ACTA ORNITHOLOGICA
Vol. 47 (2012) No. 1

Local and landscape-level factors affecting the density and distribution of the Feral Pigeon *Columba livia* var. *domestica* in an urban environment

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Abstract. Urbanization is the most dynamic phenomenon worldwide and many species colonize urban environment. Some of these species became so abundant in towns and cities that they are regarded pests, are human health hazard, causes damage to buildings and affect other urban species. Therefore, it is important to understand how such successful colonizers utilize urban environment and which factors affects their population densities. One of such species is the most common urban pest bird in the world, the Feral Pigeon *Columba livia* var. *domestica*. The aim of this study was to investigate how local food resources and the composition of the urban landscape affects densities of Feral Pigeon in the city of Poznań (Western Poland). Three counts were made in summer 2010 in 60 0.5 km x 0.5 km plots (25 ha) distributed randomly across residential areas in the city. The density of pigeons showed significant spatial autocorrelation, both positive and negative one. The density of pigeons was highest in plots with more tall buildings (over four floors), a large number of human-related food resources, schools, and a high proportion of green space. The density of pigeons was lower in plots with a higher density of streets and located further from the city centre. The solution to the pigeon problem appears to be to plan residential areas with low-rise buildings. To control the number of pigeons in urban areas, we suggest preventing access to local food resources by using litter-bins that are inaccessible to animals. The public should also be educated to behave appropriately towards pigeons and refrain from feeding them intentionally.

Key words: urban ecosystems, pest, landscape ecology, residential areas, spatial autocorrelation

Received — April 2012, accepted — June 2012

INTRODUCTION

Towns and cities are nowadays the most quickly developing areas in the world and they have profound effect on wildlife (Tomiałojć 1976, Marzluff et al. 2001, Lin et al. 2008, Evans et al. 2010). In urban landscapes, the presence of animals is limited by the availability of habitats, human disturbance, collisions with vehicles, predation and behavioural shyness (Górski & Antczak 1999, Fernández-Juricic & Jokimäki 2001, Randler 2003, Chace & Walsh 2006, Ditchkoff et al. 2006, Wang et al. 2009). Although many organisms colonized towns and cities there are some species which are so abundant there, that they have strong direct impact not only on other species but also on humans. Due to their noise, the possible transmission of disease, accumulation of excrement or even aggression towards people, these species are a serious global problem in many cities (Rock 2005, Dinetti 2006, Ditchkoff et al. 2006). Various techniques to control their numbers and eliminate their side effects have been necessary, all of which involve a financial cost (Górski 1989, Belant 1997, Rock 2005, Dinetti 2006). Thus, the knowledge about factors affecting population density of super-abundant urban colonizers may help to understand how these species achieved such high evolutionary success and, eventually, to work out the efficient measures to control their abundance.

Feral Pigeons *Columba livia* var. *domestica* are one of the most recognized, widespread and numerous pest bird species living in cities across Europe (e.g., Haag-Wackernagel 2000, Hetmański et al. 2011). The major health problem is the harmful effect of pigeon faeces as dust floating in the air that can be inhaled (Haag-Hackernagel & Moch 2004). This is particularly a problem where pigeons gain access to the interior of a building. They can infect people with viruses, bacteria, fungi and pathogenic protozoans (Haag-Wackernagel & Moch 2004, Vlahović et al. 2004). Moreover, in large towns, they are a source of ornithosis in humans through infection by *Chlamydophila psittaci* (Magnino et al. 2009). Thus, it is obvious that high pigeon densities are a human health hazard. Moreover, pigeon excrement is difficult and expensive to remove. Pigeon activity in, and around, a building may directly damage its structure since pigeons are capable of lifting roof coverings to force entry. Pigeon faeces also represent an aesthetic problem. To prevent local concentrations of pigeons, pigeon-deterring devices are often used, such as nets or spikes fixed to buildings (Haag-Wackernagel 2000).

The population size of Feral Pigeons depends largely on the area of the town (Barbieri & De Andreis 1991, Hetmański et al. 2011), but Jokimäki and Suhonen (1998) showed that it also depended on the density of the human population. It is well known that people living in cities provide abundant food resources for many birds, including pigeons (Jokimäki & Suhonen 1998, Jokimäki & Kaisanlathi-Jokimäki 2003, Marzluff et al. 2001, Fuller et al. 2008, Robb et al. 2008).

