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Sex and Age Effects on Monk Parakeet Home-Range Variation in the Urban Habitat

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Abstract: Home-range size is a key aspect of space-use, and variation in home-range size and structure may have profound consequences for the potential impact of damage and control strategies for invasive species. However, knowledge on home-range structure of naturalized parrot species is very limited. The aim of this study was to quantify patterns of home-range variation according to sex and age of the monk parakeet *Myiopsitta monachus*, an invasive parakeet in Europe. Mean kernel home-range size was 12.4 ± 1.22 ha (range 1.7–74.1 ha; *N* = 73 birds). Juveniles had a larger home-range size than adults, but sexes did not differ in kernel home-range size. The mean maximum distance moved by monk parakeets was 727 ± 37.0 m (range: 150–1581 m), and it was not dependent on either the sex or age of the birds. Having a small home range is one of the conditions for the feasible eradication of an invasive species; hence, the small home range of urban monk parakeets that we report here is good news for pest managers. However, this small home-range size can limit the effectiveness of culling operations with traps or feeders with contraceptives or poison, and other alternatives, such as funnel nets or traps, should be used.

Keywords: *Myiopsitta monachus*; home range; sex; age; urbanization; invasive alien species

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1. Introduction

Animal movement and space-use is a key topic in ecology [1]. Early work mostly focused on describing movement patterns and their links with external factors (e.g., the environment), neglecting the individual causal drivers of this movement [2–4]. More recently, research effort has focused primarily on understanding the reasons for consistent intraspecific variation among individuals, investigating how morphological, behavioral, sexual, or age variation affect movement patterns [5–7].

Knowledge on the reasons and pattern of individual movements is especially important in the management of pests, to ensure that pest control actions are undertaken at a scale relevant to the species. Knowledge on home-range size and use is critical, for instance, to determine number and density of traps, their placement, and timing of trapping operations [8–11]. The same scale problem is applicable to other control methods, such as contraceptives or poison baiting [12,13]. Simulation models to manage the population dynamics and spread of pest species also need estimates of home-range parameters [13,14]. Sex and age are two main individual causal drivers of variation in home range [7], and because of that, any pest control plan has to scale actions having taken into account these two key variables [14].

Psittaciformes (parrots) is one of the most endangered bird orders in the world [15], and, at the same time, this group also contains some of the most invasive and damaging alien species [16,17]. However, knowledge on movement patterns of parrot species, including invasive ones, is very limited. Current available information is based on the study of a few species and provides data on just a few radio-tagged individuals [18–22], which reduces generalization of results found. Given that many parrot species are generally monomorphic [23], current available work does not provide any data on sexual differences in home-range use. Invasive parrot species are typically linked to urbanized habitats [24], but apart from the ring-necked parakeet *Psittacula krameri* [19], no information is available on home range-use in urban habitats.

The limited knowledge on movement patterns of parrots is probably due to the fact that parrots are difficult to capture and that their strong beaks easily destroy most devices that allow individual identification of the birds without having to recapture them [20]. However, we recently designed a metal tag attached to the bird neck with a collar that has proved very useful for the long distance identification of marked parakeets [25]. The method is simple and cheap, which allows marking a high number of individuals in an economically feasible way.

The aim of this paper is to take advantage of this marking method to study monk parakeet *Myiopsitta monachus* variation in home-range size and movements according to the sex and age of the birds. The monk parakeet is a highly successful invasive species in Europe and North America [24,26]. The marking device has been successfully used to determine dispersal patterns of the species in an urban environment [27]. However, similar to other parrot species, no detailed data is currently available on its home-range size. The monk parakeet is sexually monomorphic, but we use specifically developed genetic methods [28] to sex our birds and to analyze for sex specific home-range patterns. Data on home-range variation and movements is later used to delineate strategies for the control of the species.

2. Materials and Methods

The study was performed in the city of Barcelona, located on the northeastern coast of the Iberian Peninsula. Extending over 102.16 km^2, Barcelona is structured in 10 districts, with approximately 73% of the city built up. We concentrated our sampling efforts in and around the Parc de la Ciutadella area (625 ha) (Figure 1), which holds the highest monk parakeet density in the city [29]. Previous information (based on a smaller sample size) on the movement of monk parakeets showed that maximum home-range distances (between the center and the maximum extremes of the range) moved by juveniles were 1113 $\pm$ 103 m and 496 $\pm$ 122 m for adults [30]. This made us confident that the size of the area sampled was adequate to locate most daily home-range movements of the birds. Monk parakeets were captured using a modified Yunick trap at the Natural Sciences Museum of Barcelona, and marked with metal rings and a medal attached to a collar [25]. These unique identification tags allowed the identification of the birds without having to recapture them. The marking of birds has been carried out for two 6-week sampling periods (winter and summer) every year since 2002 [31].

