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Effects of human-related disturbance on breeding success of urban and non-urban blue tits (*Cyanistes caeruleus*)

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Abstract There is a need to study the effects of urbanization on wildlife in order to understand the ecological implications of increasing urbanization and find out how to reduce its threats to biodiversity. The blue tit evolved as a forest species and prefers deciduous and mixed forests, whereas its nesting in urban habitats is a more recent phenomenon. Our long-term study of blue tit populations has been conducted in two habitats: an urban parkland (frequently visited by people) and a deciduous forest outside of the city. Using linear mixed modeling, we revealed that a relationship of blue tit breeding success (and the number of fledglings) with thermal conditions in May differed between the urban parkland and the forest. While the relationship was positive in the forest, it was negative in the parkland. In addition, breeding success in the parkland increased with increasing number of rainy days in May. We argue that the main possible reason for such patterns is human activity in the parkland, which interferes with tit parental care, especially the regular feeding of nestlings, whereas it is evidently associated with weather conditions. Human disturbance in the forest is likely to be negligible.

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Introduction

The exponential growth of urban areas has become one of the most important environmental issues worldwide; therefore studies in urban areas should be multiscaled and investigate plausible mechanisms, preferably comparing the same species (densities and mechanisms such as reproduction) in similar habitats across different hierarchical landscape levels (Chamberlain et al. 2009; Hedblom and Söderström 2012). Urban studies have paid special attention to effects on birds. Bird behavior is heavily affected by urban development, particularly as a result of predation risk, urban features (e.g. buildings, pathways, paucity of natural food and access to urban leftovers, taxonomic composition of flora, low density of trees) and various human activities (Ortega-Álvarez and MacGregor-Fors 2011). In this context urban parks are important biodiversity hotspots in cities - a park of 10–35 ha would contain most of the bird species recorded in the city (Jokimäki 1999; Fernández-Juricic and Jokimäki 2001).

Animals in general are expected to maximize fitness by overestimating rather than underestimating risks. Overestimation costs (e.g. lost feeding opportunities) have smaller fitness consequences than underestimating the danger that potentially leads to death (Bouskila and Blumstein 1992). The impacts of nonlethal human-caused disturbance on the behavior and reproductive success of animals are often analogous to predation risk (Gill et al. 1996; Gill and Sutherland 2000; Frid and Dill 2002; Le Corre et al. 2009; Kociolek et al. 2011; Marzano and Dandy 2012). Thus, the reaction of birds to the presence of mammalian predators or humans may trigger a variety of behavioral and physiological responses. A primary behavioral reaction is elicited by the central nervous system after detecting a predator. An adrenocortical response and the release of glucocorticoids evokes a secondary behavioral response (Müller et al. 2006). Birds have been found to react to the presence of a predator or human with a behavioral response (disturbing the regularity of feeding nestlings), or with an adrenocortical response (increasing the level of stress hormones), or with both those effects at the same time (Holberton et al. 1996; Platteeuw and Henkens 1997; Silverin 1998; Fowler 1999; Romero and Remage-Healey 2000; Verhulst et al. 2001; Cockrem and Silverin 2002; Nephew et al. 2003; Clinchy et al. 2004; Jarvis 2005). In small birds, like tits, the presence of humans near the nest may provoke strong behavioral responses. A parent emits alarm call and hesitates to approach the nest, and if this disturbance lasts for a long time it may cause some nestlings die from starvation or hypothermia (Müller et al. 2006).

The blue tit (*Cyanistes caeruleus*) evolved as a forest species and is well adapted to conditions of deciduous and mixed forests (Cramp and Perrins 1993). It survived the last glaciations mainly in the Balkan and Iberian refugia and after the last Ice Age, it have colonized Europe from these two areas (Kvist et al. 2004). Thus the availability of urban habitats suitable for breeding blue tits is a rather more recent phenomenon (Bańbura and Bańbura 2012).

