

Urban corvids on the move: habitat use and movement ecology of the Little Raven *Corvus mellori* at a peri-urban wetland

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Corvids can prey intensely on threatened birds, such that this process is difficult to manage and represents a significant conservation challenge. Fundamental to developing any management intervention is the need to understand habitat use and movement of the target species. Global Positioning System (GPS) tracking devices were fitted to Little Ravens *Corvus mellori* in a wetland complex where they were known to prey extensively on ground-nesting Red-capped Plover *Charadrius ruficapillus* eggs. Movement data of nine Little Ravens were acquired between June and July 2013. Movements were recorded for a mean of 7.70 ± 0.56 days (range 4.79 – 9.94 days). Data on sightings of colour-banded birds also were collected to investigate dispersal from the trapping site (total number of birds banded = 112 during October 2011 – July 2013). Little Ravens used large areas [mean 53.41 ± 21.17 se km² (range 1.90 – 206.78 km², $n = 9$)], within which they were highly mobile, moving up to 10.6 km in an hour ($n = 1272$ movements). Most birds used both human-modified and natural habitats, preferring open (56.2%) and urban habitats (28.8%). The mean dispersal distance of males from the trapping site was 42.3 percent shorter than that of females. The use of large areas and variation among individuals in habitat use may render localised management of Little Raven populations problematic. Management options, such as the use of small scale raven exclusion cages, may be effective in protecting populations of their prey.

INTRODUCTION

Space use and movement patterns of animals are intricately linked with their use of habitats, resources, and landscapes (Cagnacci *et al.* 2010; Potts *et al.* 2014). Resources can vary temporally and spatially with varying degrees of predictability and animals that exploit such resources adjust their movement patterns accordingly (Matthews *et al.* 2011; Barnett and Semmens 2012). Space use patterns of highly mobile animals, especially those that are either threatened or that perform a critical ecological function in the landscape (e.g. predators), are key to understanding the functions of habitats and landscapes which constitute the basis for conservation and management (Louzao *et al.* 2012; Schofield *et al.* 2013). Recent studies on space use and movement patterns of bird species that thrive in human-modified landscapes have elucidated the extent to which these birds exploit anthropogenic resources (e.g. studies of foraging, breeding, roosting) (Marzluff and Neatherlin 2006; Salinas-Melgoza *et al.* 2013). Knowledge of space use of such species, especially if they are predators that can affect the survival of members of prey species, is of particular interest with respect to managing species, ecosystems and landscapes (Scarpignato and George 2013).

Corvids are well known for their predatory behaviour in many natural and human-modified landscapes (Austin and Mitchell 2010; Peery and Henry 2010; Barbaree *et al.* 2014). Their ability to exploit anthropogenic resources and urban habitats has contributed to substantial increases in abundance of some corvid populations (Archer 2001; Brown and Jones 2016; BirdLife Australia's atlas of Australian birds and Birdata

2017). Some corvids are versatile and effective egg predators, and considered to be amongst the most intelligent of birds (Santisteban *et al.* 2002; Emery and Clayton 2004; Izawa and Watanabe 2011). They can learn from conspecifics, and this cultural learning underpins rapid foraging adjustments and diet shifts (Sonerud *et al.* 2001; Holzhaider *et al.* 2010). Corvids can move considerable distances in response to temporal and spatial variation in food availability (Marzluff and Neatherlin 2006). They can also aggregate near colonies of ground-nesting bird species and prey heavily on eggs (Ewins 1991; Kelly *et al.* 2005). Growth in corvid populations, coupled with increasing rates of egg depredation on other species, has resulted in corvids being increasingly recognised as a threat to native biodiversity (Luginbuhl *et al.* 2001; Peery and Henry 2010), yet in some places including Australia, their patterns of space use and movements have received little attention.

Our study was predicated on high rates of egg loss of a common, ground-nesting, shorebird species, the Red-capped Plover *Charadrius ruficapillus* (hereafter 'plover') at Cheetham Wetlands, a peri-urban wetland in south-central Victoria, Australia (Ekanayake *et al.* 2015c). Little Ravens *Corvus mellori* (hereafter 'ravens' or 'Little Ravens') are the principal predators of plover eggs and have also been observed preying on adults and young (Lomas *et al.* 2014; Ekanayake *et al.* 2015c; Tan *et al.* 2015). The plover breeding season is long (August – March) at this site, and yet the species exhibits extremely low reproductive success which may threaten population viability (Lomas *et al.* 2014; Ekanayake *et al.* 2015c; Tan *et al.* 2015). Although ravens have not yet formally been recognised as a significant threat to biodiversity, the impact of their growing

populations and increasing predation rates may soon require management. Therefore, the objective of this study was to examine the spatial ecology of Little Ravens, as it is important to gain a better understanding of habitat use and movements to develop effective management strategies.