On capture, we determined the age of the birds (juveniles or adults) based on molt patterns and capture history [32]. We also obtained a blood sample that allowed us to sex the birds molecularly (see Dawson-Pell et al. [28]).

The sampling of parakeets for the study of home range was carried out from 15 January to 15 July of 2016 and 2017 by direct observation and georeferencing of the marked individuals (visual recapture) in the Ciutadella Park area (Figure 1). This period of sampling was chosen because natal dispersal by juveniles in their first year, if present, has already taken place and the birds are ready to breed, building or maintaining nests, or actively breeding [30]. Monk parakeets are sedentary, long-lived, and use the nests year-round for roosting and breeding for multiple years [27,31]. The species is also colonial, building large compound nests [27]. About 80% of birds breed in the same nest in successive years, and dispersing adult birds move an average distance of just 37 m [27], removing any bias of using two years. Data from juvenile birds includes only resightings within the year in which they were aged as juveniles, because in the second year they were, by definition, adult birds, but also because some juveniles may disperse in their second year. In Barcelona, only about 50% of birds breed in their first year, with the others showing delayed breeding [27,33]. A transect was made on foot every weekday (on average 3 h per day, avoiding days with poor weather). In practice, the use of transects means that there was only one location per individual per day. Four different transects, with a total length of 15.4 km, were established through the study area. The transects visited all the green areas and locations where previous information indicated there could be parakeets breeding, resting, or foraging. Note that the area has been intensively surveyed since 2001 during a succession of different studies [27,29–31,33,34]. Data on individual identification, location, date, and time was stored in the field using app *iNaturalist* (https://www.inaturalist.org; accessed on 10 November 2021). The transects were carried out at different times of the day at random in order to avoid any bias due to the activity of the birds (observations made between 800 and 1400 h and between 1400 and 2000 h). We additionally included observations of birds seen at the trap at the Museum, since this is a regular feeding point for many birds at the Ciutadella Park (Figure 1). We additionally visited, in an opportunistic way, some green areas out of the study area to confirm that no marked birds were present.

Figure 1. Map of the study area. The yellow box includes the study area (625 ha) where the transects were carried out. The blue circle indicates the location of the Museum trap. The green areas in the city are colored green.

We used the program Ranges 9 [35] (http://www.anatrack.com; accessed on 10 July 2017) to analyze home-range size of Monk parakeets. We used the kernel estimation of home-range size, which determines the probability of use of space, creating nuclei according to the density of observations of the animal at different locations [36]. This is a measure of the area most used by the individual, calculated using 95% of the estimated total area [37]. Ranges 9 also computes the activity center as the location at which the Gaussian kernel estimator indicates highest density [36]. The kernel method, however, excludes movements outside of "normal activities". Hence, and in order to have information on movement potential away from the "normal" home range, we also computed maximum distances moved by an individual, which are computed by Ranges 9 as the maximum distances from locations to the range center. Incremental area analysis, also implemented in Ranges 9, was used to determine the minimum number of locations to be used per individual. Consecutive areas, which tend to increase initially as the animal is observed using different parts of its range, were plotted against number of locations until there was evidence of stability, indicating that adding further locations did not improve the home-range estimate [35]. The number of locations needed to reach the asymptote was estimated to be 21, and so analyses were conducted only on individuals located ≥21 times ($N = 73$). Kernel home-range size did not follow a normal distribution, the distribution being skewed to the right, and did not follow homogeneity of variances (Shapiro–Wilk W = 0.70, $p < 0.001$; Levene's test for homogeneity of variances $F_{3,69} = 6.34$, $p < 0.001$; skewness = 3.43 ± 0.28). Hence, to test for the relationship between home-range size and sex and age, we used a general linear model (GLM) on the logarithmic transformation. Logarithmic transformed data fit to a normal distribution and showed homogeneity of variances (Shapiro–Wilk W = 0.99, $p = 0.57$; Levene's test $F_{3,69} = 1.55$, $p = 0.21$; skewness = −0.05 ± 0.28). We used the kernel home-range size as a dependent variable, and we included sex and age (juvenile or adult) of the birds as categorical fixed factors. Mean maximum distances moved, again, did not follow a normal distribution (Shapiro–Wilk W = 0.93, $p < 0.001$; skewness = 0.76 ± 0.28; Levene's test $F_{3,69} = 0.97$, $p = 0.41$). Logarithm transformation overcorrected the data, which still did not fit to a normal distribution and was skewed to the left (Shapiro–Wilk W = 0.94, $p = 0.01$; Levene's test $F_{3,69} = 0.03$, $p = 0.99$; skewness = −0.73 ± 0.28). In such cases, square root transformation is advised [38,39]. The squared root transformed data did not fit to a normal distribution (Shapiro–Wilk W = 0.96, $p = 0.02$), but showed homogeneity of variances ($F_{3,69} = 0.27$, $p = 0.85$) and reduced skewness (0.07 ± 0.28), and thus this was the transformation we used in analyses. We used a GLM with the maximum distance as a dependent variable, and sex and age (juvenile or adult) of the birds as categorical fixed factors.