Urban ecology research could be transformed into practical applications for urban landscape management and planning and that is why there is a need to study the effects of urbanization on wildlife in order to understand the ecological implications of increasing urbanization and how to reduce its threats to biodiversity (Chamberlain et al. 2009; MacGregor-Fors 2011). The effect of urbanization can be immense, yet our understanding is still rudimentary (Chace and Walsh 2006) and therefore Chamberlain et al. (2009) note that further comparative research between urban and non-urban populations of birds is to be welcomed.

We studied blue tit populations in two habitats: an urban parkland (frequently visited by people) and a deciduous forest (outside of the city). We assumed that human visitors often interfere with parental activities of adult blue tits in direct proportion to visiting frequency, which should lead to a difference between an urban park and a rural forest in the way in which the weather in May (the time of the nestling stage) influences breeding success. Essentially, the warm weather should be advantageous for breeding, but in the case of the urban parkland it also drastically increases the frequency of visitors. Consequently, we expected that the nice weather (warm with low rainfall) should positively influence breeding success in the forest, but the effect should be negative in the urban parkland.

Study area and methods

This study was carried out in 2000–2013 as part of a long-term project of research on the breeding biology of hole-nesting birds occupying nestboxes near Łódź, central Poland. The study areas are located in two, 10 km apart, structurally contrasting habitats: an urban parkland and a deciduous forest (Glądalski et al. 2016). The parkland site (51°45'N; 19°24'E), c. 80 ha (including: the zoological garden of 16 ha and the botanical garden of 64 ha), has a highly fragmented tree cover (formed artificially) and is a major recreation and entertainment area in Łódź. The forest study site (51°50'N; 19°29'E) is c. 130 ha area in the center of a mature mixed deciduous forest (1250 ha in total), bordering on the NE part of the city of Łódź, with oaks *Quercus robur* and *Q. petraea* as predominating species.

The data analyzed include seasons 2000–2013 in the parkland and 2002–2013 in the forest. Both areas have been equipped with wooden nestboxes (Lambrechts et al. 2010). The diameter of the nestbox entrance hole was 29 mm. All the nestboxes were placed on trees (usually on oaks) at a height of circa 2.5 m. In both study areas, distances between neighbouring nestboxes were about 50 m. Mean densities of nestboxes did not differ between the parkland (2.3 ± 0.052 nestboxes/ha) and the forest (2.2 ± 0.03 n/ha) (Student's t-test for independence samples, $t = 1.90$, df = 24, $p = 0.07$). Nestboxes in both the study areas were not exposed to direct sunlight during breeding seasons. We investigated orientation of the nestboxes and it had no influence on densities of birds or breeding performance (unpublished data). From early spring on, all nestboxes were checked at least once a week to detect all breeding attempts and, subsequently, breeding characteristics of tits were collected. A total of 666 first clutches of blue tits were analyzed (Table 1). Mean lying date in the parkland was only 2 days earlier than in the forest (Glądalski et al. 2015). Mean clutch size ranged from 9.69 (2013) to 11.36 (2011) in the parkland and from 10.39 (2006) to 13.03 (2003) in the forest (Glądalski et al. 2015). The breeding density of blue tits did not differ between the two sites (Student's t-test for paired samples, $t = 1.57$, df = 11, $p = 0.16$) (unpublished data, article in review). Breeding success refers to the proportion of eggs resulting in fledglings that left the nest (and refers to the nests from which at least one young left the nest). In this paper we focus on the site-specific and year-specific mean breeding success.

The open areas of the parkland are often used for playing games (large groups of children with teachers), physical recreation, concerts (sometimes very noisy) and other entertainment activities. In addition, May is the main time of the year when different building works, earthworks and maintenance of the park area are conducted. Their intensity is usually

Table 1 The numbers of clutches of blue tits and available nest-boxes analysed in this study

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Sum
Blue Tit Parkland	27	29	22	17	22	13	17	25	28	22	25	15	33	25	320
Blue Tit Forest	-	-	20	32	50	37	21	42	53	26	29	8	15	13	346
Nest-boxes (Parkland)	189	189	189	178	178	178	178	178	178	182	184	187	186	186	-
Nest-boxes (Forest)	-	-	110	197	246	246	244	241	244	246	296	296	297	297	-

associated with the nice weather, resulting in numerous workers in the field with their loud machinery like tractors, trucks, gasoline-powered ride-on mowers and others.