Despite of often high abundance of the Feral Pigeon there are still relatively few studies on its ecology. Little is known about local and landscape factors affecting the density of Feral Pigeons within the city (Sacchi et al. 2002, Rose et al. 2006). Knowledge on how the landscape composition affects the density of this species may be crucial in urban planning to prevent new residential areas from supporting large number of pigeons and to teach society how to control local densities of this species.

The aim of this paper is to investigate the effects of structural complexity and composition as well as the number of potential food resources in residential areas within a city on the density and spatial distribution of Feral Pigeons.

METHODS

Study area

The study was conducted in Poznań (52°17′34″–52°30′27″N, 16°44′08″–17°04′28″E), in western Poland in 2010. Poznań is one of the largest Polish cities with 556 thousand inhabitants and covers an area of 261.3 km^2 (population density 2,123 people per km^2). Altitude ranges from 60 m to 157 m. The climate of Poznań is continental humid with relatively cold winters and fairly hot summers (mean temperature in the coldest month, December, is 0.2°C and in the hottest, June, is 17.4°C). Annual rainfall is about 500 mm (Anon. 2003).

Bird counts

To estimate the density of Feral Pigeons we selected 60 0.5 km x 0.5 km (25 ha) plots within the residential areas of the city. Plots were chosen by random selection of geographical coordinates of points that were upper-left corners of the square plots. The selection was performed with Quantum 1.5 GIS software. Pigeons were surveyed between the beginning of June and beginning of July. This period covers the peak of reproduction of this species in Poznań (Dabert 1987). Three counts were done in each plot at approximately 10-day intervals. Each visit to each plot lasted 1 hour. Counts were made during favourable weather conditions (without rain and heavy wind). We walked throughout plots (one observer per one plot) to cover entire area visually. All birds seen within plots were counted but we did not count overflying flocks. We scanned by binoculars all buildings to find pigeons sitting on roofs or windowsills. We also visited all sites where birds gathered for foraging. Many birds could be individually recognised by plumage characteristics thus observers did not count birds that were suspected to be already counted. Because many Feral Pigeons breed in inaccessible lofts we were unable to establish exact number of breeding pairs and our analysis was based on the number of individuals.

Environmental explanatory variables

The following environmental explanatory variables potentially affecting the density of pigeons were measured in each plot (Table 1):

1. Number of food resources. We counted all sites where birds fed (based on direct observations of people feeding birds and left food remains), the number of litter-bins (of any type), and the number of groceries and fast-food restaurants. The number of food resources was a sum of these elements (Table 1). When litter-bins occurred in groups (e.g. in refuse heaps) each litter-bin was treated as a separate unit. We originally intended to use each category as a separate variable but they were highly positively correlated (all $r > 0.700$).
2. Number of schools (e.g. kindergartens, primary, secondary and high schools). It is a common practice that birds are fed by students in Polish schools. Moreover, there are often extensive green areas at schools offering foraging grounds for pigeons.
3. Density of streets (metres per 10 ha, Table 1). Traffic may influence mortality of pigeons through collisions with vehicles (Erritzoe et al. 2003).
4. Density of hedgerows (m per 10 ha, Table 1). A hedgerow was defined as a line of closely spaced shrubs. In a preliminary study we observed that pigeons frequently sought food along hedgerows. Thus we expected a positive association between densities of pigeons and hedgerows.
5. Percentage cover of green space (Table 1). Green space was defined as all the parks, squares, lawns and fallows within residential areas.
6. Percentage cover of tall buildings (of over four floors) in the plot (Table 1). We expected a positive association between this variable and the density of pigeons because more people live in higher buildings, therefore more additional food (e.g. on windowsills or just thrown out throughout the window) for pigeons is expected in such areas.

We also noted the percentage cover of low-rise buildings up to four floors (e.g., family houses) but since this variable was highly negatively correlated with the cover of tall buildings ($r = -0.795$, $p < 0.001$), only the latter was used in analyses.

