The breeding ecology and movements of the Little Eagle in the ACT and nearby NSW, 2017-2020 with reference to the Ginninderry development area

Prepared by Stuart Rae on behalf of the Little Eagle Research Group.

little.eagle.research@gmail.com

July 2021

Executive Summary

The Little Eagle *Hieraaetus morphnoides* is listed as Vulnerable in the ACT and NSW and has nested in the Ginninderry area. Ginninderry Joint Venture joined and has partly funded a cooperative study of the Little Eagle in the ACT and nearby NSW since its inception in 2017. The project aims to gain insight into the bird's population in the ACT, its breeding ecology and movements, how the birds use the proposed Ginninderry development area, and provide information to guide conservation of the species. This report gives preliminary results from the first four years of study.

Main points:

- A minimum of 15 Little Eagle territories were identified in the ACT. There were minima of 9 pairs in 2017, 2018 and 2020 and 10 in 2019. The whole of the ACT was not surveyed and it is likely that there were more, undetected, breeding pairs. Six territories were identified in nearby areas of NSW and there were minima of two pairs in 2017, five in 2018, four in 2019 and five in 2020.
- The annual mean number of chicks that fledged per pair with a nest in the ACT was 0.40, range 0.30-0.55, and 15 chicks were reared over the four years. In NSW, the mean fledging success rate was 0.67, range 0.50-0.80.
- 397 prey remains and 810 pellets collected. The main prey were European Rabbit (39.9% of prey remains, 43.2% of remains in pellets), birds (43.5% of prey remains, 37.4% remains in pellets) and reptiles, all of which were lizard species, (6.9% of prey remains, 16% of remains in pellets). Carrion was seldom taken.
- The mean nearest-neighbour distance between nest sites in the ACT was 5.59 km, range 0.9-10.5 km, which was closer and more uniformly spaced than random.
- 16 birds were fitted with GPS-transmitter tags to investigate their movements. All six territorial males mostly stayed within 3 km of their nest site during the breeding season, mean 80.7% of records, range 66.3-92.9%. And 90.5% of records from one female were within 3 km.
- Birds were recorded in most of the northern part of the ACT, ranging over grassland, woodland, the forested Brindabella hill range, pine forest and undeveloped ground in or near urban and industrial areas.
- All five adult males and one of two adult females tagged in the ACT left in dispersive migration post breeding, and four tagged juveniles dispersed similar distances and directions: mean distance 1543 km, mean direction NNW, 331°.
- Six birds flew to savannah in the Northern Territory and far north Queensland, one wintered in the cane field district of south-east Queensland, one went east to the coastal forests of south-east New South Wales, two flew as far west as grasslands in south-east South Australia, and one wintered in heavily industrial parts of inner Melbourne. One adult female remained in the ACT, 20 km from her nest site.

The report finds that the Little Eagle is widespread in the ACT, and one pair that nest 1.5 km outside the Ginninderry development area use parts of that area for hunting. Following three dry years, more birds laid eggs and hatched young in the fourth, wet, year. The main prey, rabbits, were abundant following the rain. This might have been the reason more eagles bred that year. Although this is a descriptive study, and long-term data are required to achieve significant data analysis to identify the main factors in the ecology and movements of the Little Eagle, the information gained so far has already aided management decisions for conservation of the species in the ACT.

Acknowledgements

The Little Eagle Research Group is a collaborative study group and I thank the other members for their strong teamwork and help with development of the programme, fieldwork, analysis of data, and comments on this report; these being Jacqui Stol, Micah Davies and Melissa Piper (CSIRO Land and Water, Black Mountain), Michael Mulvaney, Renee Brawata, Claire Wimpenny, Melissa Snape and Zohara Lucas (Conservation Research Unit, ACT Government), David Roberts (Ginninderry Joint Venture), Penny Olsen (Research School of Biology, Australian National University), Stephen Debus (University of New England) and Don Fletcher. The study is largely voluntary with partial funding and professional expertise in data analysis provided by Ginninderry Joint Venture, ACT Government Conservation Research Unit, and CSIRO Land and Water. Canberra Ornithologists' Group allocated a grant for pellet analysis and Red Hill Regenerators provided money for the purchase of four GPS-transmitters. Jerry Olsen caught and fitted a GPS-transmitter to a bird prior to this study and this report refers to some of the data recorded from that bird.

The study could not have achieved what it has without the additional information supplied by the public as to the whereabouts of Little Eagles and to landowners and managers who have allowed access to nest sites and hunting areas. All nest sites are georeferenced and archived, but this information is not made available to the public at the request of some of the landowners and managers and for the protection of the eagles and the integrity of the research.

We acknowledge the Ngunnawal People as the Traditional Custodians of the land on which this study is undertaken and pay our respects to Elders past, present and future. We acknowledge their continuing culture and connection to Country and the contribution that they and the broader ACT Aboriginal and Torres Strait Islander community make to the ACT and region.

An adult Little Eagle at a hunting perch in the shady foliage of a tree.

Introduction

The results presented in this report are from four years of study by the Little Eagle Research Group, drawing on the members' knowledge of scientific research, fieldwork expertise and resources. The study has been running since 2017 and the period covered by this report is from the beginning of the breeding season in August 2017 to the end of the breeding season in March 2021. Previous reports have given annual updates on the study's findings (Rae *et al.* 2018, 2019, 2020 and 2021a), this report gives a fuller interpretation of the results so far. The study is ongoing and in addition to the reports noted at the end of this report, further reports and journal papers will be published as the considerable amount of collected data are processed.

The Little Eagle *Hieraaetus morphnoides* is listed as vulnerable in the Australian Capital Territory (ACT) and New South Wales (NSW), and it is considered that a thorough study of the species is required to gain insight into the bird's breeding ecology and so improve advice on the bird's conservation (Rae *et al.* 2018). The bird is a small eagle that hunts and nests in woodland and open country, it is migratory and widespread over the Australian mainland, and it is a generalist feeder; taking mainly small to medium-sized mammals, birds, and reptiles (Marchant and Higgins 1993, Debus 2017). The main laying period in south-east Australia is August-October, the usual clutch is 1 or 2 eggs, and most fledged broods are of one chick, occasionally two (Marchant and Higgins 1993).

The overall aim of the study is to determine the population ecology of the Little Eagle in the ACT and nearby NSW. This can only be done by finding as many breeding pairs as possible to ascertain a minimum population figure. The project has a long-term plan, as long-term studies have been shown to be valuable for ecological understanding and conservation of raptors (Thiollay 2006, Steenhof and Peterson 20090, Moss *et al.* 2012, Watson *et al.* 2012). The main aspects that this study has focused on are the Little Eagle population status, breeding success, diet, and dispersion locally and nationally. Such information helps assess the main habitats used, foods eaten, and productivity, which is necessary for guidance of any conservation of a species. The study area includes adjacent parts of NSW to obtain a wider sample, so as not to study the birds of the ACT in isolation and to include the full breeding territories of birds ranging across the border.

As the Little Eagle is a migratory species, the local population cannot be studied in isolation. Therefore, all movements, local and national, from a sample of birds are being tracked with GPS-transmitters. This provides information on nation-wide as well as local dispersion and habitat-use, which can elucidate the range of the local population of Little Eagles and how they are related to the national population.

The first three breeding seasons were dry, the 2019-2020 especially so (Bureau of Meteorology (BOM) 2018, 2019, 2020a). Environmental conditions in the ACT and surrounding area were extreme, with the highest average daytime temperatures on record, low rainfall, and long dry periods (BOM 2020b). The very warm and dry conditions affected general bird activity (Holland 2019a), numbers of birds were generally low and fewer were breeding (Holland 2019b). Rainfall increased after the end of the 2019-2020 breeding season and there was more than twice the rainfall in the study area in 2020 than in 2019 (Bureau of Metrology (BOM 2021). Grasses and herbs grew tall after the late winter and spring rain, and European Rabbit *Oryctolagus cuniculus* numbers were high in south-east Australia (Local Land Services 2020, *The Canberra Times* 2021). Therefore, rabbits were abundant during the

Little Eagle breeding season, but there was also heavy rain during the nesting period when young are vulnerable to poor weather. Such differences in environmental conditions need to be considered when assessing raptor behaviour and illustrate the value of data collected over four years.

Limits of the study.

This report gives a provisional summary of population, breeding status, diet and movements of a sample of Little Eagles in the ACT and surrounding area of NSW from the first four years of the project. Minimum figures are given for the numbers of territories occupied and breeding success. The data from the GPS-telemetry cannot be fully analysed until all are received from the transmitters, which is expected in 2023. Long term data are important in understanding the complex issues involved in raptor population ecology. Annual variations such as those of weather and food abundance can have strong effects on birds, particularly on breeding success (Watson and Rae 2019), which in turn can affect the sustainability of a population. Hence, the study is ongoing.

A female Little Eagle eating a rosella provided by her mate.

Methods

The main data recorded to assess the population and breeding success of Little Eagles were the locations of nesting territories, their occupation by a breeding pair or single bird, whether eggs were laid, whether young hatched, and the number of young reared (Hayhow *et al.* 2017, Steenhof *et al.* 2017). Well established techniques were followed to locate birds, breeding pairs, nests, and record breeding success. These were developed by the author and colleagues over many years of raptor research, especially Golden Eagle *Aquila chrysaetos*, and adopted for national surveys in Scotland (Dennis *et al.* 1984, Watson *et al.* 1992, Hardey *et al.* 2013, Hayhow *et al.* 2017, Watson and Rae, 2019). Digital cameras, which recorded still images at time-lapse settings, were deployed at four nests to monitor the birds' behaviour at the nest and provide additional information, such as laying and fledging dates and causes of failure. All previously known sites of Little Eagle nests in the ACT were checked for occupancy. These were all those held in the species records by the Conservation Research Unit, ACT Government, and other nests known to have been used in previous years by the author.

The Little Eagle breeding season in the ACT area is approximately August-February. Therefore, the seasons studied were in 2017-2018, 2018-219, 2019-2020 and 2020-2021. For brevity these are referred to as 2017, 2018, 2019 and 2020.

Vantage point watches were made over potential nest and hunting sites from late July to February to watch for eagle flight behaviour which might lead to locations where any were nesting. When such sites were identified, ground searches were done to confirm nesting. Most of the birds in the study were unmarked with bands. Therefore, as many eagles as possible were photographed at their nest sites to help identify different individuals by their plumage patterns or distinctive features.