METHODS

Study site and species

This study was conducted at, and around, the Cheetham Wetlands, west of Melbourne, Victoria, Australia (37° 53' S, 144° 47' E; 420 ha; Fig. 1). There is a sizeable (minimum count = 200 individuals) population of breeding red-capped plovers at the wetland (Tan *et al.* 2015), and ravens intensively prey upon the eggs (78.6% of clutches) of breeding plovers (Ekanayake *et al.* 2015b; Ekanayake *et al.* 2015c). Therefore, the study area was centred on the wetlands and the surrounding landscape, which comprised a mixture of open space (grassland and agricultural fields), urban areas and industrial estates, that were potentially used by ravens.

Ravens were trapped at Cheetham Wetlands from October 2011 – July 2013 using a ‘Modified Australian Crow Trap’ (Moran 1991). To increase capture success, free feeding of ravens was undertaken at the trapping site two weeks prior to trapping. A mixture of meat, dog food and bread was offered before and during trapping, and water was provided inside the trap. Trapping was conducted during daytime (0730 – 1630 hr). The trap was monitored continuously while set and all captured birds were removed immediately. Birds were then measured and released as quickly as possible. A total of 112 ravens were captured.

Each trapped bird was banded on its right tarsus with an Australian Bird and Bat Banding Scheme (ABBBS) metal band and colour-banded on its left tarsus with a plastic yellow band with a unique three-digit number to permit identification from a distance. The age (juvenile, immature or adult, based on eye colour; Rowley 1970) was recorded for each bird. Up to three sub-humeral feathers from the underwing and blood (70 µl) from the tarsal vein were collected for genetic determination of sex in this monomorphic species (Bedrosian *et al.* 2008).

GPS tracking device attachment and deployment

Eleven adult ravens were fitted with GPS tracking devices (Quantum 4000E Mini Backpack, 18 g; Telemetry Solutions, Concord, California, USA; hereafter ‘tracking devices’). These devices were manufactured with a ‘remote data download’ functionality which enabled the GPS locational data (hereafter ‘GPS fixes’) acquired to be downloaded remotely (within a ~100m radius) without the need to recapture the bird. This feature was purposely added to the tracking devices because of the low rate of recapture of ravens (2.7% recapture rate, $n = 112$). A small Very High Frequency (VHF) transmitter was fitted to each tracking device to enable us to locate birds using conventional radio-tracking methods and then download the data remotely. Thus, each tracking device possessed two antennae; a thicker antenna for the remote download of data and a thinner antenna for the VHF transmitter. The tracking devices were configured to acquire GPS fixes every 15 minutes from

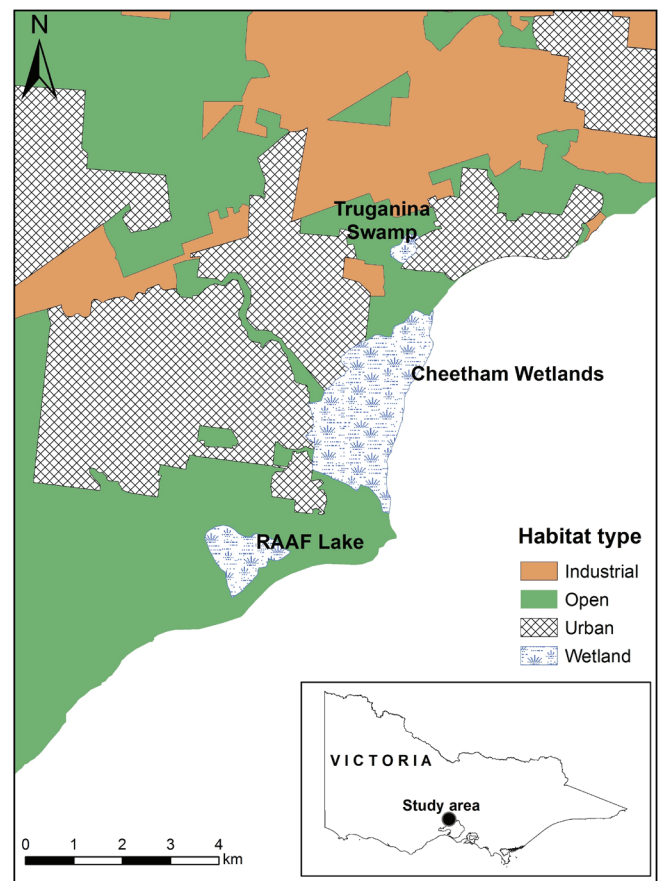


Figure 1. Location of the study area in peri-urban Melbourne, Victoria. Different habitat types close to where Little Ravens were trapped (Cheetham Wetlands) are shown.