7. Distance of the plot to the city centre (taken as the historical central square in the Old City district) (Table 1).

Variables 1–2 were recorded directly in the fields. Variables 3–7 were determined from aerial photos supported by field data and calculated in ImageJ and Quantum GIS software.

Our dependent variable was the density of pigeons, calculated as the mean number of individuals per 10 ha from the three surveys.

Statistical analysis

The first analytical goal was to estimate detection probability of Feral Pigeons within plots using the approach proposed by MacKenzie et al. (2002). The detection probability was modelled using a generalized linear model with a logit-link function in Presence 3.1 software (Hines 2006). We modelled two scenarios with the detection probability of individuals independent on the survey $p(.)$ and a survey-specific detection probability of individuals p(t). However, the estimated proportion of sites occupied did not differ substantially from our naive estimates of occupied plots without correction for detectability. Therefore, it was not necessary to consider imperfect detectability in our statistical analyses (see Cozzi et al. 2008).

We used Moran's I correlograms (Legendre 1993) to describe the spatial aggregation in the density of the species. The spatial autocorrelation value at a given distance class indicates how predictable (positively or negatively) pigeon population density is at a given point of the sampling framework. Autocorrelation using Moran's index typically varies between -1 and 1, with non-significant values close to zero. To test the significance of the autocorrelation we estimated p-values based on 500 Monte Carlo simulations.

We used model selection procedures based on information theory (Burnham & Anderson 2002) to identify factors affecting pigeon population

Table 1. Mean values of the habitat and landscape characteristics in the studied plots (n = 60) in residential areas of Poznań. Explanations: FoodRes — sum of all food resources (waste bins, restaurants, groceries, feeding sites), NSchool — number of schools of any type, StreetDen — density of streets (m per10 ha), HedgDen — density of hedgerows (m per 10 ha), GreenArea — percentage of the plot covered by green area (parks, lawns, fallows etc.), HighBuild — percentage of the plot covered by tall buildings, CityCentr — distance of the plot from the city centre (km).

Variable code	Mean	SE	Min–Max
FoodRes	32.9	4.9	0–197
NSchool	1.0	0.2	0–8
StreetDen	1346	45	515–1970
HedgDen	173	15	0–485
GreenArea	22.9	2.1	0–63
HighBuild	28.6	3.4	0–89
CityCentr	4.5	0.3	0.1–9.3

density in Poznań. Akaike information criterion corrected for small sample size (AICc) was used to identify the most parsimonious model from each candidate set. To take spatial autocorrelation into account we applied the approach proposed by Diniz-Filho et al. (2008). We defined two categories of explanatory variables: the "fixed" explanatory variable which was obligatorily present in all models, and the "floating" explanatory variables, which were those for which all possible combinations were found, allowing detection of the model with a minimum AIC value. For the "fixed" explanatory variable we defined a spatial term that was added to the models to eliminate spatial autocorrelation in the residuals, whereas environmental variables (variables 1–7 listed above) were used as "floating" variables. The fixed spatial variable was defined as an autoregressive term given by ρWY, where W was the connectivity matrix, Y the response variable, and ρ the autoregressive coefficient. Thus, our spatial model was a lagged-response regression model (Dormann et al. 2007): $Y = \rho WY + \beta X + e$, where β was the estimated ordinary least square function slope, X was an independent explanatory variable and e an error term. Finally, we ranked all possible 127 model combinations according to their ΔAICc values and used models with the lowest AICc together with associated weight values (the probability that a given model is the best) as that best describing the data. We considered models with ΔAICc lower than 2 as equally good (Burnham & Anderson 2002). We used model averaging for estimates of function slopes of parameters of interest (Burnham & Anderson 2002). Finally, the model weights were used to define the relative importance of each explanatory variable across the full set of models evaluated by summing weight values of all models that included the explanatory variable of interest (Burnham & Anderson 2002).

When necessary, we used natural log transformation to reduce the effects of outlier observations (Quinn & Keough 2002). Moreover, in all regression models, variables were standardized to allow a direct comparison of beta (slope) estimates (larger values of betas indicate stronger relationships between explanatory and dependent variables). Variables included in the analyses were weakly correlated (all $r < |0.35|$). It is believed that regression models are robust to multicollinearity if the correlation between variables is lower than $r = |0.6|$ (Mertler & Vannatta 2002).

