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Research Article

Factors influencing the abundance and distribution of feral pigeons (*Columba livia*) in urban environments in Malta

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Abstract. This study aimed at identifying factors that influence the abundance and distribution of feral pigeons (*Columba livia*) in urban environments in Malta, making it the first study of its kind locally. Feral pigeons were censused using transect surveys in different types of urban environments, which were categorised as in proximity of an agricultural area, main road, park, side street and suburb. The cluster density and the cluster abundance were then estimated using distance sampling analysis. The number of pigeons in clusters was two or three. The cluster density of feral pigeons was estimated to be $6.51 \times 10^{-5} \pm 1.57 \times 10^{-5}$ ($1.44 \times 10^{-5}\,\text{km}^{-2}$) in a total area of $4.52\,\text{km}^2$, with the highest estimate corresponding to the 'Park', followed by the 'Mainroad', 'Agricultural area', 'Sidestreet' and 'Suburb' , in this order. The cluster abundance in the same area was estimated to be 293.89 ± 70.87, with the highest estimate corresponding to the 'Mainroad' , followed by 'Park', 'Sidestreet', 'Agricultural area' and 'Suburb' in this order. Negative binomial regression was used to study the possible influence of environmental factors on feral pigeon abundance. The results of statistical analysis showed that the abundance of feral pigeons is mostly affected by architecture: abundance was low where there was a preponderance of modern buildings. This study may contribute to a tailor-made and economical scientific management plan for controlling feral pigeons in urban settings.

Keywords: Distance sampling, generalized linear models, Urban environmental variables, density, synanthropic species

1 Introduction

Feral *Columba livia* is a major synanthropic species worldwide (Amoruso et al., 2014) which occurs both in urban and semi-natural habitats. The wild counterpart of the feral pigeon originally prevailed in Mediterranean bordering countries, as well as in parts of Europe, Northern Africa and Western Asia. The pigeon was introduced and subsequently proliferated in North, Central and South America, as well as in all of Europe (Baptista et al., 1997). The domestication of feral pigeons in the Mediterranean region is thought to have occurred around 3,000 BCE (Driscoll et al., 2009; Johnston et al., 1995; Murton et al., 1972a; Murton et al., 1972b). Concomitantly, artificial selection favoured certain traits, including an annual high reproductive success, docile behaviour, and non-aggressiveness between males (Magnino et al., 2009). Initially, pigeons were bred as a source of food (Driscoll et al., 2009; Stringham et al., 2012; Tchernov, 1984); however, they were later used as carrier pigeons and/or racing pigeons, as well as for the decorative value of fancy breeds. With artificial selection, humans unintentionally contributed to behavioural and morphological advantages that have enabled *C.livia* to successfully exploit urban habitats (Bowman, 2009).

Wild *Columba livia* is a medium sized compact bird with a length between 29 to 35 cm and a wing span of between 60 and 68 cm. It has a small head, rounded breasts to support its strong wing muscles, and short legs covered with scale-like skin. In its typical coloration, it has pale grey plumage on the back and upper wings and its head, neck and breast are darker in colour, while the underwings and rump are a contrasting white; it also exhibits two distinguishable black wing bars. In flight, it moves in straight paths with clipped wing beats. When on the

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ground, it walks with bobbing head movements. The wild form feeds on plant material such as grains and seeds. It has reddish eyes, as well as a dark bill, which, unlike most other birds, has partly covered nostrils, hence the pigeon can drink with the bill lowered in the water. Its preferred nesting sites include holes in trees, rock faces and cliffs (Svensson et al., 2010). The feral counterpart is identical in shape; however, it may exhibit many plumage variants. Such variants include variegated white and grey, all dark grey, dark pink-buff or dark piebald. They can also look like the wild counterpart, without the white rump, or may retain odd white remiges (Svensson et al., 2010).

The wild counterpart of the feral pigeon originated from rocky cliff habitats. As vertical-sided urban buildings provide similar environmental characteristics to the natural environment, the abundance of the feral pigeon in urban areas might be attributed to an innate preference for cliff-like habitats. However, their abundance in urban areas can also be attributed to the easily obtainable food supplied both intentionally and unintentionally by humans. Studies indicate that the densest populations of feral pigeons occur in historic town centres, as the old buildings provide ample nesting sites, while the high human population density of both locals and tourists in historic towns results in constant food sources (Buijs et al., 2001; Johnston et al., 1995; Sacchi et al., 2002). Other factors that lead to high population densities revolve around the reduction of selective action from natural factors such as predation and severe weather, and therefore less stress (Dobeic et al., 2011). The distribution and abundance of feral pigeons in urban environments therefore depends on a number of interacting variables, which may vary in importance depending on location.

