Breeding status of invasive Rose-ringed Parakeets *Psittacula krameri* in Durban, South Africa

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Abstract

The Rose-ringed Parakeet *Psittacula krameri* has established feral populations in South African suburban areas. However, the information on the breeding biology of parakeets remains poorly documented in the country. We assessed parakeets' breeding status and behaviour by locating their roost and breeding sites in Durban, eThekwini Metropole, KwaZulu-Natal province. We also placed artificial nest boxes to determine the occupancy of parakeets or other bird species. We identified 39 parakeet breeding sites with a total of 72 nests. There were no significant differences between the number of active parakeet nests in the first (n = 53 nests) and second breeding seasons (n = 59). Rose-ringed Parakeets used four tree species for nesting, with the white milkwood *Sideroxylon inerme* used the most (71%). Only East African lowland honey bees *Apis mellifera scutellata* and Common Mynas *Acridotheres tristis* used the artificial nest boxes. Parakeet fledgings recorded ranged between one and three per nest, and their numbers differed significantly between seasons. The number of fledglings was not influenced by any of the tree variables measured and distance or location. The distance between the parakeets' roosting and breeding sites ranged from 1.43 to 5.0 km. Our study provides essential data for an overall management strategy, including eradication programs for this species in South Africa.

Keywords: cavity nesters, fledging, invasive species, nest-site competition, urban habitations

Introduction

The Rose-ringed Parakeet *Psittacula krameri* (Scopoli 1769) is one of the world's worst invasive bird species and has successfully established in many countries, including South Africa (Hart and Downs 2014; Symes 2014; Ivanova and Symes 2019; Shivambu et al. 2021a). It was first introduced in South Africa in the late 1900s through pet trade (Hart and Downs 2014; Symes 2014; Ivanova and Symes 2019). The species was first reported breeding in the 1970s and has since established feral populations in urban areas of Gauteng, KwaZulu-Natal and Western Cape provinces (Perrin and Cowgill 2005; Hart and Downs 2014; Symes 2014). Its population has increased at an alarming rate, particularly in urban landscapes (Dean 2000; Roche and Bedford-Shaw 2008; Hart and Downs 2014; Ivanova and Symes 2019). An estimated population of *ca.* 2 500 birds in Victoria Park, Gauteng alone, was reported in 2016 (Whittington-Jones 2017). The rapid increase in the species' population within South Africa is of concern due to the documented negative conservation and economic impacts (Shivambu et al. 2020, 2021a). Such impacts include their depredation of crops in both their native and invaded ranges (Ahmad et al. 2011;

Ahmad et al. 2012; Mentil et al. 2018; Shiels et al. 2018; Klug et al. 2019); and outcompeting native species for nests, e.g. Nuthatches *Sitta europaea*, threatened Greater Noctule bats *Nyctalus lasiopterus* and Blue Tits *Cyanistes caeruleus* (Strubbe and Matthysen 2009a; Covas et al. 2017; Hernández-Brito et al. 2018). As a result, these native species have been displaced from their nest cavities, leading to their decline in numbers (Covas et al. 2017; Hernández-Brito et al. 2018).

Understanding species breeding biology is useful in evaluating potential reproductive success and determining species invasiveness (Hyman and Pruett-Jones 1995; Burger and Gochfield 2000). Avian breeding biology includes nest site selection, which involves birds identifying habitats with the characteristics required to breed (Jones and Robertson 2001). However, it is not limited to nest selection, but to other proximate and ultimate factors, e.g. food availability that coincide with favourable environmental conditions (i.e. air temperature, humidity and rainfall) during pre- and post-breeding (Hahn 1995; Rubenstein and Wikelski 2003; Ganendran et al. 2016). In addition, birds need to build nests for their successful reproduction (Perez et al. 2020). Nest building should be shaped by the local environment as nest microclimate is critical for egg development, chick growth, and fledgling success (Durant et al. 2013; Ospina et al. 2018; Perez et al. 2020). Some bird species are secondary cavity nesters, and they use nests excavated by other bird species (Rendell and Robertson 1994). They include several invasive bird species, such as Common Myna *Acridotheres tristis,* European Starlings *Sturnus vulgaris and* Rose-ringed Parakeets (Koenig 2003; Grarock et al. 2013; Charter et al. 2016). Although the latter is regarded as invasive in South Africa, relatively little research has been conducted on its breeding biology, including factors influencing their nest selection and reproductive success. In other countries, however, the breeding biology of Rose-ringed Parakeets has been studied, e.g. in Britain (Butler et al. 2013), Turkey (Şahin and Arslangündoğdu 2019), Israel (Orchan et al. 2013; Charter et al. 2016) and Belgium (Strubbe and Matthysen 2009b; Strubbe and Matthysen 2011).