To assess the diet of the Little Eagle in the study area, the remains of prey items were collected from below nests and perches used by eagles. All remains found of any prey were collected during every nest site visit, bagged individually and recorded in batches by date, so as to avoid counting a prey item more than once, and the minimum number of items per batch was calculated from distinguishable parts (Watson *et al.* 1987, Watson *et al.* 1993). Minimum numbers of any prey species were determined by counting body parts, such as heads, feet, and wing or tail feathers. Pellets ejected by the Little Eagles were also collected and stored like the prey remains. Collection of prey remains and pellets only give unknown proportionate samples of an eagle's whole diet, and each has biases (Watson *et al.* 1987). For example, small items such as insects were not recorded in prey items but might be in pellets. The results presented here are only a preliminary analysis of the prey remains in 2017-2020 and pellets in 2017-2019. Pellets from 2020 were stored for later analysis.

Prey remains are here defined as parts of animals that had been eaten by the Little Eagles and found in the field. They do not refer to animal parts that were found and identified within pellets. The counting unit in both sample sets is food item. There is overlap between the two collection methods as there would parts of animals identified in the field found in pellets. Therefore, data from the two collection methods are compared separately. The only data from the two methods that were combined are the numbers of species eaten, where one is the defining number.

Dispersion is here used to describe how birds distribute themselves over the landscape for nest sites, breeding home ranges and continental scale movements (Newton 1979). In animal behaviour generally, a home range is where an individual animal lives, and a territory is a smaller area where an individual dominates all others of the same sex, usually around their nest site (Brown and Watson 1964, Newton 1979, Watson and Rae 2019). In this study, a home range was defined as the wider area where birds moved within, during the breeding season. A territory was defined as an area where birds spent most of their time and they were associated with one or more nests in that area. Little Eagles, like many raptor species, can have alternate nests within their territory (Brown and Amadon 1968, Newton 1979). In many raptor studies, not all territories are occupied in any one year and birds can switch territories (Newton 1979), hence it can't be assumed that because any one nest is unused that the territory is unoccupied or that the birds aren't somewhere in the region, and this study does not claim to have found all active nests.

Nest sites were used as the focal point of each territory. The coordinates of each nest were recorded by GPS, and the distance between each and its nearest neighbour was measured. If there were more than one nest in any territory, the central point was taken as the measured distance point. Analysis of the regularity of the nearest neighbour distances was done with a G-test (GMASD, geometric mean, arithmetic mean square distance (Brown 1975, Newton *et al.* 1977, Watson and Rothery 1986), in which the resulting figure of 0-1 gives a scale of regularity, where 1 is regular and < 0.65 is random. The nearest neighbour distances of all nests were then compared by Analysis of Variance (ANOVA) with a set of computer-generated random points within the area north-east of the Murrumbidgee River, the main part of the study area. The nests in NSW were found opportunistically and were not adjacent, so distances between sites are not comparable with those in the ACT.

The movements of Little Eagles in this study refer to the dispersion of birds across the study area, dispersal of young birds post fledging, and dispersion of adult birds post-breeding. A sample of birds were monitored by attaching small GPS transmitters (22 g) to birds. The transmitters are backpack type, attached to the birds with a Teflon ribbon harness (Animal ethics permit CEAE 16-22 and #3340, University of Canberra). The systems are ongoing and are programmed to take nine fixes per day, 1-2 h apart during daylight hours, with an additional midnight fix to record roosting location information. Data are recorded on location, speed, altitude and the time of recording. Free-flying birds were caught in a Bal-Chatri trap with a Common Myna *Acridotheres tristis* or Common Starling *Sturnus vulgaris*, protected by the trap, as a lure, and chicks were lowered from their nests to be processed safely on the ground. Birds were marked with an individual combination of bands from the Australian Bird and Bat Banding Scheme and coloured alpha-numeric bands. Tests as to whether the orientation of the birds' dispersal differed from a uniform orientation were undertaken using Rayleigh Test (Z) in Oriana software (Kovach 2010).

The survey has been limited to the northern part of the ACT, the suburban and surrounding areas. Full analysis of data is not yet done, and only a sample of the potential information is presented in this report.

An adult female Little Eagle fitted with a GPS-transmitter.

A Little Eagle fitted with a GPS-transmitter is released.

Results

Population - Number of Little Eagle territories

In the ACT, over the four years of study, 15 Little Eagle territories have been identified as occupied in one or more years (Table 1). Not all territories were occupied in any year. There were nine pairs on territory in three years and ten in the other. And there were two single birds on territories in 2019 and three in 2020.

Nine pairs of Little Eagles were confirmed with nests in the ACT in the 2017 breeding season, and pairs were observed at two other locations but their status as territory-holding was not confirmed. Five further sightings of birds at potential breeding locations in the ACT were reported by members of the public. Therefore, it is considered that not all breeding pairs were found and other birds were likely not recorded in this initial year of study.

In 2018, nine pairs of Little Eagles were confirmed with nests. One territory that was occupied in 2017 was not occupied in 2018 and one new territory was identified. Birds had been reported at the new site in 2017, but not confirmed by the study. Other birds were observed in potential breeding habitat, some carrying food, several kilometres from any known nests, so it is considered that not all breeding sites were found.

A minimum of nine pairs of Little Eagles were confirmed with nests in 2019, and a tenth pair occupied another territory, but no association with a nest was confirmed. One known territory was unoccupied and one new territory was identified. There were single females in two further territories. And there could have been more breeding pairs as birds were observed in potential breeding habitat.

Twelve territories were occupied in the 2020 breeding season. There was a minimum of nine pairs, seven pairs were proven to have nests, two were suspected to have, and there were two single birds, a male and a female. And at one previously known site a female was observed at a lined nest, but no male and no eggs were seen. Eleven territories occupied by Little Eagles in 2020 were occupied in previous years. Six of these were occupied in all years. One territory was new in 2020, one territory had not been occupied for three years, one for two and another for one year.

Six Little Eagle territories have been identified and monitored in nearby NSW. There were minima of two pairs in 2017, five in 2018, four in 2019 and five in 2020. One territory was not occupied in 2019 or 2020.

More pairs of Little Eagles have been found in each progressive year of the study, in areas that had not been surveyed in previous years. And other birds have been recorded hunting and carrying food in areas beyond that surveyed in this study. Therefore, it likely that more pairs have held territories and bred in the study period. Therefore, the numbers reported here are regarded as a minimum population for the ACT.

The territory which includes the Ginninderry development area as part of those birds' foraging area was occupied in all four years of study. In 2017, a pair began nesting in the previously known nest within the designated protected area for the birds. However, a second male replaced the original one, and although the nest was lined and ready for eggs, the birds shifted to another nest approximately 1.5 km outside the development area. A camera was set

on the first nest and subsequent to the birds leaving it, an emergence of beetles was detected. This could have been a likely reason for the nest to be abandoned when the birds were close to laying in the by then well-lined nest.

Table 1. The number of Little Eagle territories occupied in the ACT and nearby NSW per annum by pairs (X), single male (M), single female (F) or not occupied (0). Empty cells denote that the territory was not monitored that year.

	Territory number	2017	2018	2019	2020
ACT	1	X	X	X	X
	2	X	X	X	X
	3	X	X	0	0
	4	X	X	X	F
	5	X	X	X	X
	6	X	X	X	0
	7	X	X	X	X
	8	X	X	X	X
	9	X	0	0	0
	10		X	F	M
	11			X	X
	12			X	X
	13			F	F
	14			X	X
	15				X
NSW	1	X	X	X	X
	2	X	X	X	X
	3		X	X	X
	4		X	X	X
	5		X	0	0
	6				X

Breeding success - number of young fledged

A minimum of 15 chicks were reared to fledging in the ACT in the four years of study (Table 2). The mean fledging success per pair with a nest was 0.40 chicks reared, range 0.30-0.55 (Table 4). All the successful breeding attempts were in eight of the fifteen territories. In nearby NSW, 11 chicks were reared from four of the six territories monitored (Table 3). The mean fledging success per pair with a nest in the NSW territories was 0.67, range 0.50-0.80 (Table 5). The overall mean breeding success for all pairs with nests in all years was 0.50 chicks fledged; 0.36 in 2017, 0.57 in 2018, 0.46 in 2019 and 0.58 in 2020.

In 2017, of the nine confirmed nesting pairs in the ACT, six laid eggs and four chicks were raised; one from each of two nests and two from another. This was the only brood of two

chicks reared in the four years of study. A single chick was reared at one of two nests in NSW.

In 2018, from nine nesting pairs in the ACT, seven pairs were confirmed to have laid eggs and five pairs reared a chick each. Five pairs with nests were monitored in NSW, four laid eggs and three reared a chick each.

In 2019 six of the nine pairs with nests in the ACT laid eggs. Chicks hatched in four nests and three chicks were successfully reared, all single chicks. In nearby NSW, four pairs had nests, all laid eggs, three hatched chicks and three single chicks fledged.

In 2020, six of seven pairs with nests in the ACT laid eggs, all hatched young and three chicks fledged from each of three nests. In NSW, there were five pairs with nests, and four were proved to lay eggs. All of these fledged single chicks.

The proportion of pairs with a nest in the ACT that laid eggs in 2020 was 85%, and 100% of those hatched. In the previous three years the proportions of pairs that laid eggs were 67, 77 and 67%, and hatching success was 50, 71 and 67%. Therefore, laying and hatching rates were higher in 2020 than in previous years. The main losses in 2020 occurred when no young fledged from nests where chicks had hatched, 50%. In previous years 100, 100 and 75% of chicks survived to fledging. The reasons for breeding failure in the four breeding seasons were; non-laying (11 cases), eggs failing to hatch (5), disturbance by predatory birds (4), and adverse weather (5).

In 2017, three pairs of Little Eagles did not lay eggs, one pair had an infertile egg and another pair lost their egg to predation by a bird, possibly a currawong or raven. Two other pairs lost their egg or small chick to an unknown cause.

In 2018, three pairs did not lay eggs, one nest was blown out of its tree and one pair lost their egg to a Pied Currawong. The other pair failed to hatch an egg. This egg might have been infertile, or the birds could have abandoned it after disturbance by a pair of Wedge-tailed Eagles *Aquila audax.*

In 2019, no eggs were laid at three nests. Eggs failed to hatch at two nests after prolonged incubation (minima of 66 and 78 days). One chick died when only a few days old during a period of hot windy weather. Another nesting attempt failed after disturbance by a pair of Wedge-tailed Eagles during incubation. The Wedge-tailed Eagles landed on the Little Eagle nest, displaced the smaller birds and the two eggs were broken in the process. The nest was then abandoned by the Little Eagles.