The local temperatures for Łódź were obtained from TuTiempo.net climate data base (http://www.tutiempo.net/en/Climate/LODZ/124650.htm), with some gaps being filled with data from Freemeteo.com (http://freemeteo.com/default.asp?city=%C5%82%C3%B3d%C5%BA&pid=4&inType=1&la=20). Following Perrins and McCleery (1989), to synthetically characterize thermal conditions of the nestling period, we calculated warmth sums for May every study year, as the sum of the maximum daily temperatures for that month.

Student's *t*-tests for paired and for independent samples were used to examine density of birds between both study sites and to compare density of nest-boxes between both study sites. We applied linear mixed models to test the relationship between breeding characteristics (breeding success and fledgling number) and the study site as factor in relation to the weather conditions in May (warmth sums and the number of rainy days as covariates). To stabilize variance and get normal distributions we arcsine transformed breeding success (arcsin $\sqrt{p}$) and square-root transformed the number of fledglings ($\sqrt{(n + 0.5)}$) before modeling (Crawley 2002). In these models we treated year and nest box ID as random factors and used RML to estimate parameters, with degrees of freedom being approximated by the Satterthwaite method (Heck et al. 2010). Following Crawley (2002), we judged the importance of particular effects in the models by analyzing their significance in an ancova style rather than using AIC-based model comparisons. Modeling was performed using the IBM SPSS Statistics 22 software (IBM SPSS Statistics 22 2013). While we used transformed data in models, non-transformed values are shown in the text and figures. Pearson's linear correlation analyses and t-tests were conducted applying STATISTICA 10 (StatSoft Inc, 2010). We considered $p \leq 0.05$ as significant.

Results

Mean number of fledglings of the blue tit ranged from 6.14 (2000) to 9.80 (2011) in the parkland and from 7.28 (2010) to 10.97 (2003) in the forest. Mean breeding success ranged from 56.97 % to 89.26 % at the parkland area and from 65.57 % to 89.95 % at the forest area. A linear mixed model showed a significant interaction between the study site factor and the sum of maximum temperatures (Table 2), suggesting that the relation between breeding success and temperature differed between the urban park and the forest. The significant estimates for the interaction in this model showed that the relation was negative in the parkland ($b = -0.002 \pm 0.0004$ (SE), $t_{648.9} = -5.08$, $p < 0.001$) and positive in the forest ($b = 0.001 \pm 0.0003$ (SE), $t_{645.8} = 2.61$, $p = 0.009$) (Fig. 1). We found very similar effects for the number of fledglings, with a significant interaction between the study site factor and the sum of maximum temperatures (Table 2) – corresponding estimates of regression coefficients were negative in the park ($b = -0.004 \pm 0.001$ (SE), $t_{649.1} = -5.23$, $p < 0.001$) and positive in the forest ($b = 0.002 \pm 0.001$ (SE), $t_{646.9} = 3.74$, $p < 0.001$).

We also found that an interaction that occurred between the study site and the number of rainy days in May affected breeding success of blue tit broods (Table 2), suggesting that the rainfall had a different effect on breeding success in the urban parkland and in the forest. The effect in the parkland was positive ($b = 0.014 \pm 0.01$ (SE), $t_{649.2} = 2.55$, $p = 0.011$), whereas in the forest it was non-significant ($b = -0.004 \pm 0.004$ (SE), $t_{647.2} = -0.99$, $p = 0.33$). The number of fledglings in relation to the number of rainy days in May did not show analogous patterns, with the study site being the only significant effect (Table 2).