Correlograms and multivariate analyses were run in the SAM 4.0 statistical software (Rangel et al. 2010) and all estimates of statistical parameters (means, betas) are quoted with standard errors (SE) and 95% confidence intervals (CI).

RESULTS

We recorded Feral Pigeons in 54 plots (occupancy rate: 88%). Detection probability of pigeons in a plot was high (0.89 ± 0.06) and model with constant detection probability had better support (AICc = 74.890) than the model with survey-specific detection probability (AICc = 80.501). Mean population density was 13.6 ± 1.7 pigeons per 10 ha (min–max: 0.0–53.9, Fig. 1). We found statistically significant positive spatial autocorrelation at a distance up to 1.5 km and negative spatial autocorrelation at distances of 5 km, 7.5 km, and 10 km (Fig. 2). Model selection based on Akaike's criterion showed that 10 models were equally good (Table 2). The best models explained over 50% of the variation in the density of pigeons (Table 2). The explanatory variable that was present in all the best models was the cover of tall buildings and it positively affected density of pigeons (Table 3). The next most important variables were distance to the city centre which negatively affected density of pigeons (Fig. 1) and sum of food resources which positively affected the density (Table 3). The density of pigeons was also positively correlated with the number of schools and the cover of green space but negatively correlated with density of streets (Table 3).

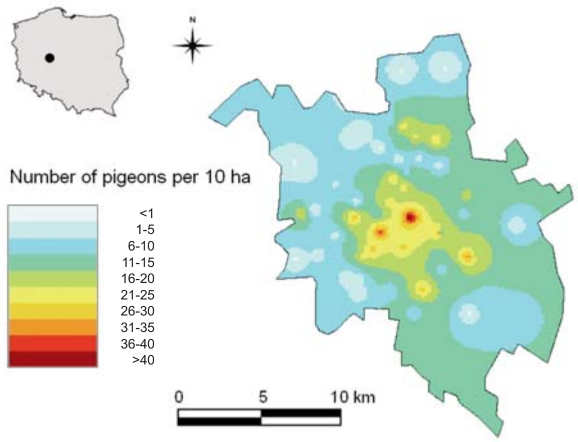

Fig. 1. The interpolated density of the Feral Pigeon in administrative boundaries of Poznań. The interpolation was performed with an inverse distance method in Quantum GIS software.

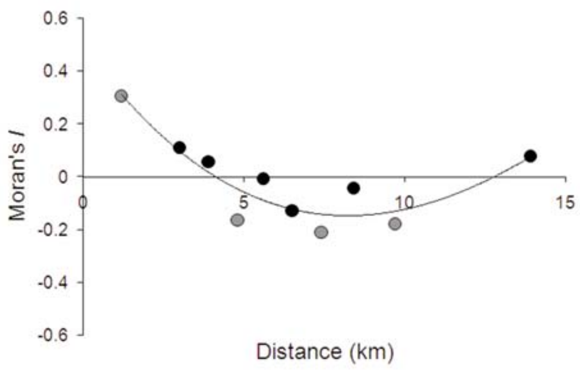

Fig. 2. Spatial autocorrelogram (Moran's I) for density of Feral Pigeons in Poznań. Grey circles indicate spatial autocorrelations significant at $\alpha < 0.05$.

DISCUSSION

Density of Feral Pigeons in our study area depended on both local and landscape-scale factors. The density was also spatially structured with significant — both positive and negative — spatial autocorrelation recorded in our study area. This indicates that densities of Feral Pigeons are spatially predictable in Poznań. For example, having the density estimation in a given plot it is possible to state that sites located up to two kilometres away will have similar population densities, whereas sites located between five and ten kilometres away will have different ones.