In 2020, two pairs did not lay eggs. Chicks died in three nests while young and downy during a period of prolonged heavy rainfall. All three nests were situated in the tops of trees with no canopy above them and a camera set at one of the nests recorded the death of one of two chicks in that nest. Another nest was disturbed by Pied Currawongs and Brown Goshawks and the eagle chicks were not seen again, they were likely killed.

The Little Eagles that have occupied the territory which includes the Ginninderry development area as part of their hunting area reared two chicks during the four years of study; one in 2018 and one in 2020. Eggs were laid in all years, but no egg hatched in 2017 for an unknown reason, and in 2019 the chick died when very young during a period of hot windy weather. Therefore, the fledging success rate for these birds was 0.50, exactly the same as that for all the pairs in the wider study.

Table 2. The number of young fledged from Little Eagle territories in the ACT, where there was successful breeding in any year. The territory numbers are the same as those in table 1. Empty cells denote that the territory was not monitored that year.

	Territory number	2017	2018	2019	2020	Territory Total
ACT	1	2	1	1	0	4
	2	1	1	1	1	4
	4	1	0	0	0	1
	5	0	1	0	1	2
	6	0	1	0	0	1
	7	0	0	1	0	1
	8	0	0	0	1	1
	10		1	0	0	1
Annual total		4	5	3	3	15

Table 3. The number of young fledged from Little Eagle territories in nearby NSW, where there was successful breeding in any year. The territory numbers are the same as those in table 1. Empty cells denote that the territory was not monitored that year.

	Territory number	2017	2018	2019	2020	Territory Total
NSW	1	1	1	1	1	4
	2	0	0	1	1	2
	3		1	0	1	2
	4		1	1	1	3
Annual total		1	3	3	4	11

Table 4. The numbers of Little Eagle pairs with nests, that laid eggs, hatched eggs and successfully reared young in the ACT in 2017-2020.

	2017	2018	2019	2020
Pair with a nest	9	9	9	7
Eggs	6	7	6	6
Hatch	3	5	4	6
Fledge	3	5	3	3
Chicks fledged per pair with a nest	0.33	0.55	0.30	0.43

Table 5. The numbers of Little Eagle pairs with nests, that laid eggs, hatched eggs and successfully reared young in NSW in 2017-2020.

	2017	2018	2019	2020
Pair with a nest	2	5	4	5
Eggs	2	4	4	4
Hatch	1	3	3	4
Fledge	1	3	3	4
Chicks fledged per pair with a nest	0.5	0.61	0.75	0.80

A fledgling Little Eagle (right) perched on a branch next to its nest. The adult female is perched on another branch behind the nest.

Diet – Items found in prey remains and pellets

Food items in prey remains

The remains of 397 individual prey items were collected, 109 in the 2017, 131 in 2018, 96 in 2019, and 61 in 2020 (Fig. 1). The most frequent prey species in the prey remains was European Rabbit (41.8%). Birds, all species, were the main food category (45.6%), and the five most frequently recorded bird species were Crimson Rosella *Platycercus elegans*, Eastern Rosella *Platycercus eximius*, Common Starling, Magpie Lark *Grallina cyanoleuca* and Red-rumped Parrot *Psephotus haematonotus* (Table 6). These four bird species represented 56% of all birds in the prey remains. Reptiles were recorded less frequently (9.1%) and the Eastern Blue-tongue *Tiliqua scincoides scincoides* was the most frequently recorded species. The most frequently recorded other mammal was Brown Hare *Lepus capensis*, and all records were of leverets.

The number of rabbits eaten in 2020 was high compared with the expected figures from chi-square analysis of the numbers of rabbits, birds and reptiles eaten in all four years (χ^2=27.89, df = 6, P < 0.0001). The percentage deviation (PD) was +33.2%, and those for birds and reptiles were lower than expected, PD -17.5% and -62.3% respectively.

Food items in pellets

A sample of 810 pellets were analysed for prey items; 155 pellets from the 2017 season, 343 from 2018, and 312 from 2019. A further 128 were collected in 2020 for later comparative analysis.

The minimum number of food items in the pellets was 326, and the frequency of rabbit was 141 items (43.2%), birds, all species, 122 items (37.4%), and reptiles 52 items (16.0%). There were minima of 11 other mammals eaten and 15 insects. The other mammals were Black Rat *Rattus rattus* (3), Eastern Grey Kangaroo *Macropus giganteus* (3), Brush-tailed Possum *Trichosorurus vulpecula* (2), Red Fox *Vulpes vulpes* (1), House Mouse *Mus musculus* (1) and Sheep *Ovis aries* (1). The reptiles were Eastern Blue-tongue (17), Bearded Dragon *Pogona barbata* (2) and 33 unidentified items. The main bird species were Common Starling (19), Rosellas - Eastern (13), Crimson (6) and unidentified (4), and Galah *Eolophus roseicapilla* (3). Single records of other bird species were; Sulphur-crested Cockatoo *Cacatua galerita*, Feral Pigeon *Columba livia domestica*, Laughing Kookaburra *Dacelo novaeguineae*, Australian Wood Duck *Chenonetta jubata*, Grey Teal *Anas gracilis*, and Superb Fairy-wren *Malurus cyaneus*. There were minima of 11 beetles, Coleoptera, and four grasshoppers, Caelifera.

Food items - all

There was an aggregate 10 species of mammal identified in the either prey remains or pellets, 33 species of birds and four species of reptile. And the counts of food items in prey remains and pellets both show that the most frequently species eaten by Little Eagles in the ACT and nearby NSW are rabbits and birds. Reptiles were a less important food item. The Swamp Wallaby *Wallabia bicolor*, Eastern Grey Kangaroo, sheep and any adult fox would have been taken as carrion, and only parts of the animals eaten. However, one fox cub was recorded in the prey remains and that would have likely been taken alive. The carrion and insects were regarded as insignificant by proportion in the birds' diet and not included in further analysis.

The food items found in the prey remains and pellets were compared from the samples collected at the same times, for the years 2017-2019. There were significantly fewer birds and more reptiles detected in the pellets than were counted at the collections sites (χ^2 = 8.6, P = 0.014, N = 642). The percentage deviation (PD) was -11.5% for birds and +23.2% for reptiles. The PD for rabbits in pellets was +4.5%.

The food items in the prey remains of the birds in the territory which hunt over the Ginninderry development area in the four years of study were rabbit, 7 items (25%), Brown Hare leveret, 1 item (3.6%) and birds, all species, 20 items (71.4%). There were no differences between the frequencies of occurrence of rabbits and birds in the prey remains and pellets found eaten by the birds whose hunting range extends over part of the Ginninderry development area (Fisher Exact test, P=0.46). The amounts of these food items in all prey remains from all other sites were, 152 (45.0%), 154 (45.6) and 32 (9.4%) respectively. There were fewer rabbits and reptiles, and more birds eaten by the eagles whose territory included the Ginninderry development area and at all other territories; (χ^2=8.9, P=0.01, df=2). Two possible reasons for these differences in the diet are that there were fewer rabbits in the hunting area of the eagles in that territory, or the male, who does most of the hunting, specialised in catching birds rather than rabbits or other mammals.

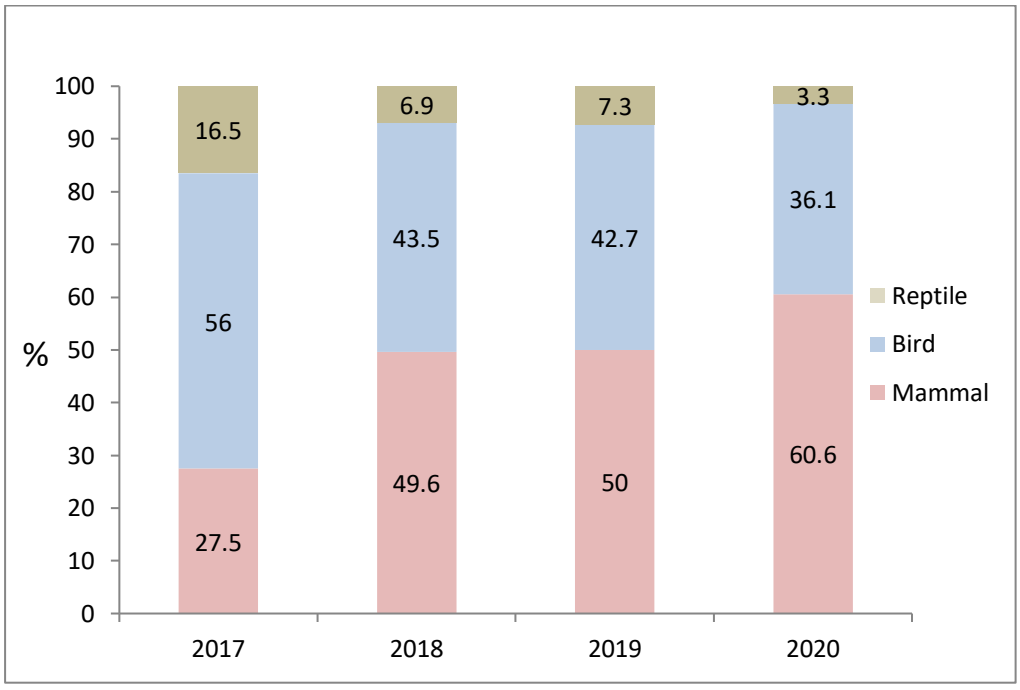

Figure 1. Proportions of prey types, mammal, bird, mammal in the Little Eagle diet from all prey remains found in the ACT and nearby NSW.

Table 6. Minimum numbers of food items identified in Little Eagle prey remains.