Table 2 A summary of linear mixed model tests of the breeding success (arcsine transformed) and the number of fledglings (square-root transformed) of blue tits in relation to the study site and the warmth sum (the sum of the maximum daily temperatures for May) and the number of rainy days (in May), with year and nestbox ID being treated as random factors. Significant *P*-values in the model are in bold

Y-variable	Covariate	Effect	Df	F	p
Breeding success (arcsine transformed)	Warmth sum	Intercept	1;649.1	100.0	**<0.001**
		Site	1;649.1	23.9	**<0.001**
		Warmth sum	1;648.9	2.3	0.14
		Site*Warmth sum	1;648.9	25.8	**<0.001**
	N rainy days	Intercept	1;648.2	598.7	**<0.001**
		Site	1;648.2	8.7	**0.003**
		N rainy days	1;649.2	1.4	0.244
		Site*N rainy days	1;649.2	6.5	**0.011**
N fledglings (square-root transformed)	Warmth sum	Intercept	1;649.3	172. 7	**<0.001**
		Site	1;649.3	23.4	**<0.001**
		Warmth sum	1;649.1	0.01	0.93
		Site*Warmth sum	1;649.1	27.4	**<0.001**
	N rainy days	Intercept	1;648.6	1484.4	**<0.001**
		Site	1;648.6	7.9	**0.005**
		N rainy days	1;649.3	0.3	0.57
		Site*N rainy days	1;649.3	3.1	0.08

We assess that in 2008–2013 the average number of visitors (ticket sales from the botanical garden and the zoological garden) to our parkland study site in May as the main period of the nestling stage of blue tits is about 75,000 or 938 persons/ha/month, with a clear tendency for the number of visitors to increase at the time of warm and sunny weather. The analogous average number of people passing throughout the forest study site (according to estimations made by the Forest Service) is assessed at about 1500 or 11.5 persons/ha/month. The total length of pathways per hectare is 4.5 times greater in the parkland than in the forest (for the parkland – 228.8 m/ha and for the forest – 51.4 m/ha), and a mesh of paths is much more dense in the parkland. Visitor numbers (2008–2013) in the parkland area were negatively correlated with days with rain in May, $r = -0.91$, $n = 6$, $p = 0.01$, and tended to be related to warmth sums of May, $r = 0.8$, $n = 6$, $p = 0.054$.

Discussion

Our predictions on an inter-habitat difference in the relationship between the May weather and blue tit breeding success were supported. There indeed was a significant interaction between the warmth sum and the study site which was affecting breeding success, with a negative effect in the urban parkland and a positive effect in the rural forest. Lower breeding success in years with warmer May in the parkland area may be associated with great numbers of visitors, entertainment events and other types of human-caused disturbance. Human recreation behaviour can interfere with wildlife in many different ways (Young et al. 2005; Chace and Walsh 2006; Remacha and Delgado 2009; Marzano and Dandy 2012). Exposure to human visitors in birds may disturb the regularity of feeding nestlings by parents (Ruiz et al. 2002; Bańbura et al. 2007, 2008).

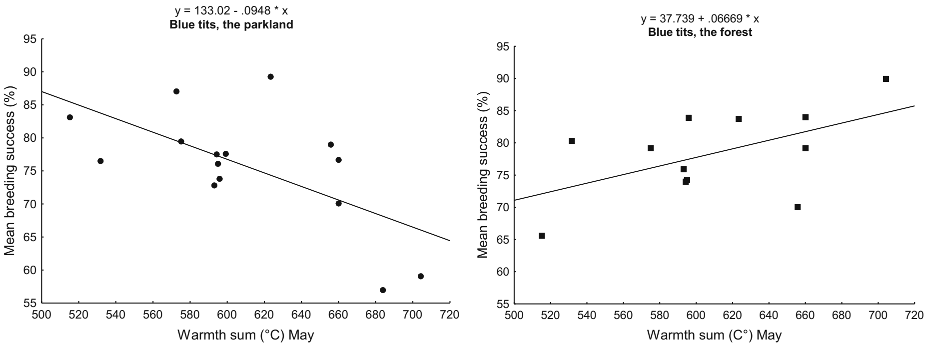

Fig. 1 Relationship between the breeding success in the parkland area (filled circles) and in the forest area (filled squares) and the sum of the daily maximum temperatures in May (seasons 2000–2013) in blue tits