In the past, interspecific interaction between pigeons and humans induced reciprocal benefits (Humphries, 2008; Johnston et al., 1995). However, in recent times feral pigeons are mostly viewed as a threat and nuisance. Research suggests that the birds may carry various pathogens including viruses, bacteria, fungi, protozoa and other parasites, and are therefore often associated with causing health problems for both humans and domestic animals (Haag-Wackernagel et al., 2004; Straff et al., 2001). They are also perceived as a threat to cultural heritage as they tend to foul and damage buildings and monuments with their excreta (Johnston et al., 1995). Indeed, many cities worldwide have been facing difficulties in managing oversized populations of feral pigeons (Haag-Wackernagel, 2005; Haag-Wackernagel et al., 2008; Magnino et al., 2009).

The most recent pigeon survey in Malta, carried out between 1998 and 2000, estimated about 1500 to 2500 pairs in the Maltese islands, whereby the majority of the population was found to be concentrated in the Valletta harbours urban areas. There is evidence to suggest that with increasing development, the feral pigeon population is expanding to the surrounding localities (figure 1), including Marsa, Ħamrun, Blata il-Bajda, Gżira & Sliema; feral pigeons have colonised the St Vincent De Paul (Luqa) and St Luke's (Gwardamanġa) hospital complexes (Sultana et al., 2011). Moreover, substantial separate populations was also noted at Balzan and on the island of Comino; however, in the rest of the Maltese islands, including Gozo, the bird is only sparsely distributed (Sultana et al., 2011).

The present study assesses the abundance and distribution of feral pigeons in different types of urban environments on Malta island, using distance sampling. This is the first time that this statistical technique was used in a study on wild animal species in Malta The study also aims to determine which urban environmental characteristics most influence feral pigeon abundance.

2 Method

2.1 General methodology

The study consisted of two stages. The first stage involved distance sampling, a technique used for the estimation of abundance and/or density of biological populations (Thomas et al., 2010). The method, described by Giunchi et al. (2007) was followed.

In distance sampling a detection function models the probability of detection of the animal of interest given its perpendicular distance from the observer (surveying line or transect). A key concept is that as the animal's distance from the observer increases, the probability of detecting it decreases. Therefore, since in distance sampling the area in m^2 surveyed in the study is incorporated in the calculations, modelling allows the estimation of the total number of animals present in the area, including those that are undetected by the observer, hence, the density and abundance in the whole study region can then be estimated (Buckland et al., 2015). Distance sampling was preferred over other sampling methods as apart from being non-intrusive, easily carried out and inexpensive, it gives more representive results as the estimation process of this technique utilizes data beyond the line transect (Richardnson, 2007).

Distance sampling has four key assumptions (Miller et al., 2017; Thomas et al., 2010):

i. all the animals of interest occurring on the line or point are detected and recorded;
ii. the individuals and their perpendicular distance are detected and recorded before the animal is disturbed;
iii. transects are randomly positioned with respect to the

distribution of the study animal;

iv. the measurements are precise.

This last can be achieved by using a rangefinder. The second stage of the study tested the relationship between the predictor variables, i.e. the environmental characteristics, and the response variable, i.e. pigeon abundance. This was achieved using generalized linear models (GLM), specifically the negative binomial regression model.

2.2 Study regions and locations

Although more complex structures exist, the survey design employed was organised using four main layers:

i. the global layer which accounts for the entire study area;
ii. the stratum layer that includes individual survey strata;
iii. the sample layer that accounts for data of individual survey lines;
iv. the observation layer which represents the data that relates to single observations (Thomas et al., 2010)

Through a desk cartographic review, three towns from each of the five districts in Malta were selected on the basis feral pigeons are known to occur within their confines (figure 1). These towns constituted the global layer. Five different types of urban environment were identified and these represented the stratum layer.

These were:

i. town centre (labelled 'Mainroad');
ii. residential areas off the town centre (labelled 'Sidestreet');
iii. residential areas on periphery of town (labelled 'Suburb');
iv. public open spaces within town (labelled 'Park');
v. open spaces at periphery of town and adjacent to agricultural areas (labelled 'Agricultural').

Within each stratum, 300 m-long transects were allocated along randomly selected roads. These transects constituted the sample layer. The counts of feral pigeon along each transect constituted the observation layer.