An increase in Rose-ringed Parakeet populations has been reported to be influenced by the abundance of nesting cavities excavated or used by other bird and bat species (Strubbe and Matthysen 2007; Hernández-Brito et al. 2018). The population size of Rose-ringed Parakeets is increasing in South Africa (Dean 2000; Symes 2014; Whittington-Jones 2017; Shivambu et al. 2021a), particularly in eThekwini Metropolitan areas (Hart and Downs 2014). Given an increase in the population of Rose-ringed Parakeets in South Africa, it is important to understand their breeding biology and potential to expand their range. In this study, we surveyed several areas in eThekwini Municipality where the feral populations of Rose-ringed Parakeets were established to determine: (1) their breeding status; (2) the types of trees used for nesting, and if the selected tree variables and location or distance between roosting and breeding sites influence the number of parakeet fledglings; (3) the nest occupancy between parakeets and native bird species; and (4) the distance between breeding and roosting sites. We predicted that there would be differences in the number of parakeet fledglings between breeding seasons, given an increase in their population size in South Africa (Hart and Downs 2014; Symes 2014; Whittington-Jones 2017; Shivambu et al. 2021a). Given the influence of habitat characteristics on Rose-ringed Parakeet nest selection and reproductive success (Butler et al. 2013; Charter et al. 2016), we predicted that tree parameters such as canopy cover, diameter at breast height, the height of the nest above the ground, tree height and nest entrance diameter would influence the number of fledglings. As Rose-ringed Parakeets are mostly secondary cavity nesters (Charter et al. 2016), we predicted that parakeets would occupy more artificial nest boxes than native bird species to avoid competition. Lastly, we predicted that the distance between breeding and roosting sites would be short and fledgling success would be influenced by distance or location, given that Rose-ringed Parakeets' feeding sites are located in the areas they roost in (Shivambu et al. 2021a,b). For example, the distance travelled by Rose-ringed Parakeets between nest and roost sites in the United Kingdom was estimated at 7 km (Butler 2021).

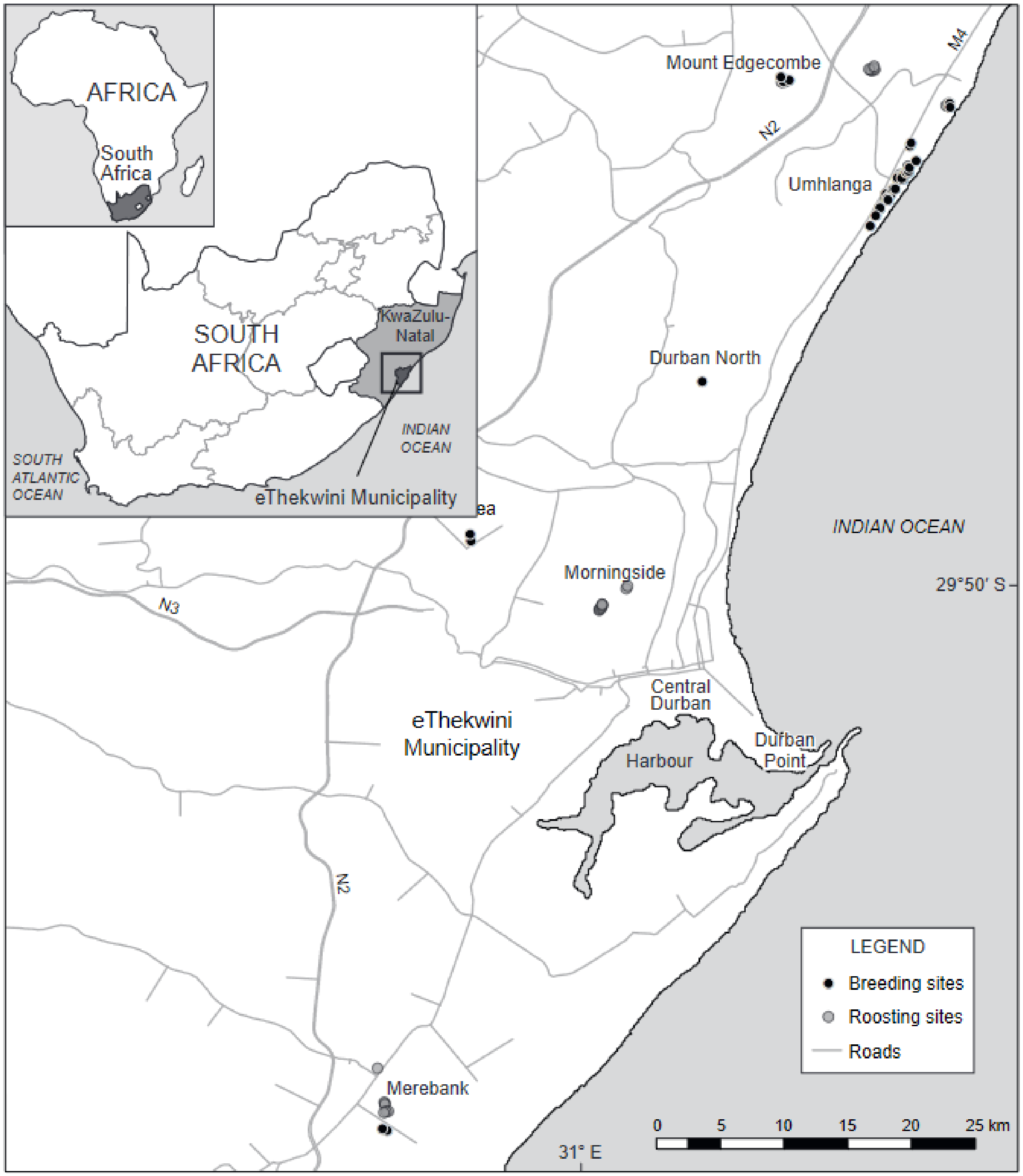

Figure 1: A map showing study sites where invasive Rose-ringed Parakeets were located breeding in eThekwini Municipality, KwaZulu-Natal Province, South Africa in the present study

Material and methods

Study sites

Our study was conducted in Durban, eThekwini Municipality, located in the eastern coastal areas of KwaZulu-Natal province (29°48′43.2″ S, 30°48′14.0″ E), South Africa (Figure 1). The size of the municipality is ~2 292 km², and most of its land is used for human settlements (Musvoto et al. 2016). The municipality is one of the largest in South Africa, with the human population estimated at 3.5 million (eThekwini Municipality 2013; Todes 2014). Approximately 75 000 ha in this municipality is part of the Durban Metropolitan Open Space

System (D'MOSS) (Zungu et al. 2019). This open space system serves as a unique habitat for flora and fauna, including humans who use them for sports and recreation (Roberts 1994; Adams 2005). The climate is categorised as subtropical, with a mean annual rainfall of 948 mm per annum (http://en.climatedata.org/location/27097/). The mean yearly ambient temperature ranges from a minimum of 14 °C to a maximum of 24 °C (http://en.climate-data.org/location/27097/). The climate is described by a long humid, sunny and hot summer, mild winter, and short spring and autumn. The type of vegetation cover found within the municipality includes Coastal Belt, Eastern Valley Bushveld, Hinterland Thornveld, Ngongoni Veld, Mangrove Forest, Northern Coastal Forest, and Scarp Forest (McLean et al. 2016).