0600 to 1800 hr and every 180 minutes from 1800 to 0600 hr. The sample size was limited to 11 birds because of available funds, but also because data with high temporal and spatial resolution from a small sample of birds were preferred to data of lower resolution from a larger sample of birds that might have been available if alternative technologies, such as conventional VHF radio-trackers (documented in Whisson *et al.* 2015), had been used.

Adult birds averaged 520 ± 8 se grams (g) and the weight of tracking devices represented 3.65 ± 0.05 se percent of body weight. Tracking devices were attached to the two central rectrices, so that they were shed during moult. Feather barbs were laterally trimmed, then superglue and Tesa tape were used to attach the tracking device to the dorsal aspect of the feather shaft. The device was positioned to ensure that the two antennae ran down the length of the rectrices to reduce potential drag and its influence on the behaviour of the bird. The antennae were attached to one of the rectrices with cotton thread and superglue. The entire attachment process lasted a maximum of 60 minutes before the birds were released at the trapping location. Tracking devices were deployed during the months of June and July in order to avoid the major part of the Little Raven's breeding season (August – November) and the period of tail feather moult (January – February) (Higgins *et al.* 2006).

Telemetry

Birds fitted with tracking devices were observed displaying apparently normal behaviour (i.e. flying, flocking and foraging with conspecifics) soon after release, suggesting that the devices were not adversely affecting their behaviour. As it was advised that battery life of tracking devices would last a minimum of 14 days, it was decided that attempts to download data remotely would occur in the following order: first attempt 5 days after deployment, second at 3 days after first attempt, third at 2 days after second attempt, and attempts every day thereafter until it was deemed that the battery had expired. To remotely download data, first the bird was located using a R-1000 Telemetry Receiver with a Three-element Yagi antenna (Communications Specialists, Inc., Orange, California, USA), either by triangulation from fixed points or by moving in on the signal. Once it was deemed that the bird was within a 400 metre (m) radius, data were downloaded using the Quantum Remote Download Base Station (Communications Specialists, Inc., Orange, California, USA) connected both to a Three-element Yagi antenna and a laptop computer. Data were accessed using the Collar software (Telemetry Solutions, Concord, California, USA).

Movement data of only nine of the 11 ravens that had tracking devices could be downloaded, because two ravens could not be located after the device was fitted (possibly due to device failure, given previous experience with other radio-tracked ravens; Whisson *et al.* 2015). The data were of limited duration (mean 7.70 ± 0.56 days) because of the unexpectedly short battery life of tracking devices (range 4.79 – 9.94 days). Eight of the nine ravens had data comprising more than 100 GPS fixes (mean 145 ± 19 fixes, range 92 – 281 fixes). Individual ravens were coded sequentially i.e. R1, R2 etc., in the order of tracking device deployment. Data from five male (R2, R5, R6, R7 and R9) and four female (R1, R4, R8, and R10) ravens were collected.

Sightings of colour-banded birds

Data on opportunistic sightings of colour-banded ravens were collected on visits to, and around, the study area and through observations by other birdwatchers, visitors to the wetlands and the public. The general Melbourne area hosts many active birdwatchers. These data were collected to gain a better understanding of dispersal (movements from the trapping site) and movements undertaken over a longer time frame which would complement data acquired through tracking devices. The colour band numbers of ravens, together with the coordinates of locations where they were sighted and the date and time of sightings, were recorded for each sighting. Sightings of colour-banded birds whose band number could not be determined because either the bird flew before the number was read or the number was obscured, were also recorded. It is acknowledged that there are biases associated with colour-band re-sighting methods, but we consider: that 1) internal comparisons (e.g. between the sexes) remain valid, and 2) sightings provide a snapshot of the minimum scale of dispersal from the study site.

Data analyses

Total range (i.e. the area used by the bird) of ravens was investigated using the home range estimator, Brownian Bridge Movement Models (BBMM) (Horne *et al.* 2007). This estimator was preferred to the traditional Kernel-Density Estimation