Prey species	**2017**	**2018**	**2019**	**2020**	**All years**
European Rabbit *Oryctolagus cuniculus*	27	63	44	32	166
Brush-tailed Possum *Trichosorurus vulpecula*	0	0	0	1	1
Ring-tailed Possum *Pseudocheirus peregrinus*	0	0	1	1	2
Brown Hare *Lepus capensis*	3	2	1	1	7
Swamp Wallaby *Wallabia bicolor*	0	0	0	1	1
Eastern Grey Kangaroo *Macropus giganteus*	0	0	1	0	1
Red Fox *Vulpes vulpes*	0	0	1	0	1
Sheep *Ovis aries*	0	0	0	1	1
All mammals	***30***	***65***	***48***	***37***	***180***
Bird unidentified	10	6	2	0	18
Common Starling *Sturnus vulgaris*	6	5	5	3	19
Eastern Rosella *Platycercus eximius*	5	15	4	2	26
Crimson Rosella *Platycercus elegans*	14	7	12	3	36
Galah *Eolophus roseicapilla*	1	0	0	1	2
Feral Pigeon *Columba livia domestica*	0	1	2	0	3
Australian Wood Duck *Chenonetta jubata*	0	0	0	1	1
Australian Magpie *Cracticus tibicen*	4	3	0	1	8
Magpie Lark *Grallina cyanoleuca*	2	5	3	1	11
Common Myna *Acridotheres tristis*	5	1	1	0	7
Red-rumped Parrot *Psephotus haematonotus*	2	2	2	4	10
Superb Parrot *Polytelis swainsonii*	0	1	0	0	1
Red Wattlebird *Anthochaera carunculata*	2	2	3	1	8
Eurasian Skylark *Aluada arvensis*	3	1	0	0	4
Australian Pipit	1	1	2	1	5

Anthus australis					
Crested Pigeon *Ocyphaps lophotes*	1	0	1	0	2
Noisy Friarbird *Philemon corniculatus*	2	0	0	0	2
Tawny Frogmouth *Podargus strigoides*	2	0	0	0	2
Dollarbird *Eurystomus orientalis*	0	0	1	0	1
Thornbill sp. *Acanthiza sp.*	0	1	1	0	2
Domestic Chicken *Gallus gallus*	0	1	0	0	1
Grey Shrike Thrush *Colluricincla harmonica*	0	1	0	0	1
White-throated Treecreeper *Cormobates leucophaea*	0	1	0	0	1
Fan-tailed Cuckoo *Cacomantis flabelliformis*	0	2	0	0	2
Sacred Kingfisher *Todiramphus sanctus*	0	1	1	0	2
Noisy Miner *Manorina melanocephala*	0	0	0	1	1
Diamond Firetail *Stagonopleura guttata*	0	0	0	1	1
Stubble Quail *Coturnix pectoralis*	0	0	0	1	1
Willy Wagtail *Rhipidura leucophrys*	0	0	0	1	1
White-winged Chough *Corcorax melanorhamphos*	1	0	1	0	2
All birds	***61***	***57***	***41***	***22***	***181***
Lizard unidentified	2	2	0	0	4
Eastern Blue-tongue *Tiliqua scincoides scincoides*	8	5	4	1	18
Bearded Dragon *Pogona barbata*	1	0	0	0	1
Cunningham's Skink *Egernia cunninghami*	7	1	3	1	12
Jacky Dragon *Amphibolurus muricatus*	0	1	0	0	1
All reptiles	***18***	***9***	***7***	***2***	***36***

Dispersion – distribution and dispersive movements

Distribution of Little Eagle nest sites in the ACT 2017-2020

The mean nearest-neighbour distance between nest sites in the ACT was 5.59 km, range: 0.9-10.5 km, which was significantly lower and less variable than a random mean of 9.31 km, range: 1.0-15.0 km (ANOVA, F = 5.4, P = 0.028, n = 13, 13). The G-test statistic for Little Eagle nest site nearest-neighbour distance in the ACT was 0.80. This is a high figure of regularity, where a value of 1 is uniform and <0.65 is random.

Dispersion of Little Eagles fitted with GPS-transmitters in the breeding season

16 birds have been fitted with GPS-transmitters to date, nine adult birds and five juveniles in the ACT, and one adult male and one juvenile in NSW. The transmitter that was fitted to the male in NSW failed a few weeks after deployment and the juvenile was killed by a feral cat soon after fledging, so the data from these birds are not included in this analysis.

The location records of all tagged birds show that Little Eagles occur in most of the northern part of the ACT (Fig. 2). They are widespread across urban/suburban areas and surrounding grasslands, woodland and forests, including high forested ground in the Brindabella range. Full analysis of habitats used will be done when all data have been received from the GPS-transmitters. As no birds in six territories have been tagged, the locations shown in figure 2 are only of birds from 60% of territories known in the ACT, and these other breeding pairs were adjacent to territories of tagged birds. Therefore, much of the area where no locations are marked was likely occupied by un-tagged birds. As the study has concentrated on birds in the northern part of the ACT, no assessment can be made on their movement behaviour in the southern part. Locations are also shown for two birds that were fitted with transmitters in NSW, an adult male, and a juvenile male.

There have been 17,160 location records during the breeding seasons from the six breeding males fitted with GPS-transmitters in the ACT. All these birds mostly stayed within 3 km of their nest site, mean 80.7%, range 66.3-92.9% of records. The median distances of each bird's records from their nest were; 0.2, 0.7, 0.7, 1.2, 1.4 and 1.9 km. All adult males occasionally flew farther than 10 km, the mean farthest distance was 30.9 km, range 13.6-49.6 km.

Three adult females have been fitted with GPS-transmitters, although data was only received from one for about a month, so those records are not included here. And another female did not have a breeding partner or nest, so those data are also excluded. There have been 3,245 location records from the remaining bird and 90.5% of these were within 3 km of the nest. The median distance of all records from the nest was 0.8 km and she also made occasional longer flights, to a maximum 20.8 km.

Five fledgling/juvenile birds in the ACT have been fitted with GPS-transmitters, but one died during the post fledging period; the remains were found below an electricity power line and pole. From the four remaining birds, there are 1383 location records prior to dispersal from the ACT and all mostly stayed within 3 km of the nest site, 99.2% of records. The median distances of each bird's records from their nest were; 0.05, 0.02, 1.16, and 0.28 km. No juvenile birds flew more than 10 km from their nest before making their dispersal flight from the ACT area.

Prior to then, the farthest each bird moved from their nest was; 1.50, 0.02, 5.85 and 6.10 km, mean 3.37 km.

The nearest nest site was approximately 1.5 km from the edge of the Ginninderry development area and the adult male of that pair was fitted with a GPS-transmitter. 3.6% of the location points of the bird were within the development area (Fig. 3). Therefore, most of his movements were outside the development area. These movements were within the area defined by the home range of a tracked male that nested in Ginninderry (previously known as West Belconnen) in two years previous to this study. That bird had a home range of approximately 65 km^2, and 16% of his location records were within the Ginninderry development area (Brawata 2017) (Fig. 4).

A Little Eagle fitted with a GPS-transmitter soars past a hillside.

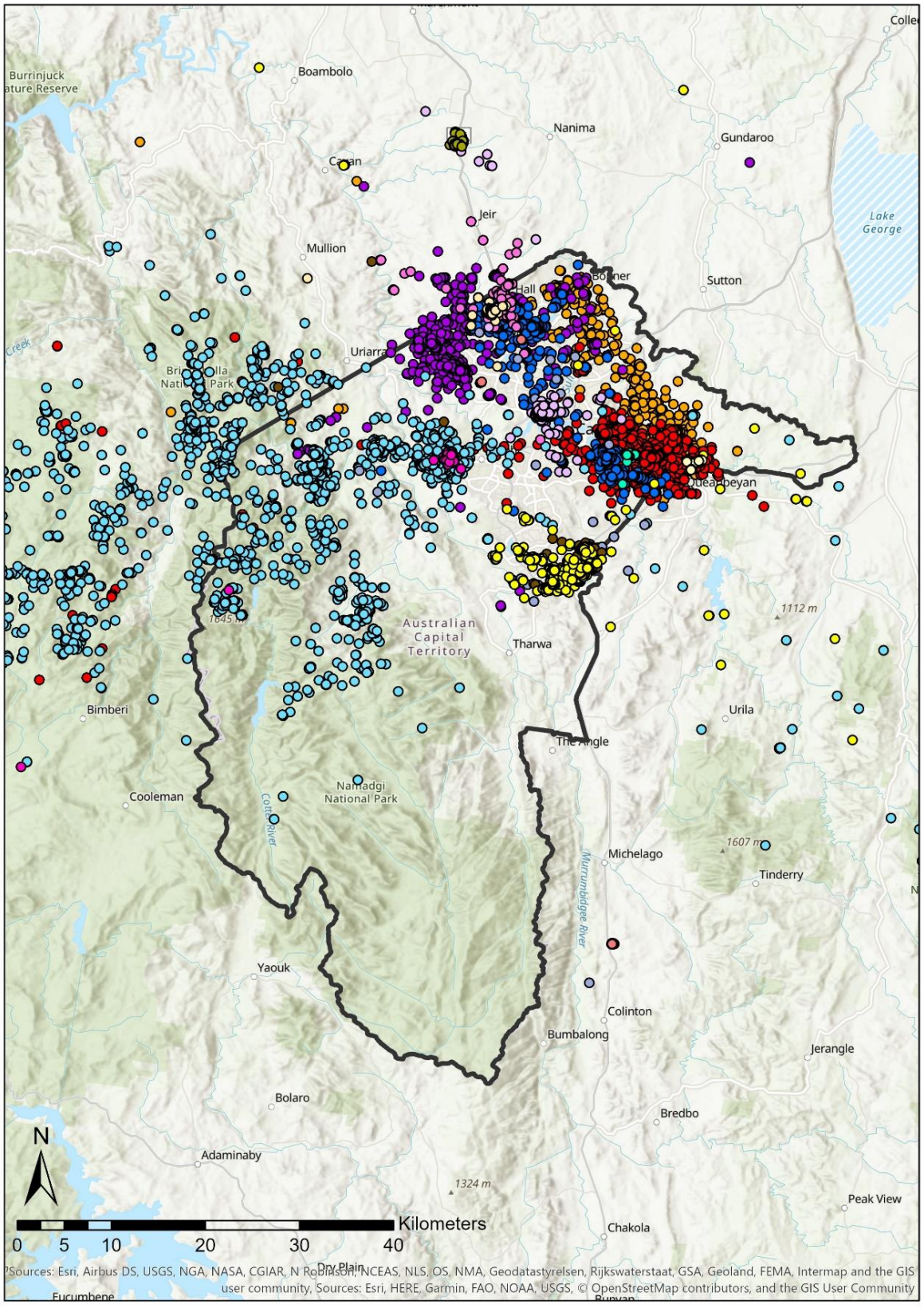

Figure 2. A composite map of the location records of 16 Little Eagles fitted with GPS-transmitters in the ACT area, showing the total distribution in the breeding season. Each bird is represented by a colour. Many of the records are overlaid by others.