The breeding locations were located in the following areas within the municipality, Mount Edgecombe, Umhlanga Rocks, uMngeni (Windsor Golf Course), Sherwood and Merebank. These areas are found within urban land-use types comprising parks, golf courses, and residential areas (Supplementary Material Figure S1; Shivambu et al. 2021a,b). Mount Edgecombe is an eco-estate located in Durban North. Within the estate, there are a series of natural forests, woodland, wetlands, and grassland. The estate is on rehabilitated agricultural lands (mostly sugarcane) mixed with land-use mosaics that integrate natural habitat and vegetation (Alexander et al. 2021). Mount Edgecombe has over 220 bird species, and the estate has bird and environment clubs comprising keen birders (Anthony Job, pers. comm.; http://www.mountedgecombe.com/downloads/MECC%20bird%20list 2019.pdf). Umhlanga Rocks is located at the beachfront, and the area has an urban-forest landscape mosaic comprising of natural coastal forest and nature reserves, mainly with Milkwood tree species *Sideroxylon* spp. (van Niekerk 2015; Shivambu et al. 2021a). Many of the trees in this area are remnants of original scattered and small forest patches of vegetation in urban parks, streets, and private gardens (Govender 2000). The Windsor Golf Course is located alongside the uMngeni River. The golf course consists of natural riparian vegetation, and the river is still a mangrove swamp (Glennie 2001). Sherwood and Merebank are suburban areas in the central and coast of eThekwini Municipality, respectively. These suburbs are relatively transformed, with most of the lands used for housing and industrial parks with both indigenous and non-indigenous vegetation in gardens.

Sampling techniques

Rose-ringed Parakeets' breeding surveys were conducted from May 2018 to December 2019. We conducted a monthly search for evidence of breeding, particularly in areas where the species was sighted by residents and researchers feeding or roosting (Hart and Down 2014; Shivambu et al. 2021a,b). We acquired information on Rose-ringed Parakeet breeding sites from various KwaZulu-Natal bird clubs, as well as residents in our study area who had joined various bird groups on Facebook. Residents who assisted with our study joined a WhatsApp group that was created so that anyone who saw or located parakeets' breeding sites or nests could share the location.

Identified Rose-ringed Parakeet breeding sites (Figure 1) were each visited three times per month per site. Here we describe a breeding site as a single tree with one or more nest holes. We recorded the number of breeding pairs and nest holes used (Figure 2). Each tree species used for breeding was identified to species level using a field guidebook (van Wyk and van Wyk 2013). We also conducted a parallel questionnaire-based survey to identify native bird species' nest cavities taken by parakeets (Shivambu et al. 2022). Symes' (2014) study also indicated that parakeets tend to open up old woodpecker or barbet holes. Nest tree variables such as nest height above the ground, tree height, diameter at breast height (DBH), and crown cover (canopy cover) length were measured manually using measuring tape and Distance Meter software (http://distancemeterapp.000webhostapp.com/). The nest hole diameter was also measured manually using a desk ruler. The measuring techniques applied here were adopted following guidelines for trees (Khan 1999; Butler 2003; Butler et al. 2013; Leverett and Bertolette 2014). All measurements were in metres (m), and the few in centimetres were converted to metres.

Figure 2: Examples of Rose-ringed Parakeets at several nesting sites in our study, where (a) and (b) show parakeets coming out of the nest excavated by native cavity-nesting birds in white milkwood tree Sideroxylon inerme (L.), (c) parakeets entering a cavity in the river red gum tree Eucalyptus camaldulensis (Dehnh.), (d) nests holes in flat-crown tree Albizia adianthifolia, (e) female parakeets entering a nest in a flat-crown tree, and (f) a breeding pair of parakeets mating in early September 2019 near one of the nest sites (© Photographs: TC Shivambu

We used these nest tree variables to determine if they influenced the number of fledglings. The clutch sizes and hatchlings were difficult to assess as the nest interiors were challenging to access. The nest interiors we observed typically had a narrow entrance passage that turned sideways into a nesting chamber, which made viewing directly into nesting chambers difficult. Parakeet chicks were considered to have fledged when we could see them out of the nest after two months (~8 weeks); therefore, we were able to document the number of fledglings per nest. We assumed incubation to have started when the female did not leave the nest for more than 20 min and when the male was seen feeding the female. Only males were seen flying back to roosts and feeding sites during this time. Five roost sites were identified in a previous study (Shivambu et al. 2021a), i.e. Berea (Clarence Road and Cowey's Park), Umhlanga Rocks (Gateway Mall), Merebank (Merebank Caltex) and Sherwood. Cowey's Park had the largest parakeet population, followed by Gateway Mall, with ~1 183 and 508 individuals, respectively. The other roost sites had less than 50 parakeet individuals. Rose-ringed Parakeets communally shared roost sites with seven bird species, including Common Myna, Hadada Ibis *Bostrychia hagedash,* Speckled Mousebird *Colius striatus,* Glossy Starling *Lamprotornis nitens,* Red-winged Starling *Onychognathus morio,* House Sparrow *Passer domesticus* and Red-eyed Dove *Streptopelia semitorquata* (Shivambu et al. 2021a). Rose-ringed Parakeets roosted in the following trees, Natal Mahogany *Trichilia emetica*, Giant Palm *Raphia australis* and Rose Gum *Eucalyptus grandis*.