(KDE) owing to the auto-correlated nature of GPS fixes acquired by the tracking devices (Horne *et al.* 2007). As there were numerous GPS fixes acquired in short time intervals, the fixes were considered spatially and temporally auto-correlated. BBMMs also can better predict movement paths and encompass exploratory movements that would not be observed with KDE methods. The estimation of BBMMs requires: 1) sequential location data, 2) the estimated error associated with location data, and 3) grid cell size assigned for the output utilisation distribution (Horne *et al.* 2007). In this study: 1) sequential location data were present for each bird in the form of x and y coordinates of GPS fixes, 2) estimated error associated with location data was present as a measure of horizontal dilution of precision (HDOP; i.e. the geometric quality of a GPS satellite configuration in the sky, which is a factor in determining the relative accuracy of a horizontal position; Spilker 1996), and 3) a grid cell size of 5 m was assigned for the output utilisation distribution to facilitate investigation of space use at a fine scale. Once the BBMMs were estimated, density contours at two levels (95% and 99%) were calculated from the utilisation distribution. The 99% contour level (hereafter referred to as ‘total range’) was chosen because it more accurately defined the area of space use in previous studies (Lewis 2007), and it was then used to investigate space use patterns relative to the landscape.

Habitat use by ravens was examined using K-select analysis for design III studies (Calenge *et al.* 2005). As the first step, Minimum Convex Polygon (MCP) ranges were created for each bird ($n = 9$), as they were deemed most appropriate for describing the areas utilised by the birds and the habitats available to them. Then, a marginality vector was defined for each bird, which is the difference between the average ‘available’ habitat conditions and the average ‘used’ habitat conditions (Calenge *et al.* 2005). As the next step, an eigenanalysis (an extension of Principal Component Analysis) was conducted to determine linear combinations of habitat variables that maximise the mean marginality (i.e. habitat use) of all birds on the first component axis. If the birds display similar habitat preferences, the first axis explains a major proportion of the total variance in the dataset. The strength of the marginality of each bird was then examined by comparing the observed marginality with that generated in 200 simulations assuming random space use.

All four habitat types, wetland, open (grassland and agricultural lands), urban, and industrial, were digitised separately at a resolution of 1:5000 from aerial photos taken in 2011 (Department of Environment, Land, Water and Planning). As boundaries between habitat types are not naturally distinct, digitised habitat layers were buffered by 200 m to create a 400 m-wide interface between habitats to account for birds that might have used both habitats. These habitat layers were then converted to raster layers. Available habitat was determined for each raven from its MCP range, and habitats used were determined from GPS fix locations. Colour band sightings data were plotted and distances of sightings from the trapping location at Cheetham Wetlands were calculated and compared between the sexes.

Estimations of home range using BBMMs were conducted and contours were created using the ‘BBMM’ package (Nielson *et al.* 2013) in R ver. 3.2.0 (R Core Team 2015). Habitats were digitised and converted to raster layers in ArcGIS

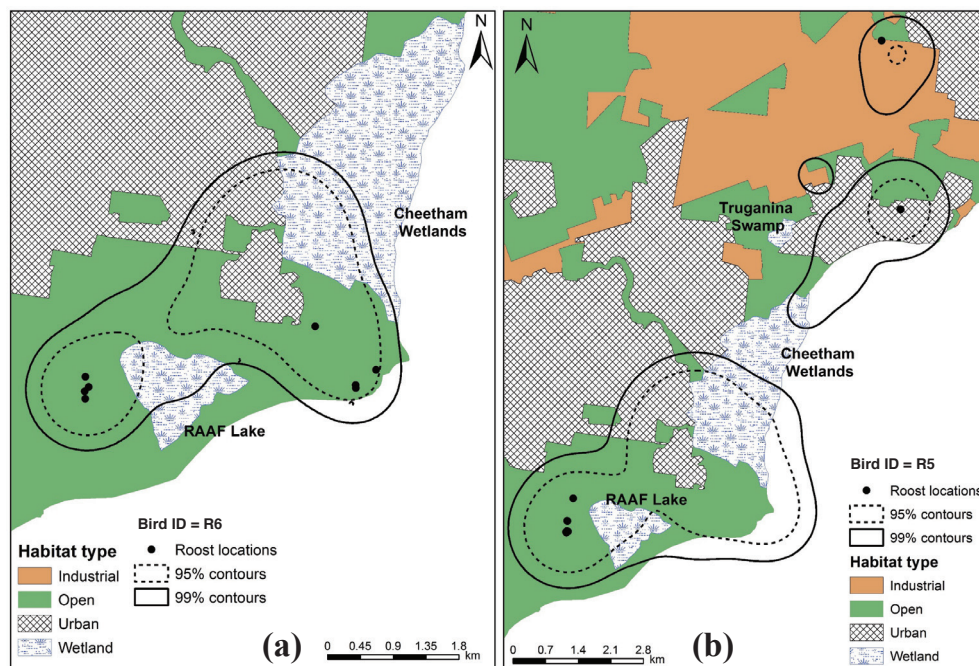


Figure 2. Total ranges (95% and 99% contours) of two male Little Ravens (R5 and R6), near Cheetham Wetlands: **a)** using multiple roost locations confined to a small area, and **b)** using multiple roost locations scattered across a larger area.