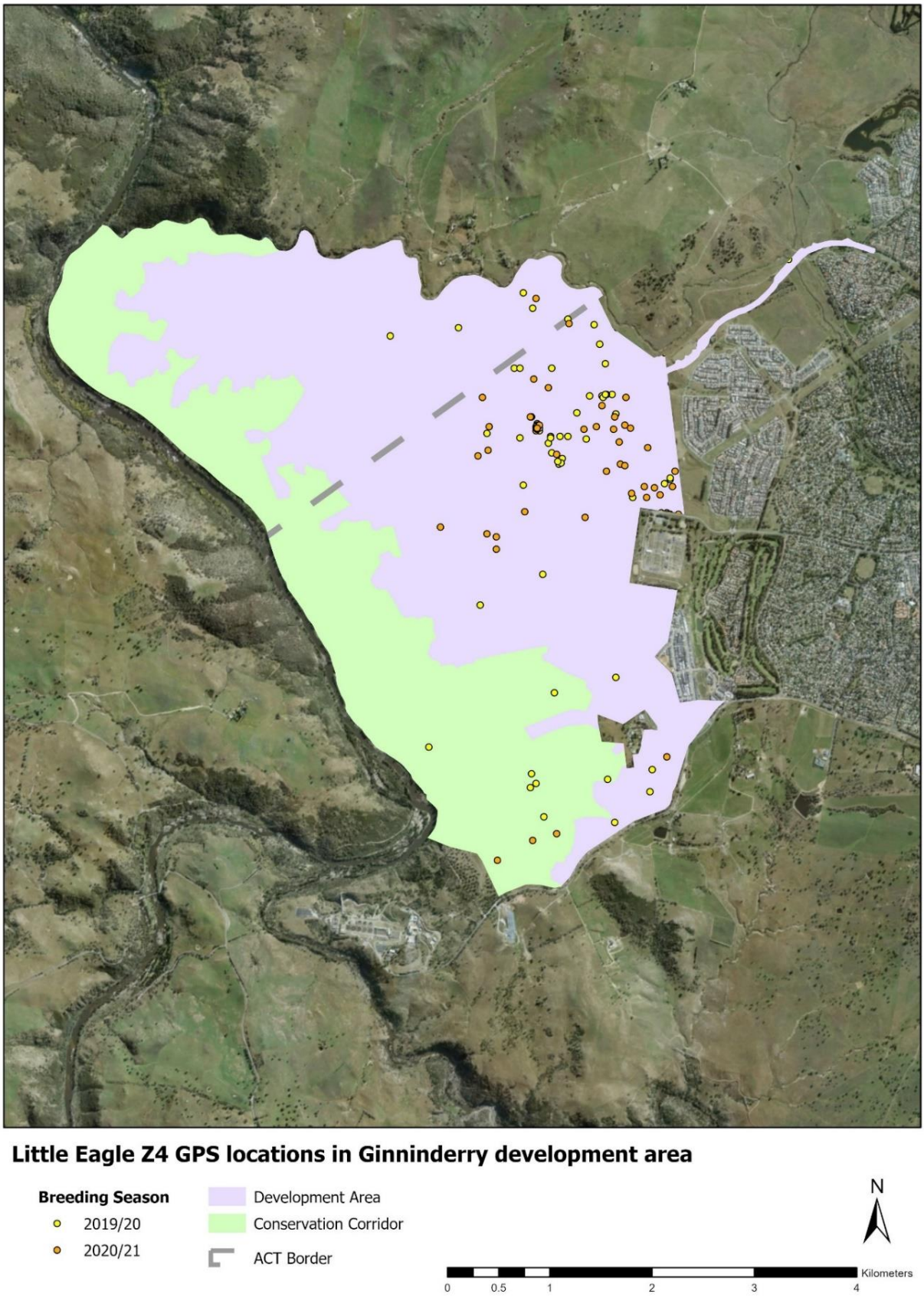

Figure 3. Location records in the Ginninderry development area of the adult male Little Eagle whose home range included the area during this study. The bird's nest was 1.5 km outside the area.

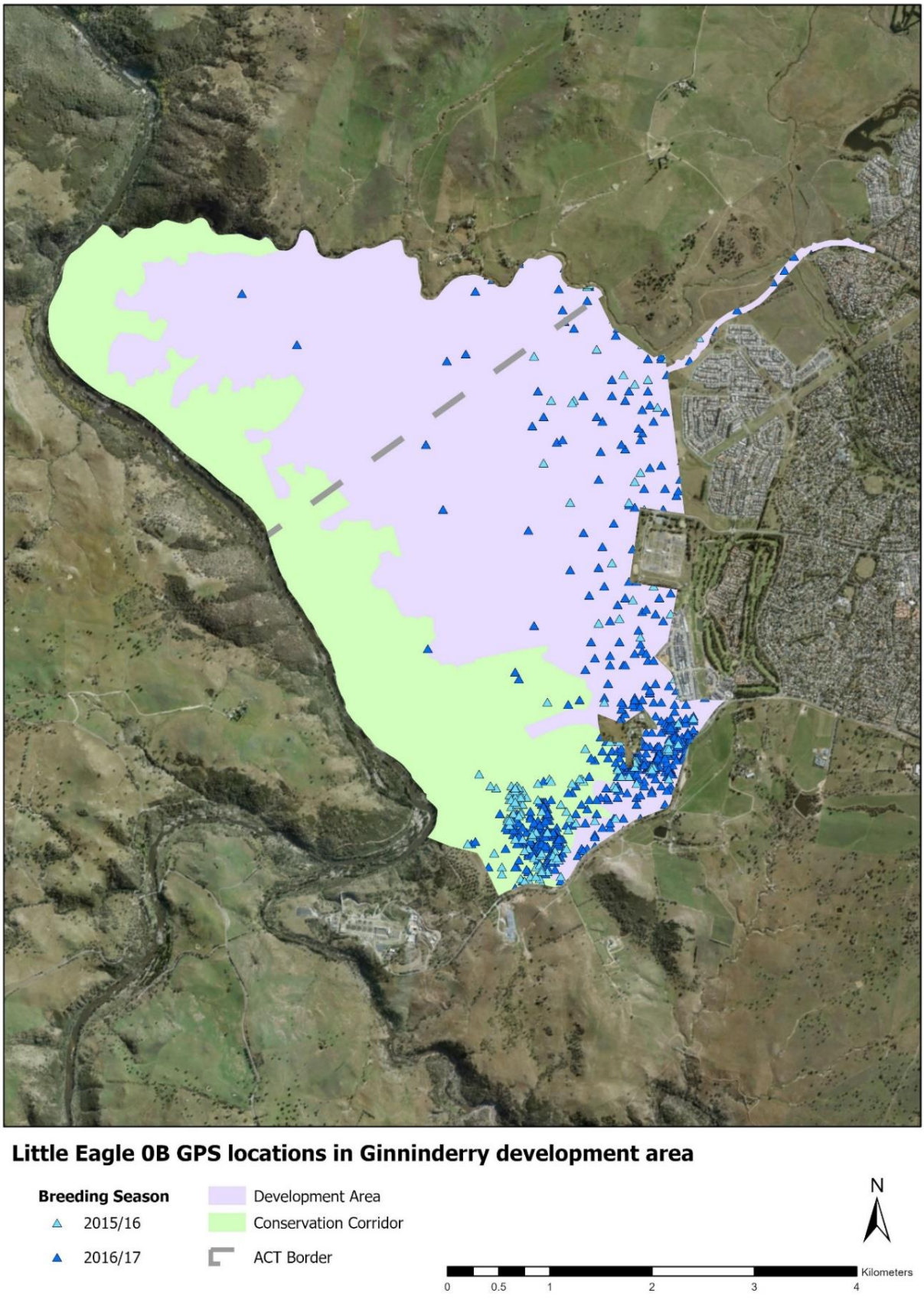

Figure 4. Location records in the Ginninderry development area of the Little Eagle tracked previously, in 2015 and 2016 (Brawata and Gruber 2017). His nest was within the area.

Dispersion of Little Eagles outside the breeding season

The national movements/migrations, including distances and directions moved and habitats used, are based on data from GPS-transmitter tags, and not all data have yet been received. The last of these are expected to be received from the currently deployed tags in 2022/2023.

All four juvenile birds and five adult breeding males left the ACT after the breeding season in all years they were tracked. The GPS-transmitter on one male failed at the end of the breeding season, so no dispersion data were collected for this individual. One adult female left, another remained all autumn and winter in the ACT, 20 km from her nest site in an area occupied by other birds in the breeding season. The mean departure date for all birds that left the ACT in all years was 14 March (day 73) (Table 7). The mean dates for each year were; 11, 09, 18 and 13 March in 2018, 2019, 2020 and 2021 respectively. There was no difference between the mean departure dates of three adult males for whom there are data in years 2019 and 2020 (ANOVA, F= 3.19, P=0.22). The earliest bird to leave the area in any year was a juvenile female (V6) on 15 February 2021. The latest was an adult male (Z4) on 23 April 2021, whose chick was the latest to fledge that year.

Table 7. Departure dates of tracked birds that left the ACT at the end of the breeding season. Juvenile (Juv), adult (Ad), male (M) and female (F).

Bird ID	2018	Day	2019	Day	2020	Day	2021	day
B6 Juv F	11/03/19	70						
D4 Juv M			01/03/19	60				
V2 Juv F			11/03/19	70				
D2 Ad M			25/02/19	56	07/03/20	67		
Z5 Ad M			09/03/19	68	08/03/20	68		
X2 Ad M			28/03/19	87	16/04/20	107		
Z4 AD M					16/03/20	76	23/04/21	113
Y4 AD M							16/02/21	47
Y2 Ad F					14/03/20	74	26/03/21	85
V6 Juv F							15/02/21	46

No tagged juvenile birds have returned to the ACT area. All the adult birds returned to the same breeding areas and those that were tracked for a second winter returned to the same wintering areas. The mean return date for adult migratory birds to their breeding territories in all years was 15 August (day 228) (Table 8). The mean annual dates were; 08 and 20 August in 2019 and 2020 respectively. There was no difference between the mean return dates of three adult males for whom there are data in years 2019 and 2020 (ANOVA, F= 0.15, P=0.74). The earliest bird to arrive back in the ACT in any year was an adult male (X2) on 20 July 2019, and the latest arrival was by the same adult male (Z5) on 05 September in two years, 2019 and 2020. That bird was very consistent in his dates as he also left on the same day in each year, although one date earlier in 2020 as that was a leap year.

Table 8. Arrival dates of tracked birds that returned to the ACT after migration. Adult (Ad), male (M) and female (F).