2.3 Data Collection

Prior to data collection, a pilot study was carried out in Msida from December 2019 to the end of February 2020 to test the data collection protocol, which was adjusted to take into account particular field circumstances. The actual study was conducted between May 2020 and August 2020 inclusive. The two months hiatus between the pilot study and the actual data collection was as a result of the COVID-19 pandemic lockdown. Data collection was made during weekdays, from 8:00 until 12:00, excluding weekends and public holidays, to ensure consistency.

Each transect of 300 m was walked, first in one direction on one side of the road, and then in the opposite one, on the other side; this took total time of about 10 minutes in total. During these walking sessions, data on the urban environment were recorded, consisting of counts of the following variables: People; Parked vehicles; Moving vehicles; Old buildings; Modern buildings; Abandoned buildings; Construction sites; Trees; Food sources; Water sources; Bins.

If pigeons were noted at any point along the transect, the transect was then walked again using the same procedure, this time counting pigeons on one side of the road and then on the other. When a feral pigeon was detected, the observer stopped and recorded the perpendicular distance of the animal to the transect line using a Tacklife MLR01 800 m Laser Rangefinder. If the pigeons occurred in a cluster, the number of birds in the group was also recorded.

3 Results

3.1 Distance sampling analysis

Three key functions with different formulations of adjustment series were used. Table 1 shows the models, their key functions plus adjustment, as well as the Akaike information criterion (AIC) computed using the R package 'Distance Sampling'. All the AIC values of the three computed models were nearly the same, hence, the best model cannot be chosen based on this measure alone.

Goodness-of-fit of the models was then checked using Q-Q plots, as well as the Cramer-Von Mises's test. Figure 2 shows the Q-Q plots obtained when the data is modelled using the (D) Half-normal key function with cosine (2) adjustment, (E) Hazard-rate key function, and (F) Uniform key function with cosine (1,2) adjustment, respectively. In this case all plots of the models had a similar structure and values close to the line $y = x$, making them 'good' models (Miller et al., 2017).

Table 1 also shows the Cramer-Von Mises test goodness-of-fit results for each model. The models have p-values larger than 0.05, so the null hypothesis is not rejected in all cases. This means that each model fits the data well (Miller et al., 2017).

Other measures that were used to determine the most adequate model included looking at the shoulder of the plot, the Standard Error (SE) and Coefficient of Variation (CV).The 'shoulder' refers to the detection function being flat near the sampling line transect and taking a shoulder-like shape in the fitted detection function overlaid on the histogram of observed distances. The shoulder is created because observers, apart from detecting the objects near them, must also detect the objects directly in front of them. Figure 2 shows the fitted detection func-