We used UltraOptec® floating sports binoculars (8 × 30; Boucherville, Canada) to observe parakeets as they flew from breeding to roost site. To determine if the same birds were flying between the roost and breeding sites, we observed Rose-ringed Parakeets from morning until dawn. Rose-ringed Parakeets made stops between roost, feeding and breeding sites. For example, when parakeets leave their breeding sites, they would stop a few kilometres or metres away from roost sites to feed. As a result, this allowed us to track them as they shifted sites (Shivambu et al. 2021b). Using the Google Earth® distance ruler, we made straight-line calculations on Google Earth Pro® (2019) to measure the distance (in kilometres) from parakeets' breeding to roost sites. We created a map showing the study areas (nest and roost site locations) using ArcGIS (version 10.4.1; ESRI 2018) (Figure 1).

We placed a total of 65 artificial nest boxes (Supplementary Material Figure S2) in five locations, namely Ballito (forest patch; n = 8), Berea (shopping centre; n = 4), Merebank (cemetery; n = 9), Mount Edgecombe (restaurant and golf course; n = 10), and Umhlanga Rocks (forest patch, park, residence, and hotel; n = 34) (Supplementary Material Figure S1). The nest boxes were placed in known Rose-ringed Parakeet breeding areas to determine the nest occupancy between parakeets and native bird species. The nest boxes were placed in August 2018 and were monitored by observing them directly once a week until December 2019. The nest boxes were made of pinewood, and the top was covered with aluminium sheeting to prevent rot. The nest box roof was longer than the base to prevent rain and sunlight from entering the nest hole. The nest boxes were painted with brown waterproof paint to blend in the environment (Supplementary Information Figure S2).

Each artificial nest box height was 41.3 cm, width 20.3 cm, breadth 30 cm and nest hole diameter 2.1 cm. Each nest box was placed at approximately ± 6.7 m above the ground in the following trees: white seringa *Kirkia acuminate*, flat-crown *Albizia adianthifolia*, white milkwood *Sideroxylon inerme* and Natal fig *Ficus natalensis*. The nest boxes were placed at the height equivalent to the natural nest cavities and faced the same directions as the natural nests.

Statistical analyses

We determined the mean (± standard deviation [SD]) for each of the following: the number of Rose-ringed Parakeet breeding pairs, fledglings, tree variables, and distance between the nest and roost sites. We tested for the normality of data using the Kolmogorov–Smirnov normality test. We found that the data were not normally distributed. As a result, we used the Kruskal–Wallis test to compare the observed number of active natural nests, breeding pairs, and fledglings between the first and second breeding seasons. The number of active nests was counted and converted to percentages. We used Generalised Linear Modelling (GLM) with backwards eliminations procedures to predict the effects of each of the nest tree variables measured (i.e. crown cover, DBH, the height of nest above the ground, nest diameter, and tree height) on the number of parakeet fledglings produced per breeding season. We also determined if roosting sites' location influence fledging success. The GLM was based on the Gaussian family where the link function '*identity*' was applied. The analyses were performed separately for each season (the first breeding season was coded 'A', while the second breeding season was coded 'B'). Before model analyses, collinearity within the independent variables was checked. We checked if the residuals were independent, identical and normally distributed using residual plots. These were tested using the Kolmogorov–Smirnov normality test and Levene's tests (Zar 1999). As a result, we found that there was no evidence of violations of the assumptions. We used the Kruskal–Wallis test to determine if there were significant differences between the distance from parakeets' roost and breeding sites. We performed all statistical analyses using R statistical software (version 3.6.1, R Core Team 2018).

Results

Natural and artificial nest occupancy

The breeding season for Rose-ringed Parakeets started at the beginning of September and continued until the first week of November each year (~69 days). The average temperature, humidity, and precipitation for the first breeding season were 20.6 °C, 72%, and 98.6 mm, respectively, while they were 21.3 °C, 77%, and 132.2 mm, respectively, for the second breeding season (Supplementary Material Table S1). A total of 39 breeding sites were identified, with a total of 72 nests used (natural nests = 69; artificial nest boxes in residential areas = 3). Of the 65 artificial nest boxes we placed, 65% (n = 42) were used by East African Lowland honey bee *Apis mellifera scutellata*, 27% (n = 18) were not used and 8% (n = 5) were used by the invasive Common Myna *Acridotheres tristis* (Supplementary Information Table S2). We recorded the most parakeet nests in the suburb of Umhlanga Rocks, with 30 nest sites. Other areas had only one to four breeding sites with less than ten nests (Supplementary Materials Table S3). Most parakeet nests were found in residents' gardens, followed by parks and forest patches. A few nests were found on school grounds, a cemetery, a golf course and a hotel garden (Supplementary Materials Table S2). In total, parakeets used 53 nests and 59 in the first (2018) and second breeding seasons (2019), respectively (Table 1).

There were no significant differences in the observed number of nests used between breeding seasons (Kruskal–Wallis test: $\chi^2 = 0.59$; $F_{1,76} = 0.72$; $p = 0.398$). We did not discover any new natural nests in the identified breeding sites in the first and second breeding seasons.