Bird ID	2019	Day	2020	Day
D2 Ad M	31/07/19	213	16/07/20	197
Z5 Ad M	05/09/19	249	05/09/20	249
X2 Ad M	20/07/19	202	24/08/20	236
Z4 AD M			25/08/20	237
Y2 Ad F			31/08/20	243

Post fledging, juvenile birds dispersed in similar distances to those of adult birds that migrated (ANOVA, F=0.56, P=0.47, n= 6,4), and in similar directions (Watson-Williams F-test, F =0.08, P=0.78, df = 1, 8) (Figs. 5 and 6). The mean farthest distance travelled by all birds that left the ACT was 1543 km. The mean farthest distance travelled by juveniles was 1179 km, range 974-2174 km and those of adults was 1647 km, range 112-2549 km. Seven birds dispersed in a NNW-N direction, one in an easterly direction and two to the south-west. The mean direction travelled by all birds was 331°, S.D. =51, S.E.=17, and this was significantly different from uniform orientation (Rayleigh Z-test = 4.53, P=0.007). One juvenile female (B6) flew north for her first winter season then south-west and back north (Fig. 5).

The habitats used nationally have not been analysed and cannot be until all data are received. However, preliminary results indicate that the birds that wintered in the far north ranged over tropical savannah grassland, one bird went to south-east Queensland sugar cane fields, one spent the winter in a south-east coastal forest area and another hunted in fragments of brown field sites or undeveloped land in and around urban industrial areas of Melbourne city.

The male whose home range included part of the Ginninderry development area was marked as Z4. For the first non-breeding season he was tracked, he migrated to Cape York. He left the ACT on 16 March 2020, which was within four days of the mean departure date of other tracked males that year. In 2021, he did not leave until 24 April and only flew as far as northern New South Wales. That was probably related to the young bird he helped rear that year being late to leave the natal area. Z4 had been with a new female early that breeding season, then when the original female returned late, he paired with her. In consequence, they were the last pair to lay eggs that year. The chick was the last to fledge and it was last seen on 20 April, and Z4 left three days after that. Another tagged male (Y4) left on migration one day after his offspring (V6) had left the natal territory.

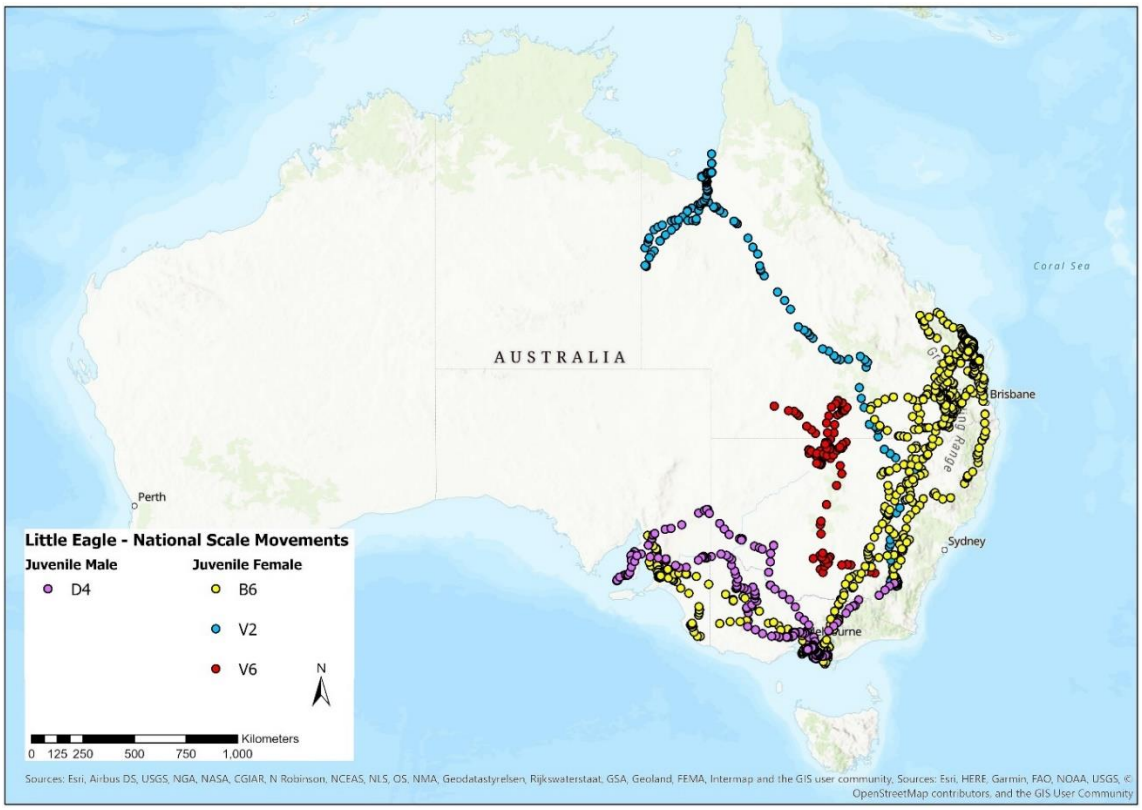

Figure 5. The dispersal routes from the ACT of four GPS-tracked juvenile Little Eagles post fledging.

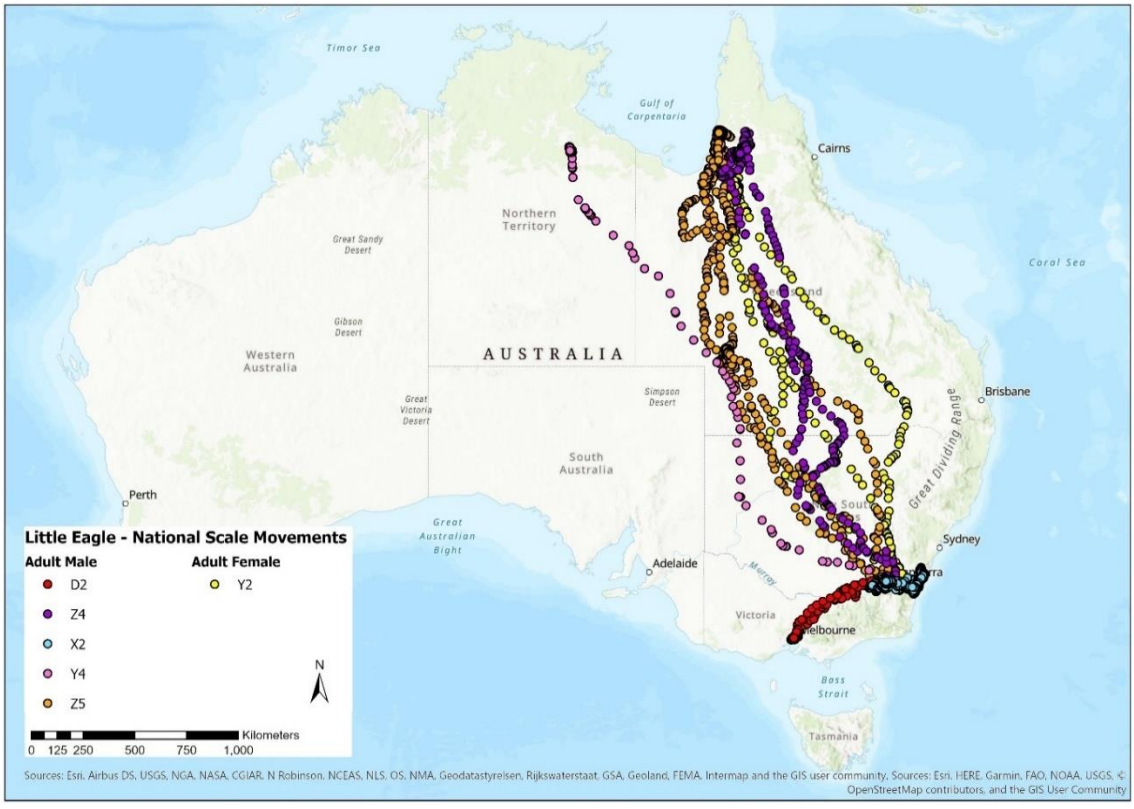

Figure 6. The migration routes from the ACT of six GPS-tracked adult Little Eagles.

Conclusions

Little Eagles were found to be widespread across the northern part of the ACT, with a minimum of 15 territories identified. As the study progressed, more pairs were found annually, some territories were unoccupied in some years, and the breeding success varied annually. These annual variations are expected in population ecology and illustrate how long-term studies can give comprehensive assessment. The southern part of the ACT has yet to be surveyed, so no assessment is given of the number of eagles in that area.

A higher proportion of pairs bred in 2020 compared with the previous three dry years (Rae *et al.* 2021a). There was more rainfall, vegetation growth, and abundant rabbits, which increase after rainfall (King *et al.* 1983), and high breeding success was possibly related to rabbit abundance in New England (Larkin *et al*. 2020). Other raptor species that feed on rabbits have higher breeding success when rabbits are more abundant, such as Wedge-tailed Eagle (Ridpath and Brooker 1986) and the Common Buzzard *Buteo buteo* in Britain (Sim *et al.* 2001). This fits with more and larger eggs being laid when food is abundant (Lack 1968, Galbraith 1988), and higher fledging success was also expected to be higher (Newton 1979, Krist 2011), but this was only slightly greater than in previous years. The high rainfall was conducive to more pairs laying and hatching eggs, but it was detrimental to fledging success. A higher proportion of chicks died in 2020 than in previous years, mostly during heavy prolonged rainfall. Exposure to rain and starvation, which can be caused by the adults inability to catch enough food during prolonged rainfall, are the two most frequent causes of death in young European Sparrowhawks *Accipiter nisus* (Newton 1986). Heavy rain is also the major cause of reproductive failure in Peregrine *Falco peregrinus* and Brown Falcons *Falco berigora* (Olsen and Olsen 1989, McDonald *et al.* 2004). And such rainfall has been related to breeding failure by Booted Eagles *Aquila pennata* in north-west Spain (Bosch *et al.* 2015). The number of young fledged per pair is the most important measure of productivity (Steenhof *et al.* 2017). Although this was high for all pairs in the ACT and NSW in 2020, it would have been higher if so many chicks had not died that year.