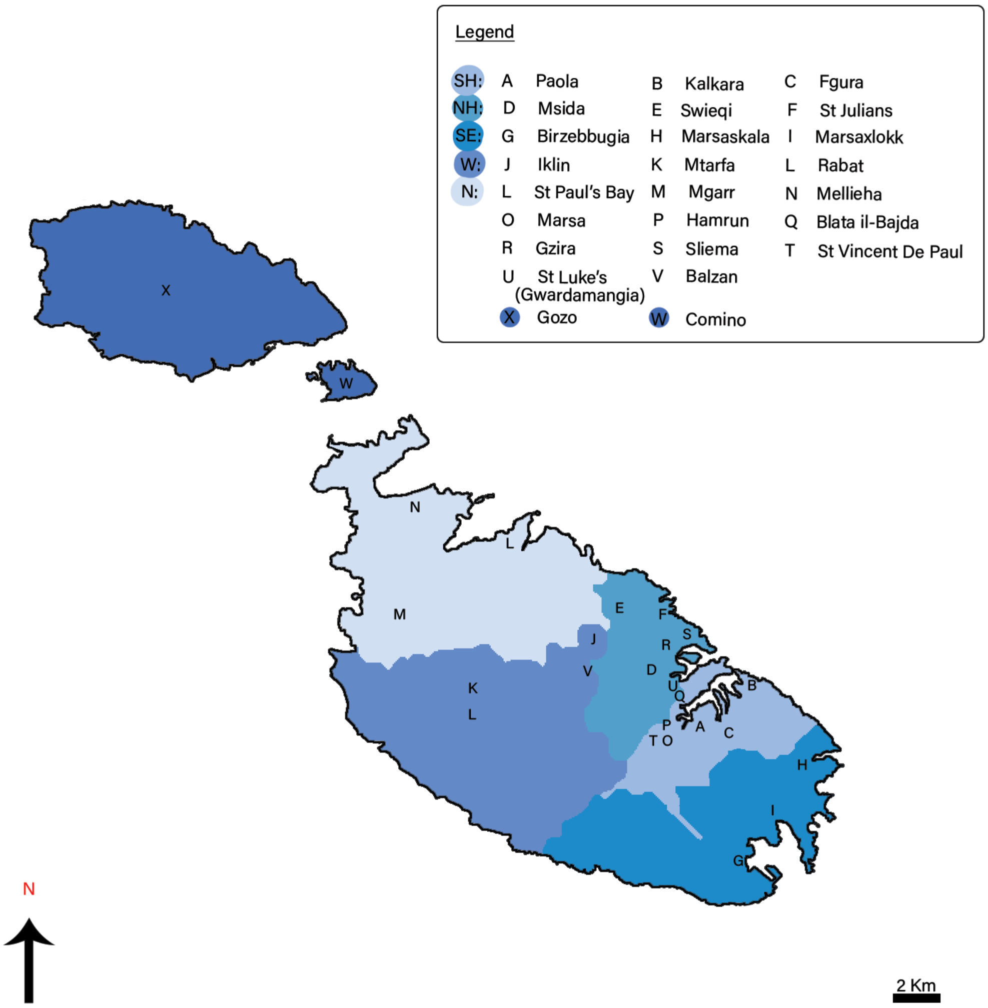

Figure 1: Map of the Maltese islands indicating the localities in the five districts i.e. Southern Harbour (SH); Northern Harbour (NH); South Eastern (SE); Western (W); Northern (N), that were sampled and other towns mentioned in the text, known to also be inhabited be feral pigeons.

tions overlaid on the histogram of observed distances for the feral pigeon data using (A) Half-normal key function with cosine (2) adjustment, (B) Hazard-rate key function, and (C) Uniform key function with cosine (1,2) adjustment, respectively. From these plots Model 3 shows the most pronounced shoulder supporting choosing this model to continue the analysis, and subsequently estimate the abundance and density of feral pigeons.

The SE and CV for detectability, given in table 1, show that the model with the smallest SE and CV is Model 3, with the Hazard-rate key function. This is yet another property that makes Model 3 the most suitable model for estimating the abundance of feral pigeons.

3.2 GLM analysis

Negative binomial regression was the GLM used to study the relationship between feral pigeon abundance and different urban environmental variables. To acquire a parsimonious model, any predictor variable whose coefficient had a corresponding *p*-value greater than 0.05 was omitted. At each step, the AIC and the Bayesian Information Criterion (BIC) of the fitted model were obtained. The AIC and BIC values decreased at a steady rate from the fit of the first model, which included all the predictors, to the fit of the model with only Old Buildings and Modern Buildings as predictors. The AIC and BIC gave slightly contradictory results when comparing the fit of the final model, a model with only Modern Buildings as predictor (i.e. 283.300 and 292.332 respectively), with the model which also included Old buildings as predictor (i.e. 283.3196 and 295.238 respectively). However, the difference in the values for the criteria for the two models is marginal and since the aim of the negative binomial regression analyses in this study is to identify the predictor variables (urban environmental characteristics) that influence the response variable (pigeon abundance), the model without Old Buildings was preferred as according to literature, the BIC is described as being the better model selection criterion for explanatory purposes (University, 2019).

3.3 Abundance of feral pigeons

The mean number of feral pigeons in the Districts, Localities within districts and urban environment (table 2) indicate that feral pigeons tend to occur in groups and sparingly within a given area.

The highest abundance of feral pigeons according to district, was for "Northern Harbour", followed by "Southern Harbour", "South Eastern", "Western" and "Northern" in this order. The abundance of feral pigeons in the localities within districts varied, with some towns not having any pigeons recorded at all. Feral pigeons were most abundant in "Park", followed by "Mainroad", "Agricultural area", "Sidestreet" and "Suburb".

To analyse whether the differences in feral pigeon count among districts and urban environments were significant, the Shapiro-Wilk test was first used to test the null hypothesis of univariate normal distribution for the different groups. Since the *p*-value in each district and transect resulted to be less than 0.05, the null hypothesis of normality was rejected and therefore the Kruskal-Wallis test was used. The test showed that there was no statistically significant difference among feral pigeon abundance in relation to districts ($X^2(2)$=0.938, p=0.649), however when considering the abundance of feral pigeons in relation to, a statistically significant difference, ($X^2(2)$=6.697, p=0.001) was found.

To identify which urban environment was responsible for the difference, the Mann-Whitney pair-wise test with the Bonferroni correction was carried out (table 3).