10.1 (Environmental Systems Research Institute, Redlands, California, USA). K-select analysis was performed in package ‘adehabitatHS’ (Calenge 2006) in R ver. 3.2.0 (R Core Team 2015). All other results are presented as means \pm *se*, unless otherwise stated.

RESULTS

Space use

The mean total range of individual ravens, as estimated by BBMMs, was 53.41 ± 21.17 square km (range 1.90 – 206.78 km², $n = 9$). There was large inter-individual variation in the size of total ranges. Among male ravens, two types of total ranges were identified. Some possessed relatively small total ranges with multiple roost locations confined to a small area (Fig. 2a; 99% contours, area = 12.16 km²), whereas some had larger total ranges with multiple roost locations scattered across a large area (Fig. 2b; 99% contours, 31.74 km²). Similarly, two types of total ranges were identified among females. Some possessed small total ranges with multiple roost locations confined to a small area (Fig. 3a; 99% contours, 42.08 km²), whereas others had larger total ranges with multiple roost locations scattered across a larger area (Fig. 3b; 99% contours, 87.51 km²). The smallest (1.90 km²) and the largest (206.78 km²) total ranges were recorded from male ravens, but their mean total range size of 51.71 km² was slightly smaller than that of females which was 55.54 km².

Habitat use

K-select analysis identified one major axis that explained 48.5% of the marginality (i.e. the difference between availability and use of habitats by ravens) of the data set. This

axis describes the gradient in marginality from ‘wetland’ habitat (negative values) to ‘open’ and ‘urban’ habitats (positive values; Fig. 4a). The second axis contributed 27.5% of the marginality and describes the difference between ‘urban’ and ‘industrial’ (negative values) habitats and ‘wetland’ and ‘open’ habitats (positive values). The high proportion of variance described by the first two axes suggests similarities in habitat use among ravens in this study.

The origins of non-centred marginality vectors indicate that availability of the different habitats varied among ravens ($n = 9$, Fig. 4b). ‘Open’ habitat was commonly available, comprising 40 – 64% of any bird’s MCP range. ‘Urban’ habitats comprised 21 – 55%, and ‘wetland/coastal’ habitats comprised 7 – 35% of a bird’s MCP range. ‘Industrial’ habitats were available to five birds, comprising 5 – 46% of their MCP ranges.

The relative length and direction of re-centred marginality vectors (Fig. 4c) indicate that seven birds preferred ‘open’ habitat (positive values for x-axis), with high marginality ($P < 0.05$) for five of them (males, R2, R5, R6; females, R4, R8). Two birds (male, R9; female, R10) appeared to prefer ‘urban’ habitat with high marginalities ($P < 0.05$).

Movements

Ravens were highly mobile, moving up to 10.6 km per hour ($n = 1272$), although most (68.2%, 867/1272) movements were less than 2.5 km per hour (median = 1.1 km h⁻¹). Most (88.6%, 62/70) of the initial locations recorded for birds each day were within 5 km of the previous night’s roosting location (median, 2.1 km). The longest distance moved by a raven from the previous night’s roosting location was 18.1 km (a female). No nocturnal movements were recorded.

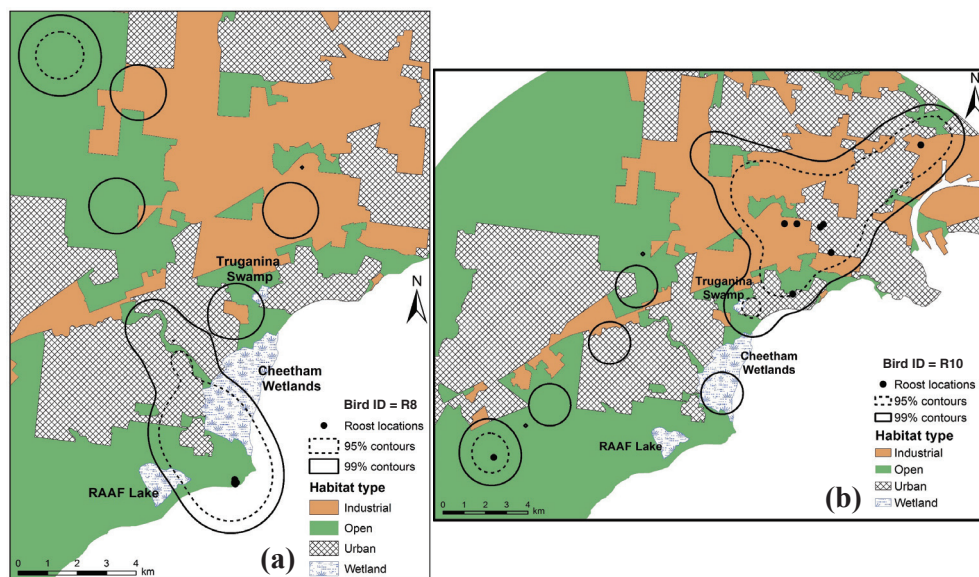


Figure 3. Total ranges (95% and 99% contours) of two female Little Ravens (R8 and R10), near Cheetham Wetlands: **a)** using a mosaic of habitats with multiple roost locations confined to a small area, and **b)** using a mosaic of habitats with multiple roost locations scattered across a larger area.