The highest densities of Feral Pigeons are regularly noted in city centres (Sacchi et al. 2002, Nowakowski et al. 2006), whereas they are rare at the peripheries of cities (Lancaster & Rees 1979, Luniak 1983). In Poznań, the highest density of birds was also found in the city centre (up to 54 individuals per 10 ha) and this value is fairly similar to results from other cities and towns in Poland (Nowicki 2001, Nowakowski et al. 2006, Hetmański & Jarosiewicz 2008). Higher pigeon density in city centres may result from the fact that the density of buildings is higher in the central parts of the city, and that more people live and are constantly present there. Also, it is possible that some historical factors, e.g., the year when city was colonized by birds may affect spatial pattern of bird's occurrence and density (Skórka et al. 2006, Evans et al. 2010). Møller et al. (2012) showed that population densities of urban birds reflect timing of city colonization and this suggests that centre of Poznań was colonized by Feral Pigeons first and then birds dispersed into other town's districts. Moreover, predation by birds of prey, martens, cats and red foxes may be smaller in centres of towns than in the suburbs that may add to higher population density of pigeons (Lucherini & Crema 1993, Turner & Bateson 2000, Randa & Yunger 2006, Sorace & Gustin 2009).

In our study, the density of Feral Pigeons was spatially autocorrelated. Spatial autcorrealtion is rarely accounted for in urbanization studies and our results are one of few where spatial pattern was analysed (Huste et al. 2006, Devictor et al. 2007). In a biological sense spatial autocorrelation may lead to spatial synchrony in population dynamics (Liebhold et al. 2004). Densities of our study species were positively autocorrelated up to a distance of 1.5 km. This distance is short and corresponds to a low rate of natal dispersal of juveniles and adults from breeding colonies observed in this species (Hetmański 2007). Much more difficult to explain is the negative spatial autocorrelation found at larger distances for the density of individuals. Negative spatial autocorrelation is rarely found in field studies (Kerr et al. 2000, Griffith 2006). In our study it probably results from the spatial pattern of densities with the highest in the city centre and the lowest in the suburbs.

We found that the most important variable influencing the density of pigeons in Poznań was the cover of high buildings (over four floors)

Table 2. Best models explaining density of Feral Pigeons in Poznań. Explanation of the variable codes — see Table 1.

No.	Model	r^2	AICc	ΔAICc	weight
1	HighBuild + CityCentr	0.525	85.250	0	0.079
2	HighBuild + FoodRes + CityCentr	0.541	85.654	0.404	0.065
3	HighBuild + FoodRes + NSchool	0.538	86.021	0.771	0.054
4	HighBuild + FoodRes	0.517	86.195	0.944	0.049
5	HighBuild + CityCentr + GreenArea	0.536	86.318	1.068	0.046
6	HighBuild + FoodRes + CityCentr + StreetDen	0.554	86.471	1.220	0.043
7	HighBuild + FoodRes + CityCentr + GreenArea	0.552	86.769	1.519	0.037
8	HighBuild + CityCentr + StreetDen	0.532	86.773	1.523	0.037
9	HighBuild + FoodRes + CityCentr + NSchool	0.551	86.962	1.712	0.034
10	HighBuild + FoodRes + NSchool	0.530	87.052	1.802	0.032

Table 3. Factors affecting the density of Feral Pigeons in Poznań. Explanation: CI — confidence interval. For further explanations see Table 1.

Variable	Beta ± SE	Lower 95% CI	Upper 95% CI	Importance
HighBuild	0.267 ± 0.089	0.094	0.441	0.955
CityCentr	-0.259 ± 0.092	-0.438	-0.079	0.753
FoodRes	0.155 ± 0.052	0.053	0.256	0.563
NSchool	0.081 ± 0.025	0.031	0.130	0.377
StreetDen	-0.071 ± 0.023	-0.114	-0.025	0.333
GreenArea	0.065 ± 0.022	0.022	0.108	0.314

which were mostly blocks of flats. In larger buildings more people live, and among them there may be more "bird lovers" willing to feed pigeons. This is in line with earlier studies (Mizera 1988, Jokimäki & Suhonen 1998, Buijs & Van Wijnen 2001) showing that the number of pigeons depends on the density of human population. On the other hand, this result contradicts some other studies (Sacchi et al. 2002, Nowakowski et al. 2006) where it was shown that pigeon population density was higher in areas with old buildings which are usually lower than tall blocks of flats.

