Barton 2009), with a limit of three terms per model, and ranked them by Akaike information criteria. We then performed model averaging on the output, which involves taking a weighted average of all models, to determine the full model-averaged coefficients of each covariate without model selection bias (Symonds & Moussalli 2011). We plotted our results using the package *ggplot2* v3.3.3 (Wickham 2016). R scripts are presented in Supplement S1.

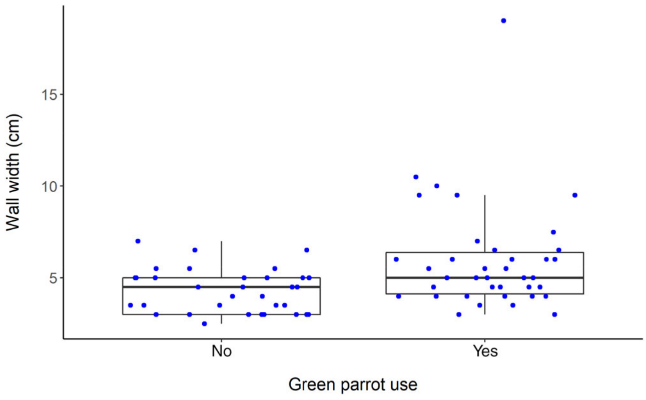

Figure 3. The average wall width of nest sites by green parrot use status. Horizontal lines represent the mean and interquartile range, while vertical lines represent the range of values, excluding outliers. All datapoints are overlayed in blue.

Results

National Park staff recorded 196 green parrot and 85 crimson rosella nesting attempts over the 8-year study period. Green parrots used 38 of 71 nests (53.5%), compared to 30 (42.3%) for crimson rosellas. Sixteen (22.5%) nests were vacant throughout the study and 13 (18.3%) were used by both species. On average, nests that were occupied were used 5.2 times (range: 1–12) by green parrots and 2.8 times (range: 1–7) by crimson rosellas. The spatial arrangement of all nest sites, by green parrot use statistics and nest type, is shown in Figure 2.

None of the 11 artificial nest sites were used by green parrots during the study period. When modeled, the best predictor of green parrot occupancy was average wall width (Fig. 3), with thicker walls positively correlated with occupancy ($\beta = 0.56$, $SE = 0.26$, $p = 0.03$, Table S1). The number of green parrot uses was independent of the variables we tested (Table S2).

For crimson rosellas, we found that both occupancy (Table S3) and total number of nest uses (Table S4) were independent of the variables we tested.

Discussion

Green parrots did not use any artificial nests over the 8-year study period. The reason for this is unclear, particularly considering crimson rosellas were observed occupying these nests. All nests included in our study contain a mixture of natural and artificial components, and therefore, the presence of natural or artificial materials at a site does not appear to impact its likelihood of use by green parrots. Similarly, while there can be significant differences in temperature and humidity when comparing natural cavities and artificial nests (McComb & Noble 1981; Larson et al. 2018; Saunders et al. 2020), the mix of materials used in all nests (e.g. concrete and metal sheeting) makes this an unlikely cause of avoidance. There was also no spatial pattern of nest occupancy by green parrots, indicating that occupancy of a given nest is independent of proximity to other nests. It is possible that artificial nests simply look too different from naturally formed nests to be attractive to green parrots. While this has not been the case for many other parrot species (e.g. Olah et al. 2014), parrots can be highly selective when choosing nests and preferences may vary between species and habitats (Renton et al. 2015). Regardless of the underlying cause behind the avoidance of artificial nests, these findings have important implications for conservation management, showing an unexpected response to artificial nest installations and highlighting the need to develop a deep understanding of the target species' natural breeding preferences to increase the chances of success.