Table 1: Tree species used by Rose-ringed Parakeets as nest sites during the breeding seasons in our study. Tree species with an asterisk are invasive to South Africa. The number in the brackets in the fledgling column is the actual number of fledging chicks recorded during the breeding seasons. SD = standard deviation

Scientific names	Common names	Locations	Number of nests	Active nests used by parakeets		Number of breeding pairs		Mean (± SD) number of fledgling chicks	
				1st breeding	2nd breeding	1st breeding	2nd breeding	1st breeding	2nd breeding
Albizia adianthifolia	Flat-crown	Umhlanga	9 (13%)	8 (15%)	9 (15%)	6 (11%)	6 (12%)	1.6 ± 1.14 (*n* = 8)	1.6 ± 0.55 (*n* = 8)
*Eucalyptus camaldulensis**	River red gum	Merebank and Sherwood	10 (14%)	6 (8.11%)	9 (15%)	8 (14%)	8 15%	1.25 ± 0.5 (*n* = 6)	1.75 ± 0.96 (*n* = 7)
Ficus natalensis	Natal fig	Umhlanga	1 (2%)	1 (2%)	1 (2%)	1 (2%)	1 (2%)	0.55 ± 0.67 (*n* = 1)	0.03 ± 0.14 (*n* = 1)
Sideroxylon inerme	White milkwood	Umhlanga	49 (71%)	38 (72%)	40 (68%)	40 (73%)	37 (71%)	1.03 ± 0.82 (*n* = 30)	1.59 ± 0.87 (*n* = 46)

Figure 3: Photographs showing (a) a Black-collared Barbet Lybius torquatus and (b) a Golden-tailed Woodpecker Campethera abingoni using privately owned artificial nests, and (c) Rose-ringed Parakeets' pair Psittacula krameri taking-over privately owned artificial nest of the respective native species; (d) an alien invasive Common Myna Acridotheres tristis using similar natural nest as used by (e) and (f) invasive Rose-ringed Parakeets during the breeding seasons in our study. ©Photographs (a–c) by Mike du Trevou, (d–f) by TC Shivambu

Tree species used for nesting

Rose-ringed Parakeets nested in a total of four tree species (Table 1, Figure 2, Supplementary Material Table S3). Some of the trees had between two to three nest cavities used by more than one breeding pair (Figure 2d). Most parakeets (71%) used the white milkwood tree *S. inerme* for nesting, followed by invasive river red gum *Eucalyptus* *camaldulensis* (14%) and flat-crown *A. adianthifolia* (13%) (Table 1). Observed parakeet's nests included natural cavities (n = 26), nests formerly used by native birds, including Crested Barbet *Trachyphonus vaillantii* (natural nests = 12 (residential area)), African Hoopoe *Upupa africana* (natural nests = 16 (residential area)), Black-collared Barbet *Lybius torquatus* (artificial nest box in private garden = 1, natural nests = 8 (residential area)) and Golden-tailed Woodpecker *Campethera abingoni* (privately owned artificial nest boxes in private garden = 2, natural nests = 7) (Figure 3). The nests in 39 breeding sites were all-natural except for three privately owned artificial nest boxes in Mount Edgecombe Estate and Umhlanga Rocks (Figure 3). During our observations, Common Mynas and Rose-ringed Parakeets used the same nests (n = 3) (Figure 3). We recorded this at two sites, Durban View Park and Ridge Road, located in Umhlanga Rocks (Figure 3). The mean (± SD) height of the nests was 10.84 ± 3.79 m above the ground with a diameter of 0.81 ± 0.22 m. The mean tree height was 22.90 ± 8.25 m, with the mean crown cover size of 8.37 ± 10.98 m. Lastly, the mean DBH was 4.15 ± 0.82 m.

Breeding success

The number of Rose-ringed Parakeet fledglings recorded in the first breeding season (1.13 ± 0.83; n = 44) was significantly lower than the number of fledglings observed in the second breeding season (1.59 ± 0.81; n = 62) (Kruskal–Wallis test: χ^2 = 5.99; df = 1; p = 0.021). Most (84%, 44 out of 53) had either one to three fledglings in the first breeding season, with only 16% unsuccessful in their breeding attempt. In contrast, only four nests did not have any fledglings in the second breeding season out of 59 nests, i.e. 6.8% were unsuccessful. None of the measured tree variables (tree height, height of the nest above the ground, nest diameter, DBH and crown cover) had a significant influence on the number of fledglings produced in both breeding seasons (Generalised Linear Modelling, p > 0.1; Table 2).

Table 2: A summary of the GLM predicting the number of fledglings in the first and second breeding season against measured tree variables. "A" represents procedure performed using first breeding season datasets, and "B" shows results from analyses using second breeding season datasets. SE = standard error

A	Estimates (β)	SE	*t*-value	*p*-value
Intercept	2.28	2.23	-0.21	0.31
Height	0.07	0.05	-0.64	0.43
DBH	0.21	0.17	1.21	0.23
Nest height above the ground	0.18	0.14	1.26	0.21
Nest diameter	0.61	0.36	0.60	0.55
Crown cover	0.26	0.15	1.63	0.11
Distance	0.33	0.30	0.86	0.40
Location: Durban North	1.44	1.40	1.03	0.31
Location: Lady Allen	0.92	0.44	0.47	0.63
Location: Merebank	2.11	1.22	1.72	0.09
Location: Mountedgecombe	1.03	0.22	0.21	0.82
Location: Sherwood	1.16	0.17	0.14	0.88
B	**Estimates (β)**	**SE**	***t*-value**	***p*-value**
Intercept	3.60	2.48	1.44	0.16
Height	0.07	0.02	0.27	0.79
DBH	0.19	0.17	0.91	0.36
Nest height above the ground	0.16	0.01	0.05	0.96
Nest diameter	0.67	0.36	0.54	0.60
Crown cover	0.17	0.28	1.64	0.11
Distance	0.37	0.07	0.20	0.83
Location: Durban North	1.54	0.06	0.04	0.96
Location: Lady Allen	1.02	0.73	0.71	0.48
Location: Merebank	1.36	0.35	0.25	0.80
Location: Mountedgecombe	1.36	1.15	1.18	0.24
Location: Sherwood	1.30	0.35	0.27	0.78