The density of pigeons was positively correlated with the number of human-related food resources. The availability of such food attracts a number of species, which congregate in such places (Belant et al. 1997, Chace & Walsh 2006). For example, Jerzak (2001) showed that the number of Magpies *Pica pica* during the breeding season was positively correlated with the concentration of litter-bins in the urban environment. In our study area, Feral Pigeons directly benefited from waste food deposited in litter-bins, but they also often foraged in their proximity by sifting through garbage previously scattered by cats or corvids. Moreover, pigeons gathered at entrances of groceries and fast-food restaurants where they were frequently fed by people. Pigeons also tried to enter (sometimes successfully) shops (authors unpublished observations). It is also well known that people living in urban areas deliberately provide food for birds (Sol et al. 1998, Marzluff et al. 2001, Fuller et al. 2008, Robb et al. 2008).

We found that the density of pigeons was positively related to cover of green space in the city. Pigeons may benefit from these areas in two ways. Firstly, birds may find natural food resources (e.g., weed seeds) in such areas. Secondly, people often visit such places and frequently feed birds, especially in city parks. Elements of the original, pre-urban landscape, such as remnant forests or trees and open fields, together with lawns, weedy vegetation, and lower building density positively correlate to the abundance of many birds in towns (Chace & Walsh 2006, Maciusik et al. 2010).

We also found an interesting positive effect of the number of schools on the density of pigeons. This relationship may be explained by the common practice of Polish students feeding birds in the school neighbourhood. Moreover, there is often green space next to schools that may offer attractive foraging grounds for pigeons.

The density of pigeons was negatively affected by a high density of streets. First, this indicates that road kills may lead to a lower local density of this species. Cars may be an important mortality factor for several species in different habitats (Erritzoe et al. 2003, Borda-de-Agua et al. 2011, Summers et al. 2011). Pigeons frequently gather at roads for foraging as was shown by Rose et al. (2006). Roads may offer a greater variety of food than can be found in the surrounding areas, e.g., garbage that has been thrown into the roads by car drivers (Slater 1994). A road surface can absorb and store great quantities of solar heat. It was found that the average temperature on a road surface is 7°–10° C warmer than the surrounding area (Whitford 1985) and it may attract pigeons, mostly during colder periods. We also observed that pigeons frequently used road puddles after rain for bathing (unpublished observations). These may increase the probability of collision with cars. Secondly, negative impact of road density on pigeons may also results from the behavioural response. Pigeons may avoid areas with high density of roads because the latter increases disturbance and generates high level of noise (Kociolek et al. 2011). Roads lead also to substantial fragmentation of urban habitats (Kociolek et al. 2011, Tremblay & St. Clair 2011) and generate habitat edges that may impede bird's movements in urban environment. All these phenomena may negatively affect local population density (Kociolek et al. 2011).

Landscape management for wildlife within the urban environment requires a balance between the creation of a healthy, rich wildlife environment and the limitation of potential hazards and nuisances. Our results enable us to make some recommendations for city planners that would assist in the control of the number of pigeons. Firstly, when planning new residential districts in a city we would recommended low-rise buildings and lower human densities than in tall blocks of flats. Thus, the concept of green cities fits our recommendations well (Li et al. 2005, Kong et al. 2010). This would have other benefits (aesthetic, health, less stress to the city inhabitants) besides controlling the density of pigeons.

According to Haag-Wackernagel (1993), long-term effective elimination requires the limitation of food supplied by "pigeon lovers". We agree with this statement. Remnants of food are often found in places visited by pigeons or near refuse heaps, which causes the birds to favour such places. Some people feed birds all year round, thus being a predictable and easily accessible source of food. The solution to this problem might be the appropriate education of local communities, especially about the various consequences related to public hygiene and the transmission of disease as the number of pigeons increases in the urban environment. The proper construction of litter bins with limited animal access is also a recommended solution to the problem of these birds in residential areas. For example, litter-bins should have closed lids, and refuse heaps should be built in enclosed spaces. This would limit access to food, not only for pigeons, but also to other undesirable species such as corvids, gulls, rodents and domestic cats. This action could be applied mostly in the city centre where densities of pigeons are the highest.