A significant difference in pigeon abundance was found in the majority of urban environment pairings with the exception of two: Suburb and Agricultural area, and Park and Mainroad. This shows that the urban environments pairs categorised as 'Suburb' and 'Agricultural area' and as 'Mainroad' and 'Park' share features that are unattractive and attractive, respectively, to feral pigeons. Model 3, consisting of the Hazard-rate key function, was used to estimate the cluster abundance and density of feral pigeons. The highest abundance was found in 'main road' followed by 'park', 'side street', 'agricultural area' and 'suburb' in this order (figure 3). The highest density of feral pigeons was found in 'park' followed by 'main road', 'agricultural area', 'side street' and 'suburb' in this order (figure 4).

4 Discussion

This study represents the first attempt to investigate the abundance and distribution of feral pigeons in Malta using the distance sampling technique and to associate these with urban environmental characteristics. Five districts in Malta were surveyed for feral pigeons between May 2020 and August 2020, hence during the Covid-19 restrictions.

Although feral pigeons were sparsely distributed, they were observed in all five districts, indicating that the species is ubiquitous to urban environments in all parts of mainland Malta. The mean abundance was low, but this was not due to insufficient sampling, but because feral pigeons occur sporadically within urban habitats, mostly in aggregates. This was the case at all spatial scales (strata): districts, towns and urban environment types.

As shown in table 2, the highest abundance found in this study, when considering localities, was in towns that surround Valletta, i.e. Msida and St Julians, hence towns that appertain to the Northern Harbour (NH) district. Al-