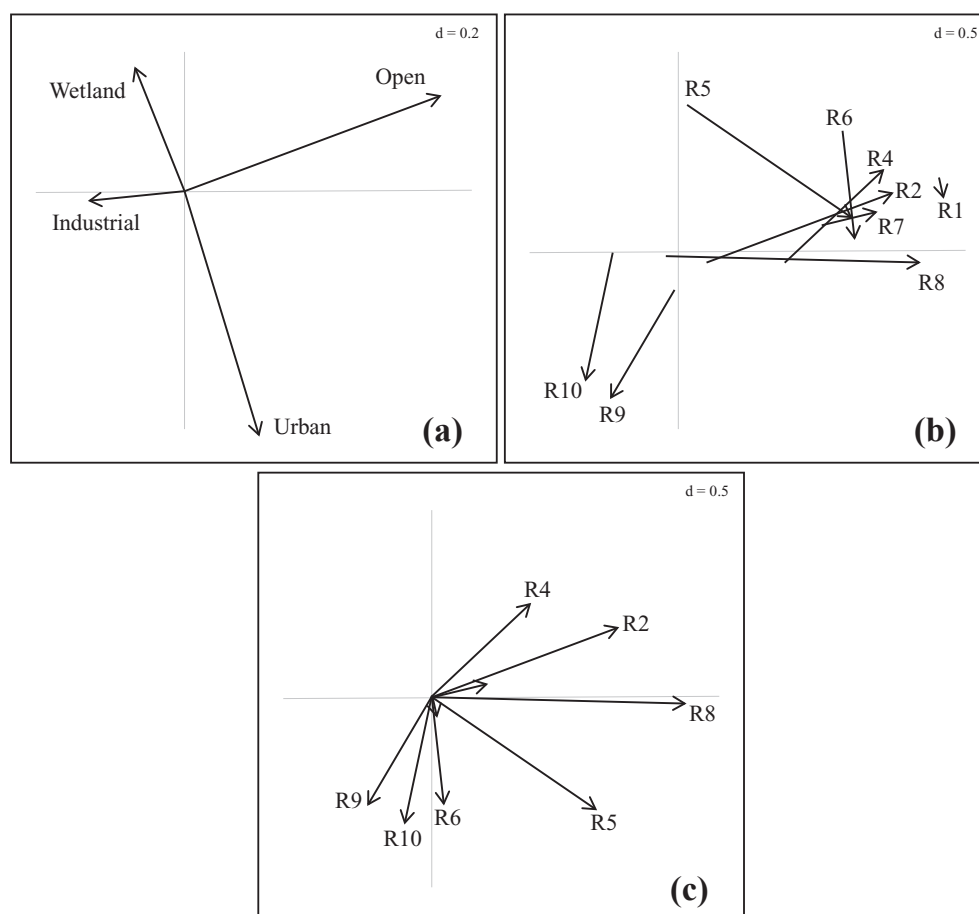


Figure 4. Results of K-select analysis of Little Raven telemetry data obtained near Cheetham Wetlands: **a)** the scores of the environmental variables on the first two axes of the K-select analysis, **b)** The un-centred vectors of marginality (the origin of the arrow indicates the centroid of the cloud of available points and its end indicates the centroid of the cloud of used points by each bird), and **c)** the re-centred vectors of marginality [significant marginality vectors ($P < 0.05$) are labelled with bird identity].