Distance between roost and breeding sites

The mean (± SD) distance from Rose-ringed Parakeets' nest sites to three major roost sites (Cowey's Park, Umhlanga Rocks and Merebank) was 2.64 ± 0.76 km (Table 3). We found a significant difference between Rose-ringed Parakeets roosts and breeding sites distances (Kruskal–Wallis test: $\chi^2 = 8.99$; df = 5; $p = 0.001$). However, we found that distance or location does not influence fledgling success (Table 2). The longest distance was from Durban North to Cowey's Park (5 km), and the shortest (1.43 km) was from Merebank Muslim cemetery to Merebank Caltex (Table 3).

Table 3: The distance (km) between Rose-ringed Parakeets roosts and nest sites in eThekwini municipality, KwaZulu-Natal, South Africa

Breeding sites	Coordinates		Roost sites	Coordinates		Distance between breeding and roost sites (km)
	Latitude	Latitude		Latitude	Longitude	
Merebank	-29.951600	30.962529	Merebank Caltex	-29.938705	30.961724	1.43
Merebank	-29.951958	30.963511	Merebank Caltex	-29.938705	30.961724	1.48
Mt Edgecombe	-29.728205	31.049168	Gateway Mall	-29.725825	31.066771	1.72
Lady Allen	-29.733201	31.083331	Gateway Mall	-29.725825	31.066771	1.80
Lady Allen	-29.733201	31.083332	Gateway Mall	-29.725825	31.066771	1.80
Lady Allen	-29.734023	31.083430	Gateway Mall	-29.725825	31.066771	1.85
Mt Edgecombe	-29.728643	31.047961	Gateway Mall	-29.725825	31.066771	1.85
Mt Edgecombe	-29.727539	31.047417	Gateway Mall	-29.725825	31.066771	1.88
Mt Edgecombe	-29.727566	31.047390	Gateway Mall	-29.725825	31.066771	1.89
Lady Allen	-29.741625	31.075126	Gateway Mall	-29.725825	31.066771	1.93
Lady Allen	-29.742240	31.074799	Gateway Mall	-29.725825	31.066771	1.98
Lady Allen	-29.745454	31.076178	Gateway Mall	-29.725825	31.066771	2.34
Lady Allen	-29.746944	31.074747	Gateway Mall	-29.725825	31.066771	2.45
Lady Allen	-29.747632	31.074508	Gateway Mall	-29.725825	31.066771	2.51
Lady Allen	-29.747928	31.074098	Gateway Mall	-29.725825	31.066771	2.53
Lady Allen	-29.748012	31.074074	Gateway Mall	-29.725825	31.066771	2.54
Lady Allen	-29.747814	31.074656	Gateway Mall	-29.725825	31.066771	2.54
Lady Allen	-29.748679	31.072742	Gateway Mall	-29.725825	31.066771	2.60
Lady Allen	-29.749114	31.072160	Gateway Mall	-29.725825	31.066771	2.61
Lady Allen	-29.748697	31.073228	Gateway Mall	-29.725825	31.066771	2.61
Lady Allen	-29.749289	31.072238	Gateway Mall	-29.725825	31.066771	2.64
Lady Allen	-29.749177	31.073086	Gateway Mall	-29.725825	31.066771	2.66
Lady Allen	-29.749363	31.073389	Gateway Mall	-29.725825	31.066771	2.67
Lady Allen	-29.751427	31.071243	Gateway Mall	-29.725825	31.066771	2.85
Lady Allen	-29.751417	31.071740	Gateway Mall	-29.725825	31.066771	2.87
Lady Allen	-29.752480	31.070125	Gateway Mall	-29.725825	31.066771	2.94
Lady Allen	-29.752583	31.070750	Gateway Mall	-29.725825	31.066771	2.99
Lady Allen	-29.752529	31.069760	Gateway Mall	-29.725825	31.066771	3.00
Lady Allen	-29.753433	31.070085	Gateway Mall	-29.725825	31.066771	3.04
Lady Allen	-29.753093	31.070313	Gateway Mall	-29.725825	31.066771	3.06
Lady Allen	-29.753515	31.069962	Gateway Mall	-29.725825	31.066771	3.07
Lady Allen	-29.753786	31.070178	Gateway Mall	-29.725825	31.066771	3.12
Sherwood	-29.826395	30.981317	Cowey's Park	-29.841022	31.008941	3.12
Clare Hills	-29.824971	30.981173	Cowey's Park	-29.841022	31.008941	3.24
Lady Allen	-29.755387	31.068382	Gateway Mall	-29.725825	31.066771	3.25
Lady Allen	-29.755472	31.068507	Gateway Mall	-29.725825	31.066771	3.26
Lady Allen	-29.757165	31.067555	Gateway Mall	-29.725825	31.066771	3.47
Lady Allen	-29.759305	31.066378	Gateway Mall	-29.725825	31.066771	3.71
Durban North	-29.792505	31.030596	Cowey's Park	-29.841022	31.008941	5.72