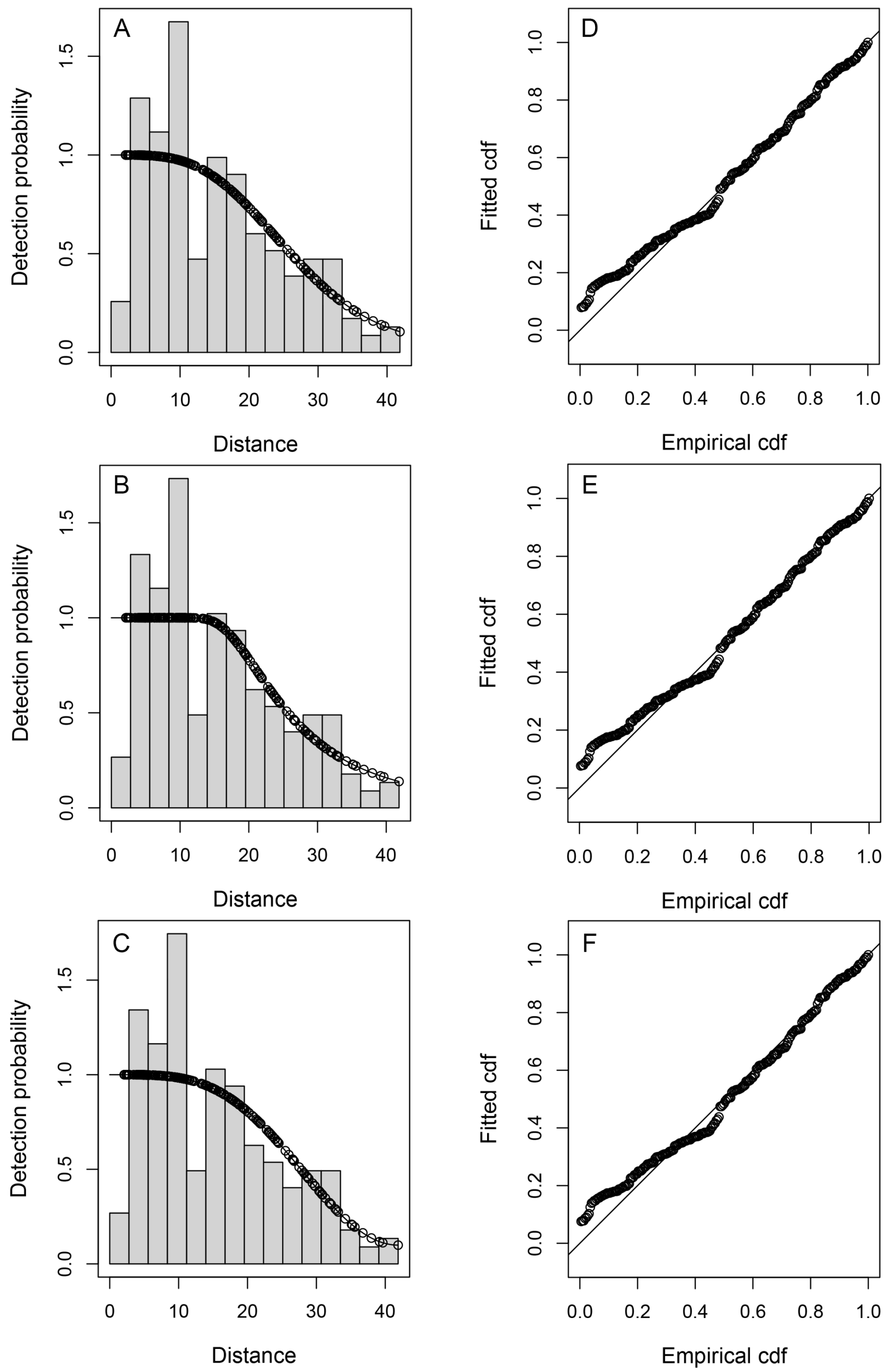

Figure 2: Key functions used for the estimation of abundance of feral pigeons (*Columba livia*) from transect data. Key functions fitted in distance sampling analysis (A) Half-normal key function with cosine (2) adjustment, (B) Hazard-rate key function, and (C) Uniform key function with cosine (1,2) adjustment. Quantile-quantile plot (D) Half-normal key function with cosine (2) adjustment, (E) Hazard-rate key function, and (F) Uniform key function with cosine (1,2) adjustment.

	Model 1	**Model 2**	**Model 3**
Key function	Uniform key function with cosine (1,2) adjustment	Half-normal key function with cosine (2) adjustment	Hazard-rate key function
AIC	1596.393	1597.352	1596.371
Test statistic	0.343619	0.304083	0.316579
p-value	0.102339	0.131644	0.121476
Formula	<NA>	~1	~1
Cramer-von Mises test *p*-value	0.12148	0.10234	0.13164
Average detectability (Pa)	0.6622	0.63553	0.65755
Standard error i.e., SE (Pa)	0.06691	0.0781	0.03901
Coefficient of variation i.e., CV (Pa)	0.10104	0.12288	0.05932
Change in AIC	0	0.02174	0.98124

Table 1: Summary for the detection function models fitted to the feral pigeon data.

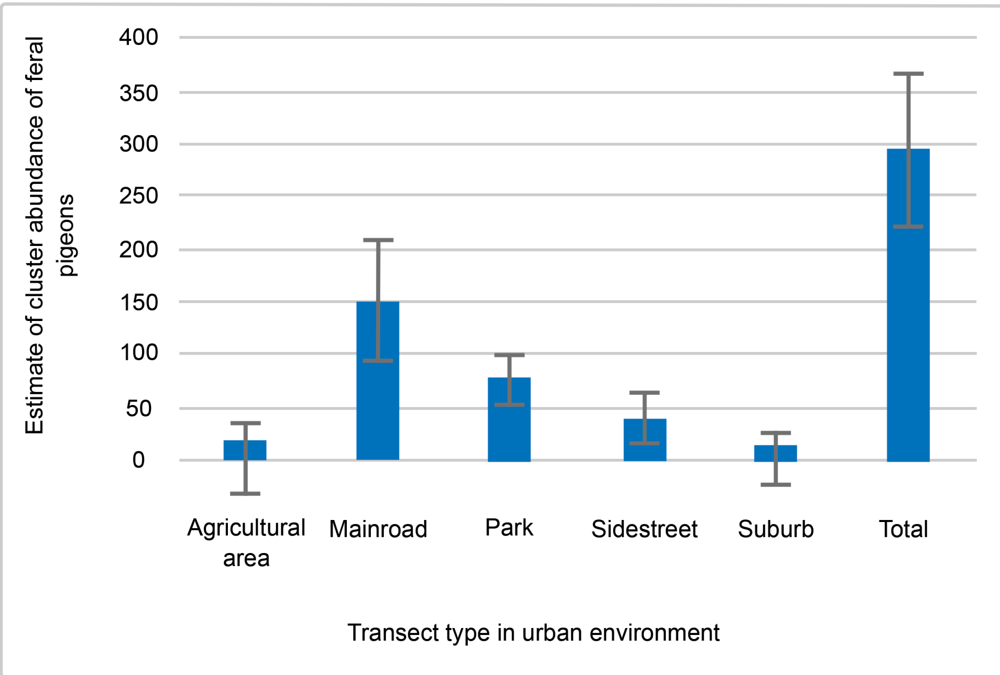

Figure 3: Estimate of cluster density of feral pigeons per sampled urban environment type in m^2 using Model 3 (error bars are ± one standard error).