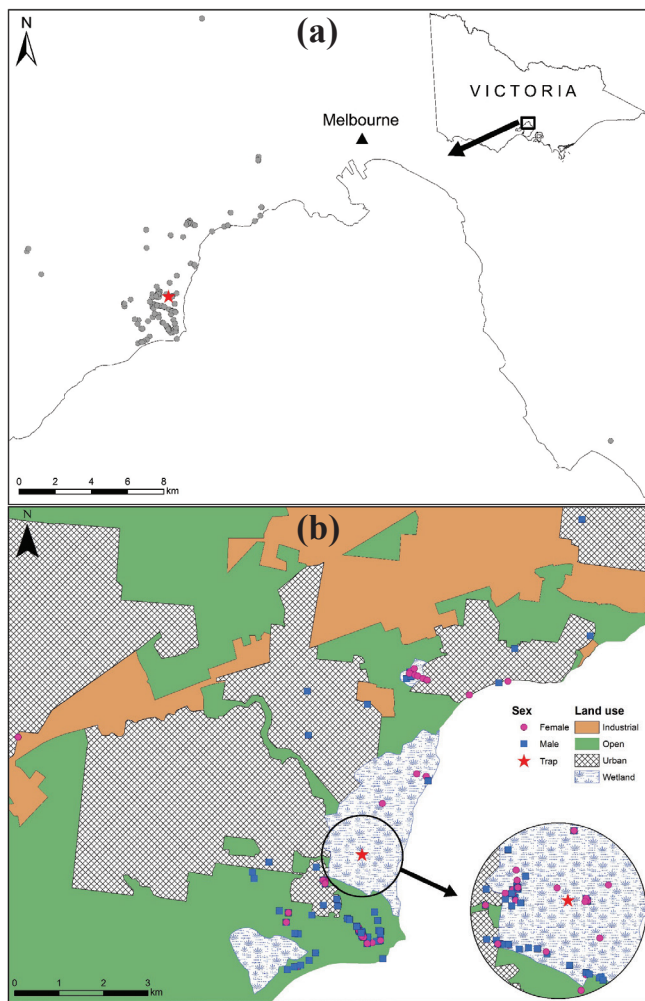


Figure 5. Map of: (a) all sightings of colour-banded Little Ravens relative to the trapping site (red star), and (b) sightings of identified male (blue squares) and female (pink circles) ravens closer to the trapping site (red star). Inset is within a 1 km radius from the trapping site, centred on Cheetham Wetlands.

Dispersal from the trapping site

Data from 557 colour band sightings were collated, with only 25 sightings for which the identity of the bird was not determined. These data suggested at least occasional longer distance movements by ravens from the trapping site, with the longest movement of 25.9 km (Fig. 5a). Both male and female ravens undertook long and short distance movements (Fig. 5b). Although detectability of ravens probably varies with distance, this effect is unlikely to differ between the sexes. The mean distance of movements of males was shorter than that of females (independent t-test, assuming each movement was independent, $t = -7.051$, $df = 357.34$, $P < 0.001$; males, 1530.60 ± 65.60 m; females, 2653.40 ± 145.11 m; Fig. 6).

DISCUSSION

The total ranges reported in this study are likely to be indicative of raven ranges throughout their non-breeding season in a peri-urban landscape, even though the duration and sample size of this study were limited. The total ranges are within the

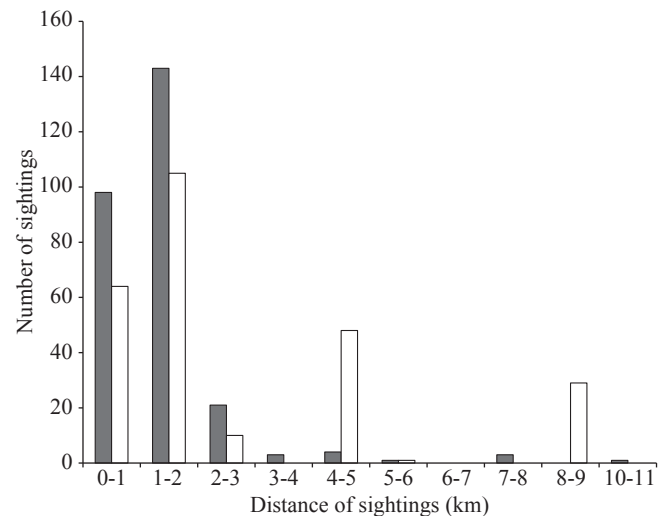


Figure 6. The number of sightings of male (black bars) and female (open bars) Little Ravens within increasing distance from the trapping site.

extent of those described for the family Corvidae worldwide (Laiolo *et al.* 2001; Yaremych *et al.* 2004). Previous studies of corvid spatial ecology suggest that there is great variation in total ranges among and within species (Yaremych *et al.* 2004; Bodey *et al.* 2009).

Movement patterns of non-breeding ravens have been associated with the presence and acquisition of different food sources (Rowley 1973). Similarly, space use of ravens in this study may have been influenced by the distribution of different food sources. Birds frequenting 'open' habitat (i.e. grassland and agricultural lands) may have been attracted by food items such as seeds, small insects, and also grubs and worms from recently ploughed agricultural fields, which have been observed attracting flocks of 200 – 300 ravens (Rowley 1971). Birds frequenting 'urban' habitat were located within new residential estates and may have been attracted by anthropogenic resources, such as overflowing residential waste bins (observed during tracking of birds), bird baths and feeding tables. Some ravens in this study frequented 'industrial' habitat near a large rubbish tip where they were probably exploiting waste, and some frequented a car park of a vehicle manufacturing plant, using tall trees for roosting purposes.