3. Results

We recorded 471 different marked individuals, with 4807 visual "recaptures". From these, we selected the subsample of birds recorded ≥21 times ($N = 73$ birds; average N observations per individual: 30 ± 1.12 SE, range 21–62; see methods). Mean kernel home-range size was 12.4 ± 1.22 ha ($N = 73$), with a median value of 10.1 ha (range 1.7–74.1 ha). Home-range size was negatively correlated to the number of observations per individual ($r = -0.25$, $p = 0.03$, $N = 73$). Some individuals showed a compact home range while some other individuals showed a multinuclear home-range area with two or three main activity areas (Figure 2).

Juveniles had larger home-range sizes than adults (juveniles: 16.0 ± 1.96 SE ha, $N = 32$; adults: 10.4 ± 1.66 ha, $N = 41$) (Figure 3), and sexes did not differ in kernel home-range size (Table 1).

The mean maximum distance moved by monk parakeets, from the center of the range, was 727 ± 37.0 m (range: 150–1581 m). Maximum distance moved was not correlated to the number of observations per individual ($r = -0.001$, $p = 0.99$, $N = 73$), but it correlated positively to kernel home range ($r = 0.40$, $p < 0.001$, $N = 73$). Maximum distance moved was not dependent on either the sex or age of the birds (Table 2).

Figure 2. Study area displaying all the visual observations of the 73 marked monk parakeets and three examples of home-range area (kernel method). Home ranges display 50, 75, and 95% contours. The home range of individual I76 is compact, while that of E44 and E71 is multinuclear, with two and three activity areas, respectively. The activity center, computed by Ranges 9 as the location at which the Gaussian kernel estimator indicates highest density, is marked with the sign +.

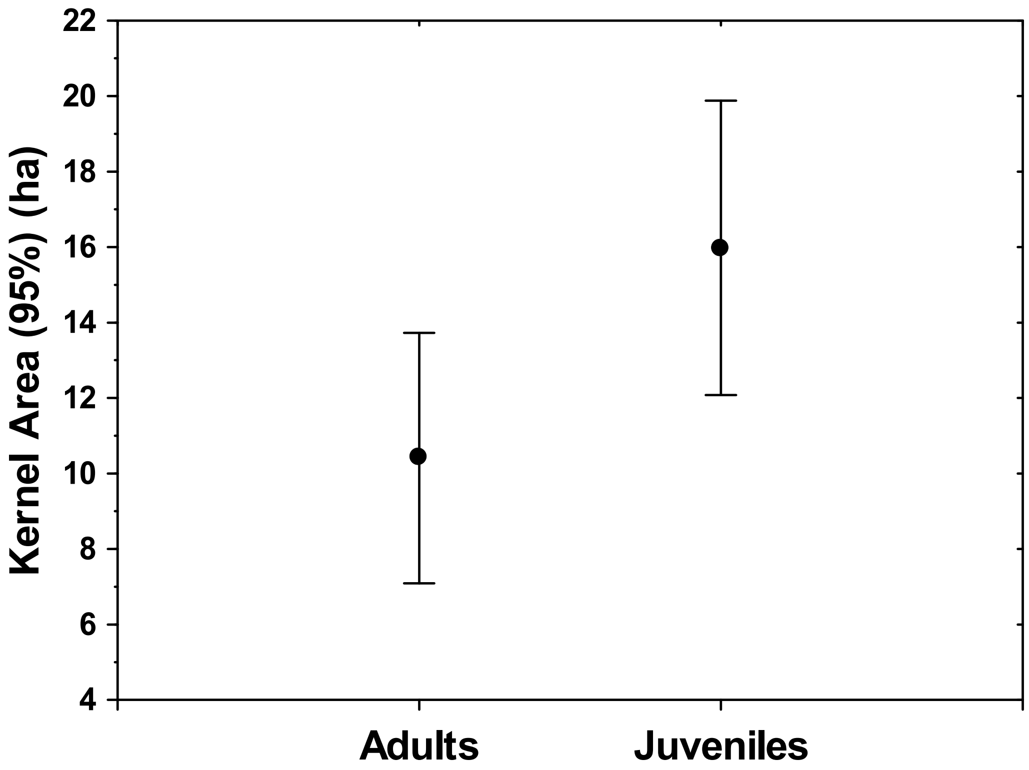

Figure 3. Variation in monk parakeet home-range size (ha ± SE) (kernel 95%) in Barcelona urban area according to the age of the birds (*N* = 73). Test of effects in Table 1.