Lower breeding success is also usually correlated with the number of rainy days, since rainfall often increases mortality of young tits (Zając 1995). Radford et al. (2001) showed that female great tits significantly reduced their feeding visit rate to the nest during intensive rainfall. Every reduction in the frequency of nestling feeding visits can cause long-term consequences, affecting the body weight, which is directly correlated with the probability of survival (Naef-Daenzer and Keller 1999; Radford et al. 2001; Naef-Daenzer et al. 2001). Yet we found that breeding success increased with the increasing number of rainy days. Overall, it means that lower temperatures and rain efficiently dissuade people from visiting the zoo and the botanic garden. Probably the absence of visitors facilitate foraging, perhaps except the days with very heavy rains.

Studying previously our population-habitat system, Bańbura et al. (2013) examined the heterophil-to-lymphocyte ratio (H/L) in blue tits at both study sites and found that nestlings had on average higher level of that stress indicator in the urban parkland habitat than in the forest habitat. The H/L is considered as a reliable indicator of chronic stress reaction in birds (Gross and Siegel 1983; Ots et al. 1998; Moreno et al. 2002; Davis et al. 2008). Ruiz et al. (2002) studied the rufous-collared sparrow (*Zonotrichia capensis*) and after two weeks of captivity rural birds developed blood characteristics that resembled those of urban birds. These indices reveal typical primary (acute), and secondary (chronic) stress characteristics in the urban birds. This effect may be partly related to the habitat fragmentation, which has been shown to increase stress and decrease nest success of some passerines (Suorsa et al. 2003; Dietz et al. 2013). These indicators were probably influenced by several factors: food abundance, which is on average regularly lower in the parkland than in the forest habitat (Marciniak et al. 2007), habitat fragmentation (being higher in the parkland) and human-caused disturbance.

Müller et al. (2006) studied effects of human presence on corticosterone levels in parent blue tits and found no adrenocortical response to this factor. Those authors suggest that birds are able to distinguish between situations that are life-threatening and situations that are not life-threatening. This may suggest that the cause of lower breeding success may at least partly be related to disturbances preventing access to the nest.

There is also a possibility of competition between blue tits and great tits. It is possible that great tits are more active during sunny weather, which may cause more cautious behaviour of blue tits (Dhondt 1987, 2010). But densities of both tits at our parkland area are rather low and, therefore, both effects are probably negligible (unpublished data). Considering intraspecific competition, it was shown to be more intense in great tits than in blue tits during the breeding season (Dhondt 1977, 2010).

It is important to emphasize that there may be other unmeasured differences between both study areas and therefore present results have their limitations. Diversity in food resources may be important, e.g. it is probable that urban birds are exploiting different types of prey than forest birds. Additionally spatial variation in predator activity and proximity may have direct and indirect effects on urban passerine distributions and breeding success (Bonnington et al. 2015). There may be also differences in the adjacent habitats or small scale differences between both study areas (Hedblom and Söderström 2012).

It is still worth pointing out that the human-induced reduction in the breeding success of blue tits we found in our study is not so heavy as to seriously limit their overall demographic balance, especially when good conditions for wintering in urban parks are taken into account (Bańbura and Bańbura 2012). Moreover, cavity-nesters may also benefit from the large numbers of nest boxes in urban parks (Jokimäki 1999). Urban parks are valuable because of the preservation of the environment similar to forest in urban areas, despite the fact that the birds are not able to use their full reproductive potential. From the point of view of the full reproductive potential, it could be suggested that in large urban parklands some especially valuable areas should have restricted access for visitors.

Our data support the hypothesis that human activity could interfere breeding success of blue tit in the breeding season. But it is important to emphasize that our results are only descriptive and future experimental approach is to be welcomed.

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