The high frequency of rabbits in the Little Eagle diet in 2020, supports the theory that more eagles breed when rabbits are abundant. The bird species most frequently eaten were woodland and grassland species; rosellas, starlings and Red-rumped Parrots, which implies that the eagles mostly hunted birds in these habitats. And there were other species taken less frequently that are only found in woodland; White-throated Treecreeper *Cormobates leucophaea,* Sacred Kingfisher *Todiramphus sanctus,* or grassland; Eurasian Skylark *Aluada arvensis* Australian Pipit *Anthus australis*. This supports previous descriptions of the Little Eagle as hunting over woodland and grassland (Marchant and Higgins 1993). The data from the GPS-telemetry also support this, although they also show that Little Eagles hunt over the urban edge, or pockets of open ground within urban areas, such as undeveloped ground, or margins of roads, rail, or waterways. Such sites could be where the eagles catch rats and mice as well as rabbits and starlings, which are all typical urban species.

The differences in frequencies of birds and reptiles in the prey remains and pellets show the value of collecting both types of food samples. This shows how it is more difficult to identify bird species from small pieces of food items in pellets compared with large feathers and body parts in the field below eagle feeding perches. And it shows how few remains are left on the ground after an eagle has eaten a small reptile. A fuller assessment of the pellets analysis is described in Rae *et al.* (2021b) with references to biases in prey-collection methods (Collopy

1983, Simmons *et al.* 1992), and the value of aggregated assessments of diet, and the need to compare like with like in dietary studies (Steenhof and Kochert 1985, Marti *et al*. 2007).

Little Eagle pairs generally nested at regular spacing at a mean distance of about 5 km. This consolidates the result from a smaller sample size of nest sites in 2017 (Rae *et al.* 2018) and is similar to that found in Victoria, 5.3 km (Baker-Gabb 1984). In New England the spacing was 2-5 km (Debus and Ley 2009) and 3.6 km (Larkin *et al*. 2020). As most breeding movement records from tracked adult males in the ACT were within 3 km of their nest, this would also support this distribution, and is similar to 73% within 3 km of the nest for the closely related Booted Eagle in Spain, which nests 6 km apart (López-López *et al.* 2016). All tracked adult birds in the ACT, male and female, made occasional long flights of more than 10 km from their nest, similar in behaviour to that of Booted Eagles, which fly over 20 km (Bosch *et al.* 2016, López-López *et al.* 2016)

The male bird that held the home range that included the Ginninderry development area in 2020-2021 was mostly recorded outside that area. Most of the location records for a different breeding male bird that previously held that home range were near that bird's nest, and the nest was within the deferred part of the development area (Brawata 2017). The bird in this study had its nest 1.5 km outside the development area and, as with the previous bird, most of the location records were near to the nest and outside the development area. The nest location and bird's location records around the nest are not shown on the maps to reduce risk of disturbance to the birds.

The mean date of adult males leaving on migration post breeding was mid-March and the return date mid-August, the earliest leaving in mid-February and the latest returning in mid-August. It seems that the adult birds might not leave their territory until their offspring have reached full independence of their parents and dispersed from their territory, as has been reported for some other raptors (e.g. Osprey *Pandion haliaetus* Bustamante 1995, Eurasian Kestrel *Falco tinnunculus* Boileau 2014).

Adult migration and juvenile post-fledging movements were dispersive. A previously GPS-tracked adult bird from the Ginninderry development area migrated to the Northern Territory (Brawata *et al.* 2019), and although the birds in this study did not all follow such a south-north direction, the mean direction followed by all adult birds was similar. The movements of some tracked birds over much of the south-east of the continent, and progressively north in autumn and winter by others, support other seasonal observations of Little Eagles and a variety of birds (Griffioen and Clarke 2002, Barrett *et al.* 2003). Such a wide dispersal of Little Eagles outside the breeding season illustrates how the ACT breeding population cannot be considered in isolation from that of the wider national population. The habitats used by birds when outside the ACT were similar to those used locally, such as grassland, woodland, extensive forest, and pockets of urban open land. These movements and habitat use show that this is a mobile and adaptable species.

Little Eagles in the ACT nest in and hunt over land that is in public and private management and the birds seem to be tolerant of proximity to features of urban development and human activity (Rae *et al.* 2018). Urban development was found to positively affect the Booted Eagle via increase in potential prey in urban areas (Palomino and Carrascal 2007), and the increase in the population of the Booted Eagle in western Europe may be a consequence of the species capacity to adapt to environmental change (Suarez *et al.* 2000). It is not known if the Little Eagle population in the ACT is increasing (Olsen and Rae 2017), although the species is adapting to environmental change, as it now lives in urban environments, such as in

the ACT and Melbourne. The way that different raptor species respond to urbanisation is not uniform and may depend on nesting requirements, feeding ecology and vulnerability to disturbance, and it is important to study the breeding performance of raptors in urban environments on a species-by-species basis (Kettel *et al.* 2018).

A large-scale management approach has been recommended for the Booted Eagle, taking into account the full home range and all habitats used by hunting birds when applying conservation measures (López-López *et al.* 2016). The current study has such information, which can be and has already been used to guide conservation of the Little Eagle in the ACT. Nest site locations and delineation of breeding territories are already providing information relevant to and considered within ACT planning and development decisions. The information provided by the study has also guided management activities, such as the location and timing of prescribed burns, the timing of weed spraying, usage and maintenance activities within ACT Government horse paddocks and how rabbit and rodent control is undertaken.

This study has confirmed that a national approach is required for successful conservation of the Little Eagle, and application of the knowledge gained can help guide other local land managements and aid cumulative nationwide conservation.

A Little Eagle flies over power-lines in an urban area of the ACT, and a Dusky Woodswallow *Artamus cyanopterus* passes close overhead.

Research reports and journal papers based on results from this study

Rae, S. (2018). Little Eagles in the ACT and nearby NSW in 2017/18 A brief summary from the Little Eagle Research Group. *Gang-gang* April 2018: 6.
http://canberrabirds.org.au/wp-content/uploads/2012/03/GG-2018-April-web.pdf

Rae, S., Fletcher, D., Mulvaney, M., Davies, M., Roberts, D., and Olsen, P. (2018). Notes on the breeding ecology of Little Eagles in the ACT in 2017/2018. *Canberra Bird Notes* 43: 186-193.
http://canberrabirds.org.au/wp-content/uploads/2012/03/CBN-43-2-final.pdf

Brawata, R., Rae, S., Gruber, B., Reid, S. and Roberts, D. (2019). Confirmation of Little Eagle (*Hieraaetus morphnoides*) migration by satellite telemetry. *Australian Journal of Zoology* 66: 247-250.
https://www.publish.csiro.au/ZO/ZO18060

Rae, S., Wimpenny, C., Mulvaney, M., Davies, M., Fletcher, D., Roberts, D., and Olsen, P. (2019). Preliminary results from study of Little Eagles in the ACT and nearby NSW in 2018-2019. *Canberra Bird Notes* 44: 145-151.
http://canberrabirds.org.au/wp-content/uploads/2019/07/CBN_44_2_final-for-web.pdf

Rae, S., Mulvaney, M., Fletcher, D., Wimpenny, C., Brawata, R., Kiggins, R., Stol, J., Davies, M., Roberts, D. and Olsen, P. (2020). The breeding success and diet of Little Eagles in the ACT and nearby NSW in a dry year, 2019. *Canberra Bird Notes* 45: 158-166.
http://canberrabirds.org.au/wp-content/uploads/2020/07/CBN-45-2-final-2.pdf

Rae, S., Mulvaney, M., Wimpenny, C., Brawata, R., Stol, J., Davies, M., Fletcher, D. Roberts, D. and Olsen, P. (2021). The breeding ecology of Little Eagles in the ACT and nearby NSW in 2020. *Canberra Bird Notes* 46: 57-63.

Rae, S., Davies, M., Mulvaney, M., Fletcher, D., Kiggins, R., Stol, J., Roberts, D., and Olsen, P. (2021). Prey items identified from Little Eagle pellets collected in and around the Australian Capital Territory. *Canberra Bird Notes* 46: 64-69.

Rae. S. and Roberts. D. (in prep). Nest abandonment by Little Eagles and emergence of beetles from the nest.

Further information on the Little Eagle Research Project can be accessed online at:

Website: https://littleeagleresearch.blogspot.com/

Facebook: https://www.facebook.com/LittleEagleResearchGroup/

References

Baker-Gabb, D. J. (1984). The breeding ecology of twelve species of diurnal raptor in north-western Victoria. *Wildlife Research* 11: 145-160.

Barrett, G., Silcocks, A., Barry, S., Cunningham, R. and Poulter, R. (2003). *New atlas of Australian birds*. Birds Australia, Melbourne.

Boileau, N. and Bretagnolle, V. (2014). Post-fledging dependence period in the Eurasian Kestrel (*Falco tinnunculus*) in western France. *Journal of Raptor Research* 48: 248-256.

Bosch, J., Martínez, J. E., Calvo, J. F., Zuberogoitia, I., & Jiménez-Franco, M. V. (2015). Does rainfall affect the productivity of the Booted Eagle (*Aquila pennata*) during the breeding period in Mediterranean environments? *Journal of Ornithology* 156: 1-8.

Bosch, J., Calvo, J. F., Bermejo, A., & de la Puente, J. (2016). Factors influencing the movements during the breeding season of a female booted eagle (*Aquila pennata*) tagged by satellite in central Catalonia (Spain). *Slovak Raptor Journal* 10: 81-94.

Brawata, R. and Gruber, B. (2017). *A comparison of the breeding and non-breeding home range of a male Little Eagle (Hieraaetus morphnoides) near the proposed Ginninderry Development, Australian Capital Territory*. Phase 2 report to Riverview Developments. (Institute for Applied Ecology: University of Canberra, Canberra).

Brawata, R., Rae, S., Gruber, B., Reid, S. and Roberts, D. (2019). Confirmation of little eagle (*Hieraaetus morphnoides*) migration by satellite telemetry. *Australian Journal of Zoology.* 66: 247-250.

Brown, D. (1975). A test of randomness of nest spacing. *Wildfowl* 26: 102-3.

Brown, L., and Amadon, D. (1968). *Eagles, Hawks and Falcons of the World*. Hamlyn Publishing Group Limited, Feltham.

Brown, L.H. and Watson, A. (1964). The Golden Eagle in relation to its food supply. *Ibis* 106: 78-100.