Discussion

In this study, we found that most of the Rose-ringed Parakeet breeding sites were distributed in the suburb of Umhlanga Rocks, typically in residents' gardens and parks. The Umhlanga area included natural forest patches and parks, while other areas, such as Cowey's Park and Merebank, were mainly dominated by anthropogenic developments with increased housing density (Maseko et al. 2020). As a result, forest patches, parks and gardens provide food sources for both native and invasive species during pre- and post-breeding periods (Shivambu et al. 2021b). In South Africa, these parakeets are generally distributed in human-dominated areas and typically occupy urban parks, with their roosting sites also found in the urban areas (Dean 2000; Roche and Bedford-Shaw 2008; Hart and Downs

2014; Ivanova and Symes 2019; Shivambu et al. 2021a). Most urban parks have different tree species used by most cavity nesters, including parakeets (Strubbe and Matthysen 2007; Strubbe and Matthysen 2009a; Orchan et al. 2013; Mori et al. 2017; Rocha et al. 2020). Another explanation for more breeding sites in Umhlanga could be that several breeding sites could have been missed in areas with the largest Rose-ringed Parakeet subpopulation, such as Cowey's Park (Shivambu et al. 2021a). These results also highlight the importance of citizen science data (Hart and Downs 2014; Shivambu et al. 2022), as we could use some of the data to locate several nest sites.

Rose-ringed Parakeets mostly used secondary cavities in the indigenous white milkwood tree for nesting compared with other tree species. This tree had several dead branches enabling native cavity-nesting bird species to excavate nest holes. In addition, the white milkwood tree is the most common tree species in coastal areas, e.g. Umhlanga Rocks (Govender 2000). In our study, the invasive river red gum tree was the second most used for nesting by parakeets. This may be explained by the fact that the river red gum was the most abundant tree in the identified breeding sites in Merebank. Consequently, invasive tree species provide a breeding environment for invasive Rose-ringed Parakeets. This was also observed in Yarkon Park, Tel Aviv, Israel, where parakeets preferred the invasive river red gum (Orchan et al. 2013). Documenting which tree species the invasive Rose-ringed Parakeets use for breeding is important for management and control purposes. According to South African law, wild or feral parakeets require active management and control. As a result, information about their breeding and locations is the first step to their management. Control methods such as trapping from breeding and roost sites could reduce parakeet populations as evident in islands such as La Palma, Canary Islands (Bunbury et al. 2019; Saavedra and Medina 2020). This information is also useful in determining which native cavity nesters are outcompeted by Rose-ringed Parakeets.

We found an increase in the number of natural nest cavities used in the second breeding season. This may be explained by the fact that it was wetter in the second breeding season; therefore, more food was likely available. There was also an increase in the number of Rose-ringed Parakeets breeding pairs; therefore, this species may be expected to increase its population size (Shivambu et al. 2021a). In addition, studies by Orchan et al. (2013) and Rocha et al. (2020) found that parakeets use the same nest hole in different breeding seasons; hence we did not record any new nest cavities. In our study, the recorded number of parakeet fledglings ranged between one and three chicks. Similarly, the number of fledgeling chicks produced in the Indian subcontinent, Israel, and Britain was 1.7–3.0; 1; and 0.8–1.4, respectively (Shivanarayan et al. 1981; Butler 2003; Orchan et al. 2012; Butler et al. 2013), suggesting that the breeding success of parakeets in South Africa is in the range reported for other areas. The number of fledglings fluctuated between the first and second breeding seasons, and our results did not show a decline in their breeding success. In addition, we observed no raptors preying on the parakeets during our surveys, which may explain why their fledgling numbers were not declining. The small percentage of nests where fledging was unsuccessful were the natural nests used by both Common Mynas and Rose-ringed Parakeets, as well as three artificial nests placed for Black-collared Barbet and Golden-tailed Woodpecker by private owners in private gardens.

If Rose-ringed Parakeets use similar nest sites over the years, their numbers will likely increase, as reported by Hart and Downs (2014), Symes (2014), and Whittington-Jones (2017). In a British study conducted by Butler (2003), the reproductive rate of Rose-ringed Parakeets increased over the sampled years, which showed that fledglings had matured and contributed to the reproduction success of this species. Despite only covering two breeding seasons, it appears that the Rose-ringed Parakeets' reproductive rate is increasing as in their other non-native distribution ranges.

The breeding months for Rose-ringed Parakeets differ across continents. In our study, the parakeets bred between September and November; while in Europe (Butler et al. 2013; Rocha et al. 2020) and its native range, including Bangladesh, India, and Pakistan (Simwat and Sidhu 1973; Krishnaprasadan et al. 1988; Hossain et al. 1993), they breed between February and June. The breeding time for Rose-ringed Parakeets in South Africa may coincide with favourable environmental conditions in the country. For example, between September and December, the food sources and rainfall are plentiful (Supplementary Material Table S1; Maseko et al. 2020; Shivambu et al. 2021b). In addition, the breeding timing across the countries can be explained by phenological mismatch (Luna et al. 2017). For example, Rose-ringed Parakeets breed during dry and wet seasons (September to November) in South Africa, and during cold and dry seasons in other African countries, while in their native range and in other invaded countries, they breed during dry and cold seasons (February to June) (Hossain et al. 1993; Butler et al. 2013; Charter et al. 2016; Luna et al. 2017; Rocha et al. 2020).

None of the nest tree parameters measured influenced the number of Rose-ringed Parakeet fledglings produced in both breeding seasons in our study. However, a study by Butler et al. (2013) showed that only the woodpecker nest cavity influenced the clutch size produced by parakeets, while other variables such as DBH, nest and tree height did not influence the clutch size. These results were related to our findings, where similar variables did not influence the number of parakeet fledglings. These non-significant results collected for two seasons only.