When nest type was not included as a covariate in the model, the width of the nest wall was positively correlated with nest use by green parrots. Why this nest trait best predicted green parrot occupancy is not clear. It is possible that parrots select nests based on microclimate features because thicker cavity walls are associated with more stable internal temperatures (McComb & Noble 1981; Wiebe 2001), and nest microclimate can impact nest choice by other birds (Ardia et al. 2006). However, whether this is the case in the present study cannot be determined. Other nest characteristics—such as hollow aspect and nest materials—could also substantially alter the microclimate within the nest (Wiebe 2001; Ardia et al. 2006; Larson et al. 2018). Norfolk Island also experiences a mild temperate maritime climate with low daily and seasonal temperature/humidity fluctuation, which raises the question of whether parrots would necessarily require well-insulated nests? Further study of the thermal properties of nest sites on Norfolk Island is required to test whether the relationship between wall width and nest selection we observed is an outcome of real preferences by green parrots, an artifact of an unmeasured variable, or a type-I statistical error.

We cannot rule out the role of unmeasured characteristics in influencing green parrot nest choice. Our analysis only represents a snapshot of the last 8 years and therefore cannot account for any use of nests prior to this period. In addition, our sample only includes nests that are managed by National Park staff, many of which are designed in a similar way using similar foundations. For example, all nest entrances are more than 70 cm from the ground, despite natural nest sites often being found at ground level (Hill 2002). This design feature, implemented to discourage predation by rats and cats, may not necessarily represent the preferred characteristics for green parrot nesting. Rather, the preferences we observed may reflect a compromise, where parrots settle for a less than ideal nest because a preferred site is not available. Therefore, their true preferences cannot be identified in our sample because their choice was limited.

Crimson rosellas occupied nests independently of the characteristics we measured in this study. On mainland Australia, crimson rosellas are known to readily use nest boxes at a height of 4–6 m (Pell & Tidemann 1997; Krebs 1998; Larson et al. 2015); however, the average nest entrance height in our study was much lower, at just 130 cm. Therefore, we were surprised that crimson rosellas did not exhibit preferences for nests with the highest entrances. This may be explained by the lack of hollow availability in the National Park, also potentially forcing crimson rosellas to use whatever nests are available. In the context of our study aims, perhaps the most significant finding regarding crimson rosella nest use is the lack of any preference for nest type. Artificial nests supported six rosella breeding attempts but no green parrot nests over the study period, suggesting that these nests are predominantly supporting a nontarget pest species. Non-target use of artificial nests is common (Pell & Tidemann 1997; Stojanovic et al. 2020, 2021*a*), and addressing this problem is an important challenge for restoration projects. This finding highlights the need to be vigilant about restoration efforts inadvertently creating new management problems by supporting the wrong species.

To add to the understanding of natural green parrot nest preferences and increase the available sample of nests, efforts should be made to discover and observe a large sample of unmodified green parrot nest sites. These data will also help to determine whether green parrots are selecting natural sites over available modified and artificial nest sites. This information is important to inform future maintenance and habitat restoration efforts. Given the resource and time intensity of maintaining and monitoring the current nest sites, the efficacy of alternative designs, particularly those successfully used for other parrot species, should also be explored (Goldingay & Stevens 2009). While some nest-box trials have taken place on Norfolk Island prior to 2001 (Hill 2002), experimentation with alternative nest designs, such as nest boxes made from local materials and hollowed stumps as described by Rueegger (2017), may prove useful for evaluating alternatives that green parrots might utilize.

While ecological restoration is fundamental to supporting biodiversity in disturbed ecosystems (Benayas et al. 2009), wildlife managers must be conscious of the potential to support nontarget pest species with these efforts. Targeted ecological restoration efforts should be tailored to the target species and regularly assessed to ensure intended objectives are met (Cowan et al. 2021). Our study reinforces the practical benefits of evaluating the efficacy of restoration efforts against their aims and shows how surprising patterns of behavior may be identified and used to plan and refine restoration projects.

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performed under Australian National University Animal Ethics Committee approval (A2020_13). Data are available upon request from the author. Data are sensitive because they involve Norfolk Island green parrot nesting locations. R Scripts are provided in Supplement S1.

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Supporting Information

The following information may be found in the online version of this article:

Supplement S1. R Script.

Table S1. Full model-averaged coefficients for green parrot occupancy.
Table S2. Full model-averaged coefficients for green parrot uses.
Table S3. Full model-averaged coefficients for crimson rosella occupancy.
Table S4. Full model-averaged coefficients for crimson rosella uses.

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