CONCLUSION

Our study revealed that several structural features and human-related factors affected Feral Pigeons. Most of the variables investigated that positively influenced density of birds were also linked with the increasing urbanization. However, there was also the association between semi-natural areas and density of Feral Pigeons. Thus, it seems the success of this species in colonization of towns relies on the ability to use both man-made structures and some semi-natural habitats as well as in the vast exploitation of human behaviour. We also found significant spatial autocorrelation in the population density that probably portrays colonization history of Poznań by this species. The increasing trend of urbanization around the world probably will add to the evolutionary success of this species. However, it is also desirable to conduct similar studies in other towns to find out if our results represent the general pattern or rather, a pattern that is specific to the study area.

ACKNOWLEDGEMENTS

This study was supported by a grant project from the City of Poznań (RoM. III/3420-56/10). We thank an anonymous referee for all critical points. We are grateful to Tim H. Sparks for his helpful comments on the manuscript and language correction.

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STRESZCZENIE

[Czynniki wpływające na rozmieszczenie i zagęszczenie gołębia miejskiego]

Urbanizacja jest obecnie globalnym zjawiskiem, które może odgrywać znaczący wpływ na funkcjonowanie populacji wielu gatunków zwierząt. Szereg gatunków skolonizowało miasta, a niektóre stały się tam tak liczne, że są uważane za gatunki niepożądane lub wręcz szkodliwe z punktu widzenia człowieka. Poznanie czynników decydujących o tym, że dany gatunek osiąga duże zagęszczenia w środowisku miejskim, jest bardzo ważne w zrozumieniu sukcesu ewolucyjnego gatunków kolonizujących miasta, a także w opracowaniu skutecznych metod niwelowania potencjalnych szkód wynikających z obecności tych gatunków w mieście. Jednym z takich gatunków jest gołąb miejski *Columba livia* var. *domestica*, który należy do najliczniejszych ptaków zasiedlających miasta w wielu rejonach świata. Celem pracy było poznanie jak źródła pokarmu oraz struktura środowiska miejskiego wpływa na zagęszczenia gołębia miejskiego w Poznaniu (Wielkopolska).

Wyznaczono 60 25-ha powierzchni, na których wykonano po trzy liczenia w okresie lęgowym, w 2010 roku. Na każdej powierzchni notowano szereg zmiennych opisujących dostępność źródeł pokarmu oraz strukturę siedlisk (Tab. 1). Gołębie stwierdzono na 54 powierzchniach. Prawdopodobieństwo stwierdzenia gołębi na powierzchni było stałe między poszczególnymi kontrolami i wynosiło 0.89 ± 0.06. Średnie zagęszczenie wynosiło 13.6 ± 1.7 osobników na 10 ha (min–max: 0.0–53.9, Fig. 1). Stwierdzono istotną statycznie autokorelację przestrzenną; dodatnią do dystansu ok. 1.5 km i ujemną przy dystansach 5, 7.5 i 10 km (Fig. 2). Selekcja modeli statystycznych opisujących wpływ różnych czynników na zagęszczenie gołębi przy pomocy kryterium Akaike'a wykazała 10 najlepszych modeli (Tab. 2). Modele te wyjaśniały około 50% zmienności w zagęszczeniu gołębi (Tab. 2). Zagęszczenie było pozytywnie związane z pokryciem powierzchni przez wysoką zabudowę, liczbą źródeł pokarmu, liczbą szkół na powierzchni i pokryciem powierzchni przez tereny zielone (Tab. 3). Zagęszczenie gołębi spadało wraz z odległością od centrum miasta (Fig. 1, Tab. 3) oraz wraz ze wzrostem zagęszczenia ulic (Tab. 3).

Uzyskane wyniki sugerują, że sukces ewolucyjny gołębia miejskiego polega na wykorzystywaniu przez ten gatunek zarówno elementów naturalnych jak i antropogenicznych w środowisku miejskim. Rozwiązaniem problemu dużych zagęszczeń gołębi w środowisku miejskim może być budowa osiedli z niską zabudową oraz stosowanie koszy na śmieci z pokrywami, zwłaszcza w centrum miast, gdzie liczebność gołębi jest z reguły największa. Mieszkańcy miast powinni być również właściwie informowani o konsekwencjach dokarmiania gołębi w mieście.