Stratum	Area within stratum	Mean number of feral pigeons	Standard deviation
District	Southern Harbour	2.2	4.93
	Northern Harbour	3.47	8.98
	South Eastern	2.13	7.08
	Western	1.56	3.89
	Northern	0.73	2.80
Locality	Paola	2.4	5.40
	Kalkara	4.1	6.30
	Fgura	0	0
	Msida	5.7	9.37
	Swieqi	0	0
	St. Julians	4.7	12.31
	Birzebbugia	2.3	4.90
	Marsaskala	0	0
	Marsaxlokk	4.1	11.32
	Iklin	0	0
	Mtarfa	1.1	2.60
	Rabat	3.6	5.87
	Mellieha	0	0
	Mgarr	1.2	3.79
	St. Paul's Bay	1	3.16
Urban environment	Agricultural area	1.2	6.57
	Mainroad	2.67	5.20
	Park	5.33	9.38
	Sidestreet	0.6	2.04
	Suburb	0.26	1.46

Table 2: The mean number of feral pigeons counted per 300m transect in each stratum: District, Locality, Urban environment. There were 30 transects per district, 10 transects per locality, and 30 transects per urban environment.

Urban environment pairing	p-value	Urban environment pairing	p-value
Suburb & Sidestreet	0.0321	Sidestreet & Mainroad	0.0121
Suburb & Park	0.0002	Sidestreet & Agricultural area	0.0338
Suburb & Mainroad	0.0021	Park & Mainroad	0.2098
Suburb and Agricultural area	0.1	Park & Agricultural area	0.0004
Sidestreet & Park	0.0016	Agricultural areas & Mainroad	0.0031

Table 3: The results of the Mann-Whitney pairwise test with the Bonferroni correction applied to all combinations of the different urban environment. (H_0: There is no significant difference in feral pigeons count among urban environments; H_A: There is a significant difference in feral pigeons count among urban environments.)

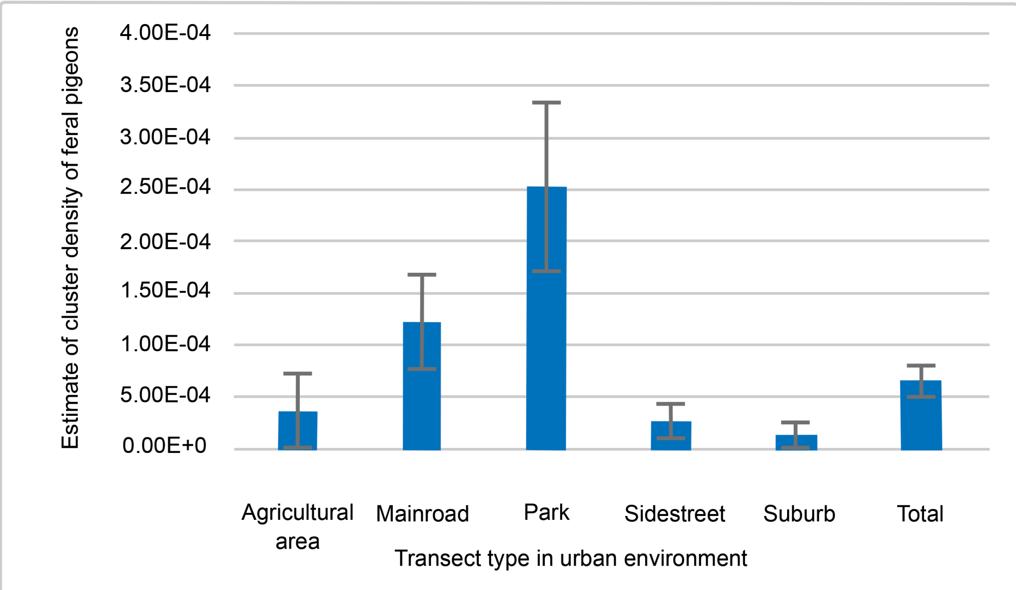

Figure 4: Estimate of cluster density of feral pigeons per sampled urban environment type in m^2 using Model 3 (error bars are ± one standard error).

though there was no statistically significant difference in the total number of feral pigeons counted in the different districts, the high count in NH is congruent with previous studies (Sultana et al., 2011) which found that Valletta had the largest population of feral pigeons in Malta. It has also been suggested that the Valletta population was spreading to surrounding localities (Sultana et al., 2011) within the NH district.