Table 1. Results from the general linear model analysis (GLM) of the variation in monk parakeet kernel home-range size (ha) according to the sex and age (juveniles and adults) of the birds.

	F	Df	*P*
Sex	0.005	1.69	0.95
Age	4.50	1.69	0.04
Sex x Age	0.008	1.69	0.93

Table 2. Results from the general linear model analysis (GLM) of the variation in monk parakeet maximum distances moved (m) according to the sex and age (juveniles and adults) of the birds.

	F	Df	*P*
Sex	0.65	1.69	0.42
Age	1.12	1.69	0.29
Sex x Age	0.11	1.69	0.74

4. Discussion

Juvenile monk parakeets had larger home ranges than adults. Although there is a lot of interspecific variation, this is typical of many species [7,40] and may be related to the fact that in Barcelona monk parakeets, about 50% of juveniles do not breed in their first year [33], and hence are not so strongly tied to the nest as adult breeding birds. Juvenile birds, therefore, may wander more widely, returning to the nest only for roosting. Similarly to other species, the nest in adult birds may therefore act as a central place which limits movements [41,42]. In contrast, we found that extreme movements did not differ between sexes and ages, which suggests that occasional forays away from the home range are carried out by all the individuals irrespective of sex and age. However, we have to acknowledge that detailed GPS data on movement patterns is needed to quantify the distance and frequency of forays more precisely. This GPS data can also help to determine whether visual data can underestimate home-range size estimation.

Monk parakeet home ranges in our study area are surprisingly small, with a median value of 10 ha. This contrasts with data for other similarly sized parrot species. Bahama parrots *Amazona leucocephala* had average home ranges of 16,000 ha (95% kernel) [22], maroon-fronted parrots *Rhynchopsitta terrisi* of 4000 to 12,000 ha (50% kernel) [21], and the mean home ranges of Hispaniolan parrots *Amazona ventralis* was 864 ha [43]. The small home ranges of our monk parakeets could be the result of extremely high resource loads in the urban environment, in part because of the public providing food to parakeets [44]. In their native range, monk parakeets normally have home ranges of 3–5 km in diameter [45], and have been found to travel as far as 16 km to feed on grain crops [46]. Although anecdotal, this was also the explanation for the small home range of an urban blue-crowned parakeet *Aratinga acuticaudata* [47]. This seems also to be the case for other urban-dwelling species with access to anthropogenic food supplies, such as foxes *Vulpes vulpes* [48] or raccoons *Procyon lotor* [49]. Ring-necked parakeets studied in an urban habitat with anthropogenic food supplies also showed a reduced home-range size (86 ha, 95% kernel) compared to parrots in the wild [19], although this home range was still substantially higher than that of the smaller monk parakeet.

The monk parakeet is considered an invasive alien species of high concern, and calls are being raised to control their populations [26,50]. Having a small home range is one of the conditions for the feasible eradication of an invasive species [51,52], and hence the small home range of urban monk parakeets that we report here is good news for pest managers. The method to be used for the control, however, is dependent on the demography and home range of the focal species. Population dynamic models have suggested that the culling of adult birds is twice as effective as efforts to suppress breeding [31]. From the different culling methods available for monk parakeets, we can generally distinguish between those methods in which the animals have to move to the control source, as in the case of traps or feeders with contraceptives or poison, and methods in which the control operation moves to locate the parakeets, as in approaches such as shooting or the use of funnel nets at nests [50]. The first group of methods can be difficult when the home range of the focal species is small, because the number of traps or feeders to be used increases inversely with the home-range size of the species under control [8,53]. In the case of monk parakeets, the small home range of the species in urban settings makes the costs of setting enough traps or feeders to cover the whole urban area of a city such as Barcelona prohibitively high, which advises against its use [50]. Hence, the alternative methods in which the control operation moves to locate the parakeets are necessary. Given that monk parakeets roost at their nests, showing high nest-site fidelity [27], focusing on the capture of birds at the nest at night with funnel nets or funnel traps could be a good alternative [50].

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Data Availability Statement: Data supporting reported results will be found at ResearchGate https://www.researchgate.net/publication/356784880_Data_from_paper_Sex_and_Age_Effects_on_Monk_Parakeet_Home-Range_Variation_in_the_Urban_Habitat_published_in_Diversity_2021.

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