Bureau of Meteorology (2018). Australian Capital Territory in 2017: warm days, chilly winter nights, and drier than average. *Australian Government*. http://www.bom.gov.au/climate/current/annual/act/archive/2017.summary.shtml

Bureau of Meteorology (2019). Australian Capital Territory in 2018: dry with record warm days. *Australian Government.* http://www.bom.gov.au/climate/current/annual/act/summary.shtml

Bureau of Meteorology (2020a). Climate data online. Bureau of Metrology, Canberra. *Australian Government*. http://www.bom.gov.au/climate/data/

Bureau of Meteorology (2020b). Australian Capital Territory in 2019: dry with the highest average daytime temperatures on record. *Australian Government*. http://www.bom.gov.au/climate/current/annual/act/summary.shtml

Bureau of Meteorology (2021). Australian Capital Territory in 2020: wet with warm nights. *Australian Government.* http://www.bom.gov.au/climate/current/annual/act/summary.shtml

Bustamante, J. (1995). The duration of the post-fledging dependence period of Ospreys *Pandion haliaetus* at Loch Garten, Scotland. *Bird Study* 42: 31-36.

Clouet, M., Gerard, J. F., Goar, J. L., Goulard, M., González, L., Rebours, I., and Faure, C. (2017). Diet and breeding performance of the Golden eagle Aquila chrysaetos at the eastern and western extremities of the Pyrenees: an example of intra-population variability. *Ardeola* 64: 347-361.

Collopy, M.W. (1983). A comparison of direct observations and collections of prey remains in determining the diet of Golden Eagles. *J. Wildl. Mgmt.* 47: 360–368.

Debus, S. (2017). *Australasian Eagles and Eagle-like Birds*. CSIRO Publishing, Clayton

South.
Debus, S.J.S. and Ley, A.J. (2009). Aspects of the breeding cycle of the Little Eagle *Hieraaetus morphnoides*. *Australian Field Ornithology* 26: 76–99.
Dennis, R.H., Ellis, P.M., Broad, R.A. and Langslow, D.R. (1984). The Status of the Golden Eagle in Britain. *British Birds* 77: 592-607.
Galbraith, H. (1988). Effects of egg size and composition on the size, quality and survival of Lapwing *Vanellus vanellus* chicks. *Journal of Zoology* 214: 383-398.
Griffioen, P. A. and Clarke, M. F. (2002). Large-scale bird-movement patterns evident in eastern Australian atlas data. *Emu* 102: 99-125.
Hardey, J., Crick, H., Wernham, C., Riley, H., Etheridge, B. and Thompson, D. (2013). Raptors: A Field Guide to Survey and Monitoring. The Stationery Office, Edinburgh.
Hayhow, D.B., Benn, S., Stevenson, A., Stirling-Aird, P.K. and Eaton, M.A. (2017). Status of Golden Eagle *Aquila chrysaetos* in Britain in 2015. *Bird Study* 64: 281-294.
Holland, J. (2019a). Summary/analysis of the past month and what to watch out for this month. *Gang-gang*, November 2019: 1-6.
Holland, J. (2019b). Sunday 10 November – Campbell Park nest workshop. *Gang-gang*, November 2019: 7-9.
Kettel, E. F., Gentle, L. K., Quinn, J. L., and Yarnell, R. W. (2018). The breeding performance of raptors in urban landscapes: a review and meta-analysis. *Journal of Ornithology* 159: 1-18.
King, D. R., Wheeler, S. H., and Schmidt, G. L. (1983). Population fluctuations and Reproduction of rabbits in a pastoral area on the coast north of Carnarvon, WA. *Wildlife Research* 10: 97-104.
Kovach, W.L. (2010). Oriana – Circular Statistics for Windows, Ver. 3. Kovach Computing Services, Pentraeth. http://www.kovcomp.com/oriana
Krist, M. (2011). Egg size and offspring quality: a meta-analysis in birds. *Biological Review* 86: 692-716.
Lack, D. (1968). *Ecological Adaptations for Breeding in Birds*. Methuen, London.
Larkin, C., Jenkins, R., McDonald, P.G. and Debus, S.J. (2020). Breeding habitat, nest-site characteristics and productivity of the Little Eagle (*Hieraaetus morphnoides*) near Armidale, New South Wales. *Pacific Conservation Biology* 26: 258-268.
Local Land Services (2020). Rabbits a strong focus this spring. *New South Wales Government*. https://www.lls.nsw.gov.au/regions/murray/articles,-plans-and-publications/production- advice-august-2020/rabbits-a-strong-focus-this-spring
López-López, P., de La Puente, J., Mellone, U., Bermejo, A., & Urios, V. (2016). Spatial ecology and habitat use of adult Booted Eagles (Aquila pennata) during the breeding season: implications for conservation. *Journal of ornithology* 157: 981-993.
McDonald, P. G., Olsen, P. D., and Cockburn, A. (2004). Weather dictates reproductive success and survival in the Australian Brown Falcon *Falco berigora*. *Journal of Animal Ecology* 73: 683-692.
Marchant, S. and Higgins, P.J. eds. (1993). *Handbook of Australian, New Zealand and Antarctic Birds*, Vol. 2 (Oxford University Press, Melbourne).
Marti C.D., Bechard, M. and Jaksic, F.M. (2007). Food habits. *Raptor Research and Management Techniques* (Eds D.M. Bird, K.L. Bildstein & A. Zimmerman) pp. 129-152. Raptor Research Foundation, Washington.
Moss, E. H., Hipkiss, T., Oskarsson, I., Häger, A., Eriksson, T., Nilsson, L. E., and Hörnfeldt, B. (2012). Long-term study of reproductive performance in Golden Eagles in relation to food supply in boreal Sweden. *Journal of Raptor Research* 46*:* 248-257.
Newton, I. (1979). *Population ecology of raptors*. Poyser, Berkhamsted.
Newton, I. (1986). *The Sparrowhawk*. T & A D Poyser Ltd. Waterhouses.

Newton, I., Marquiss, M., Weir, D.N. and Moss, D. (1977). Spacing of sparrowhawk nesting territories. *Journal of Animal Ecology* 46: 425-441.

Olsen, P.D. and Olsen, J. (1989). Breeding of the peregrine falcon *Falco peregrinus*. III. Weather, nest quality and breeding success. *Emu* 89: 6–14.

Olsen, P. and Rae, S. (2017). Invalid evidence for purported 'collapse' in the number of breeding Little Eagles in the Australian Capital Territory. *Canberra Bird Notes* 42: 245-249.

Palomino, D. and Carrascal, L. M. (2007). Habitat associations of a raptor community in a mosaic landscape of Central Spain under urban development. *Landscape and Urban Planning* 83: 268-274.

Rae, S., Fletcher, D., Mulvaney, M., Davies, M., Roberts, D., and Olsen, P. (2018). Notes on The breeding ecology of Little Eagles in the ACT in 2017/2018. *Canberra Bird Notes* 43: 186-193.

Rae, S., Wimpenny, C., Mulvaney, M., Davies, M., Fletcher, D., Roberts, D., and Olsen, P. (2019). Preliminary results from study of Little Eagles in the ACT and nearby NSW in 2018-2019. *Canberra Bird Notes* 44: 145-151.

Rae, S., Mulvaney, M., Fletcher, D., M., Wimpenny, C., Brawata, R., Kiggins, R., Stol, J., Davies, M., Roberts, D., and Olsen, P. (2020). The breeding success and diet of Little Eagles in the ACT and nearby NSW in a dry year, 2019. *Canberra Bird Notes* 45: 158-166.

Rae, S., Mulvaney, M., Wimpenny, C., Brawata, R., Stol, J., Davies, M., Roberts, D. and Olsen, P. (2021a). The breeding success and diet of Little Eagles in the ACT and nearby NSW in 2020. *Canberra Bird Notes* 46: 57-63.

Rae, S., Story, G., Davies, M., Mulvaney, M., Fletcher, D., Kiggins, R., Stol, J., Roberts, D., and Olsen, P. (2021b). Prey items identified from Little Eagle pellets collected in and around the Australian Capital Territory. *Canberra Bird Notes* 46: 64-69.

Ridpath, M.G. and Brooker, M.G. (1986). The breeding of the Wedge-tailed Eagle *Aquila audax* in relation to its food supply in arid Western Australia. *Ibis* 128: 177-194.

Sim, I. M. W., Cross, A. V., Lamacraft, D. L., & Pain, D. J. (2001). Correlates of Common Buzzard *Buteo buteo* density and breeding success in the West Midlands. *Bird Study* 48: 317-329.

Simmons, R.E., Avery. D.M. and Avery. G. (1992). Biases in diets determined from pellets and remains: Correction factors for a mammal and bird-eating raptor. *Ibis* 25: 63-67.

Steenhof. K. and Kochert. M.N. (1985). Dietary shifts of sympatric buteos during a prey decline. *Oecologia* 66: 6-16.

Steenhof, K. and Peterson, B.E. (2009). American Kestrel reproduction in southwestern Idaho: annual variation and long-term trends. *Journal of Raptor Research* 43: 283-290.

Steenhof, K., Kochert, M.N., McIntyre, C.L. and Brown, J.L. (2017). Coming to terms about describing Golden Eagle reproduction. *Journal of Raptor Research* 51: 378–390.

Suárez, S., Balbontín, J., & Ferrer, M. (2000). Nesting habitat selection by Booted Eagles *Hieraaetus pennatus* and implications for management. *Journal of Applied Ecology: Standard Papers* 37: 215-223.

The Canberra Times (2021). Canberra feral rabbit population increases due to weather. https://www.canberratimes.com.au/story/7111721/whats-behind-canberras-feral-rabbit-boom/

Thiollay, J. M. (2006). The decline of raptors in West Africa: long-term assessment and the role of protected areas. *Ibis*, *148*(2), 240-254.

Watson, J., Langslow, D.R. and Rae, S.R. **(**1987). *The Impact of Land-Use Changes on Golden Eagles in the Scottish Highlands*. CSD Report no. 720. Nature Conservancy Council, Peterborough.

Watson, A. and Rae, S. (2019). *Observations on Golden Eagles in Scotland*. Hancock House,

Surrey.
Watson, A. and Rothery, P. (1986). Regularity in spacing of Golden Eagle *Aquila chrysaetos* nests used within years in northeast Scotland. *Ibis* 128: 406-408.
Watson, J., Leitch, A.F. and Rae, S.R. (1993). The diet of Golden Eagles *Aquila chrysaetos* in Scotland. *Ibis* 135(4): 387-393.
Watson, J., Rae, S.R. and Stillman, R. (1992). Nesting density and breeding success of Golden Eagles in relation to food supply in Scotland. *Journal of Animal Ecology* 61: 543-550.
Watson, A., Rae, S., and Payne, S. (2012). Mirrored sequences of colonisation and Abandonment by pairs of Golden Eagles *Aquila chrysaetos*. *Ornis Fennica* 89: 229-232.

An adult female Little Eagle perched in a deciduous tree in winter in the ACT, overlooking a rabbit warren.