We expected that ravens would strongly prefer 'wetland' habitat, given the observations of their intensive exploitation of shorebird eggs as prey at Cheetham Wetlands. However, none of them showed a strong preference for this habitat. This could be attributed to the timing of this study, which coincided with the non-breeding season of plovers. Therefore, it is possible that ravens in this landscape derive food from mostly anthropogenic sources during the plover non-breeding season, and exploit the natural food source of shorebird eggs during the plover breeding season. This ability of corvids to adjust and exploit both natural and anthropogenic food sources has helped them thrive in human-modified landscapes worldwide (Marzluff *et al.* 2001; Marzluff and Neatherlin 2006).

Corvids can adjust their movement patterns and total ranges in response to seasonal variations in distribution and

availability of food sources (Rolando and Carisio 1999; Scarpignato 2011; Scarpignato and George 2013; Ekanayake *et al.* 2015a; Ekanayake *et al.* 2016). Anecdotal observations of Little Ravens in south-eastern Australia provide support for seasonally varying numbers stemming from movements, of unknown distances, into other areas possibly in response to food availability (Rowley 1971). Furthermore, raven colour-banding studies (Rowley 1971) provide evidence for longer movements than described in our short-term telemetry study. However, the tracking described in this study indicates that during the raven main non-breeding period of Little Ravens, they appear to reside in large total ranges probably exploiting numerous types of food sources and undertaking the occasional longer movement.

This study is the first to use GPS tracking devices to investigate space and habitat use by Little Ravens. The accuracy of fixes acquired by GPS tracking devices may be greater than that of fixes acquired via triangulation with conventional VHF radio-trackers, and the fixes are independent of receiver location. Therefore, this study's results provide a more accurate account of space and habitat use by Little Ravens than is currently available. A few limitations associated with the use of these GPS tracking devices were encountered. These devices did not provide the expected sequential GPS fixes over lengthy periods of time, and for most devices there were extended periods when no locational data were recorded. Sequential fixes would have enabled the analysis of tracks of movements and identification of associated food sources. Furthermore, the battery life of these tracking devices was much shorter than anticipated and therefore we could only acquire locational data for birds over a short duration.

Sightings of colour-banded ravens showed dispersal from the trapping site which was consistent with the results obtained from the tracking devices. Evidence of long distance movements by both male and female ravens indicated the presence of large total ranges, although there were more short than long distance movements. These observations are consistent with the assumption that longer distance movements are less frequent than short distance movements in ravens (Paradis *et al.* 1998; Weston *et al.* 2009). Similar observations have been made of Common Ravens (*Corvus corax*) making frequent short distance movements and occasional long movements of up to 65 km (Engel and Young 1992). The difference in frequency between short and long distance movements could also be due to more frequent detection of short distance movements, because of the lower detection probabilities associated with long distance movements and greater search effort near the trapping site (Koenig *et al.* 2000). The mean distance of movements of males was shorter than that of female ravens. Among some corvids, females travel longer distances than males (Gienapp and Merilä 2011) whereas among others the opposite pattern has been observed (Langen 1996; Williams and Rabenold 2005).

CONCLUSIONS

Australian corvids are renowned agricultural pests (Rowley 1971, 1973), but their impact on other wildlife as an avian egg and chick predator has only recently been described (Berry 2002; Everding and Jones 2006; Maguire *et al.* 2009; Lomas *et al.* 2014; Ekanayake *et al.* 2015a; Ekanayake *et al.* 2015c; Tan *et al.* 2015). The population of Little Ravens considered in

this study has already been implicated as the principal predator of eggs of a resident shorebird population in a high-value wetland located in a peri-urban landscape (Lomas *et al.* 2014; Ekanayake *et al.* 2015c; Tan *et al.* 2015). Ravens thrive and increase in abundance in human-modified landscapes and this will likely exert more pressure on prey populations. As shown by our results, Little Ravens have total ranges encompassing various habitats that probably offer them abundant food sources. With respect to managing egg predation within the high-value wetland, managing the raven population not only within the wetlands but also in the surrounding areas, as well as managing other food sources which ravens rely on, may need to be considered. As managing a large raven population, as well as their food sources, is practically unachievable, management options such as the use of raven exclusion nest cages may be more effective in sustaining prey populations (Tan *et al.* 2015).

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