The present study was designed to survey different localities that were as similar as possible in their urban environmental characteristics. Through distance sampling, apart from the abundance of feral pigeons in the total area sampled by transects (4.52 km^2), an estimate of the abundance of the pigeons within each urban environment identified was also acquired. This indicated where the feral pigeons prefer to inhabit and hence enables identification of the urban characteristics they prefer, in this case, local centres and public open spaces located in the town centres, thus implying that these urban environment habitats share features that promote the feral pigeon's survival and proliferation (figure 3).

Studies have shown that the occurrence of feral pigeon in urban settings is greatly influenced by resource distribution, principally food, water, and shelter (Haag-Wackernagel, 1995; Murton et al., 1972a; Murton et al., 1972b). The 'Mainroad' was located in the historic centres of the towns surveyed, which represented the oldest part of a town (Hughes, 1956). Old buildings provide ample roosting places through their more elaborate design, with high physical complexity (Haag-Wackernagel et al., 2008). Main roads also tend to be lined with numerous restaurants and kiosks satisfying yet another of the birds' basic needs, that of food. Feral pigeons prefer to eat protein-rich food such as crop grain when possible (Johnston et al., 1995) however this is not always seasonally available. Hence, the feral pigeon has adapted to scavenge in urban environments where spillage of food is common and available in proximity of their roosting sites, thereby the birds expend less energy in foraging (Johnston et al., 1995). In fact, a study by Ryan (2011) showed that feral pigeons adapted to human foods since the birds preferred areas close to pigeon feeder sites, public spaces, and to landscape types with a high human density (Ryan, 2011). Water is another essential resource; feral pigeons satisfy their need for water from moisture in the food they forage or by drinking from whatever water is available, including rainwater puddles (Johnston et al., 1995). Town or village centres in Malta may have the occasional decorative water fountain, often found in parks. In fact, most parks are located in the same town or village centres or at a small distance from them, either way, easily reachable by feral pigeons. Public open spaces are usually situated in the vicinity of a parish church or chapel, whose architecture offers many opportunities for the pigeons to roost. Apart from this, people enjoy eating in parks, providing another indirect food source for the birds, or even a direct one when people feed pigeons. Hence, both 'Mainroad' and 'Park' satisfy all the basic needs of feral pigeons.

The negative binomial regression analysis was used to study possible relationship between feral pigeon abundance and urban environmental variables. The urban environmental characteristics which were initially included in the GLM were 'Moving vehicles', 'Bins', 'Foodsource', 'Watersource', 'Old buildings' and 'Modern buildings', with the latter two having the strongest correlation with feral pigeon abundance. The predictors included in the GLM were not multicollinear and significantly influenced abundance when testing was carried out univariately.

The model with the best fit retained only one predictor variable: 'Modern buildings'. Therefore, according to the negative binomial regression, the abundance of feral pigeons is mostly affected by the presence of modern buildings and the relationship is a negative one, i.e., abundance is low where there is a preponderance of modern buildings. A study by (Sacchi et al., 2002) reached similar conclusions. The fact that the presence of modern buildings had a negative influence on pigeon numbers might lead one to expect to find the opposite effect from old buildings, which was not the case in this study. In the present investigation, the 'Old buildings' predictor variable was not retained in the model with the best fit; the amount of transects carried out could be a contribution to this result, as an insufficient number of transects may have been used. These types of relationships might, however, be influenced by other factors that have not been considered in the present study.

The higher density of feral pigeons in the 'Park' rather than in the 'Mainroad' might be attributed to the fact that, in this investigation, from a total study area of 4.52 km^2 only 0.30 km^2 represents public open spaces ('Park') within towns, whilst the local centres ('Mainroad') are represented by 1.24 km^2. The preference for public open spaces within towns rather than local centres is very likely a result of the calmer ambiance present in a park. Hence, in the 'Park' there are more feeding opportunities and less stress.

The data gathered in the present study can be used as a starting point to investigate the ecology of feral pigeons in the urban environment of Malta. Repeating the study at time intervals will show whether the trends identified here change with time, including after the effects of COVID-related restrictions on human activities are no longer felt. Abundance estimation using distance sampling can be implemented throughout the Maltese islands, thereby identifying hotspots of feral pigeon occurrence and numbers. This study lays the ground for further research on feral pigeon populations and their ecology in urban environments as well as contributing information for management programmes that are tailormade to the local situation and circumstances. Periodical censuses of feral pigeons could also be useful for urban management of these birds.

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