In other studies, the selection of nest sites was influenced by artificial nest boxes placed for native bird species but taken over by parakeets, resulting in sustained feral populations (Butler 2003; Braun and Wink 2013; Charter et al. 2016). Out of 69 natural nests recorded in our study, 43 nests were previously used by native birds, including three privately owned artificial nest boxes. Species replaced by parakeets in their nests included the Crested Barbet, African Hoopoe, Black-collared Barbet and Golden-tailed Woodpecker. Although we did not observe parakeets directly replacing native birds from the remaining 26 natural nests, it is likely that native birds also used those nests before parakeets used them. Some of the nests were expanded by parakeets so that they could use them. In addition, Rose-ringed Parakeets often occupy nest cavities early in the season to prevent other birds from using them (Orchan et al. 2013). Common Mynas were the only other alien invasive species observed using the same nest cavities as the parakeets. This may result in complex competition between native and non-native bird species. In addition, native cavity nesters may not nest in locations where nest cavities are unavailable because of invasive Rose-ringed Parakeets and Common Myna occupying all breeding holes. Nest site competition between the Common Myna and Rose-ringed Parakeets was also observed by Orchan et al. (2013). In Belgium, Rose-ringed Parakeets have been implicated in displacing native Blue Tits and Nuthatches (Strubbe and Matthysen 2009a; Covas et al. 2017). In other studies, woodpecker species such as Great Spotted Woodpecker *Dendrocopos major*, Green Woodpecker *Picus viridis* and Syrian Woodpecker *Dendrocopos syriacus* have had their nest sites taken by parakeets (Butler et al. 2013; Braun and Wink 2013). This may negatively impact the population areas, including South Africa.

In this study, native bird species and Rose-ringed Parakeets did not use our artificial nest boxes, but African honey bees and Common Mynas used them. Downs (2005) also found that the same bee species occupied artificial nest boxes placed for wild endangered South African Cape Parrots *Poicephalus robustus,* with an occupation percentage of 20% between 2000 and 2003. Occupation by bees or Common Mynas in our study may have impeded native bird species or parakeets from using the nests. Given that bees can use nest boxes (MacIvor 2017), it is likely that African honey bees will colonise artificial nest boxes placed for native birds. Another explanation for the artificial nest box non-uptake could be that the breeding sites have enough natural nest cavities for parakeets to breed. The Common Myna was reported to affect the breeding success of the Eastern Rosella *Platycercus eximius* and Crimson Rosella *Platycercus elegans* by taking over their nest boxes in Canberra, Australia (Grarock et al. 2013). Charter et al. (2016) in Tel Aviv, Israel, found that Common Mynas occupied the majority (62–74%) of artificial nest boxes compared with Rose-ringed Parakeets (5–14%). It is possible that Common Mynas will continue to use artificial nest boxes, given their population size in South Africa and their aggressive behaviour towards other bird species (Harper et al. 2005; Peacock et al. 2007; Lowe et al. 2011).

The Rose-ringed Parakeet distance between roost and breeding sites differed as some were close (~1.3 km), while others were far (~5 km). We found that most of the parakeet nesting sites were relatively close to roosting sites, and many were feeding on the tree species that they nested in, e.g. white milkwood fleshy fruits (Shivambu et al. 2021b). In Britain, Butler (2003) found parakeets travelled ~6 km between nest and roost sites; while in Brussels, Belgium, Pârâu et al. (2016) found that they travelled ~9 km. This similarity in distance travelled between nesting and roosting sites may account for the distance that Rose-ringed Parakeets travelled in KwaZulu-Natal, South Africa. However, distances more than 10 km travelled by these parakeets have been observed in Amsterdam (12 km) and Germany (15 km) (Keijl 2001; Kahl-Dunkel and Werner 2002).

Recommendations

We recommend further studies on the breeding biology of Rose-ringed Parakeets, given that their population is increasing in different provinces of South Africa (Dean 2000; Roche and Bedford-Shaw 2008; Hart and Downs 2014; Ivanova and Symes 2019; Shivambu et al. 2021a). In addition, a long-term study of the parakeet breeding biology may provide a robust breeding status, including its breeding behaviour and population trends. These parakeets are secondary cavity-nesting species and have displaced native cavity users in other countries and South Africa (Strubbe and Matthysen 2009a; Symes 2014; Covas et al. 2017; Tinyiko C Shivambu pers. comm.; present study). Therefore, it is essential to assess parakeets' impact on native cavity-nesting birds, primarily through competition. Our study reported a total of 39 parakeet breeding sites, fewer than the number of parakeets estimated (~2 000, Shivambu et al. 2021a) in eThekwini Municipality; it is therefore recommended that their movement patterns be assessed using radiotelemetry to locate additional breeding sites. Given that nest boxes have been used successfully by Rose-ringed Parakeets (Butler et al. 2013; Charter et al. 2016) and other psittacid species such as macaws *Ara* spp. (Munn 1992; Nycander et al. 1995), Green-rumped Parrotlet *Forpus passerines* (Beissinger and Bucher 1992) and the Yellow-crowned Amazon *Amazona ochrocephala* (Sanz et al. 2003), it is recommended that parakeets be monitored to determine if they may use artificial nest boxes in the long run.

Conclusions

We concluded that the Rose-ringed Parakeets' breeding is contributing to their population growth in eThekwini Municipality, which is a concern. They successfully found and used secondary nest cavities and likely competed with some native species for nest sites. Moreover, the findings of this study provide essential data for an overall management strategy and can be used to inform decisions on eradicating this species in South Africa.

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Data availability

The data belong to the University of KwaZulu-Natal but are available on reasonable request from the corresponding author.

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