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Character of surrounding habitat determines nest predation in suburban idle fields

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Abstract. Fragments of idle fields in urbanized zones may attract threatened bird species to nest, but, at the same time, may be favoured by generalist nest predators attracted by food resources abundant in urban areas. Only few studies have analysed effects of nest predation risk in suburban habitat fragments while considering the character of the surrounding landscape. We used artificial nests to examine possible effects of patch size and edge distance, extent of surrounding urbanization, habitat composition and heterogeneity on nest predation risk to ground-nesting birds in idle fields within suburban areas. Nest predation risk varied regardless of patch size. Edge effect appeared only combined with the proportion of particular habitat types in the surrounding landscape. Character of surrounding landscape was strongly influential. In particular, predation risk was positively correlated with proportions of unstable disturbed sites nearby but negatively correlated with proportions of adjacent meadows and forests. From the standpoint of nature conservation and effective support to bird diversity in suburban areas, we highlight the importance of diverse nature-like stands such as meadows or forest fragments.

Key words: bird conservation, generalist predator, hen eggs, fragmented patches, landscape heterogeneity urbanization

Introduction

Worldwide destruction of natural habitats negatively affects animal life (Blair 2004, Fuller et al. 2007) and considerably reduces diversity of plant and animal communities (Wilson & Peter 1988, Noss 1991). Historically, expansion of urban environment (building conglomerates and technical structures interspersed with gardens, parks, ornamental plantations and idle patches), has contributed to reducing original habitats, i.e. to substitute the fertile native habitats by the sterile urban habitats. On the other hand, these extensive landscape changes may augment landscape heterogeneity, because they extend the variety of habitats in the landscape (Gering & Blair 1999, Blair 2004) and intensive habitat fragmentation rapidly increases the proportion of edge structures (Andrén & Angelstam 1988, Paton 1994, Bayne & Hobson 1997, Villard 1998, Zanette & Jenkins 2000, Ries & Sisk 2004). Some of recently created habitat types, such as idle fields, may partially compensate the loss of natural stands for at least some species that are tolerant of human-induced environments with disturbance effects. Fragments of idle fields spread throughout urbanized zones and dominated by early

successional vegetation may attract bird species, some of which are regionally threatened, such as, in Europe, grey partridge (*Perdix perdix*), whinchat (*Saxicola rubetra*), crested lark (*Galerida cristata*), and wheatear (*Oenanthe oenanthe*) (Blair 2004, Šálek et al. 2004, Šťastný et al. 2006). Despite their temporary character, and in contrast to the surrounding agricultural and urbanized lands, these habitats may function as refuges for the birds due to their reduced disturbance and the availability of nesting sites, plant seeds and insects that they provide (Šálek et al. 2004, Kadlec et al. 2008, Evans et al. 2009).

Urbanized areas can, however, favour also generalist predators (Hagan et al. 1996, Kokko & Sutherland 2001, Battin 2004), which are attracted by such additional food resources as garbage, industrial products, and road-killed animals (Gooch et al. 1991, Jerzak 2001, Marzluff & Ewing 2001) and may also increase their densities there (Howell et al. 2000, Jerzak 2001, Chace & Walsh 2006, Leston & Rodewald 2006, Chiron & Julliard 2007). As the diets of many generalist predators include bird eggs (Angelstam 1986, Roos 2002, Hoover et al. 2006), one might expect suburban zones to be prone to increased

incidental nest predation (Andrén et al. 1985, Vickery et al. 1992). Nevertheless, suburban areas and their surroundings have sometimes been found to be safe nesting zones for birds and their nests (e.g. Gering & Blair 1999, Antonov & Atanasova 2002, Jokimäki et al. 2005, Anderies et al. 2007). In light of these partially opposite trends, studies examining bird nest predation in suburban areas have not been consistent in their findings (Gering & Blair 1999, Blair 2004, Chamberlain et al. 2009). This inconsistency might reflect huge local variation worldwide in the richness of additional food resources for predators in urbanized areas which may result in highly variable predation pressure on bird nests. In some areas, the predators' needs can be more than supplied by foods from human sources while elsewhere food shortage leads to increased effort in searching for prey and higher incidental nest predation (Vickery et al. 1992). In general, this variation can be closely linked to urbanization rate, as urbanization influences the amount of additional secondary food and/or surrounding habitat heterogeneity. A diverse habitat mosaic should generally offer more sources than does a poor habitat mosaic. Only a few studies, however, have analysed the effects of characteristics attributable to the surrounding landscape on nest predation risk in habitat fragments (e.g. Saunders et al. 1991, Marzluff & Ewing 2001, Dunford & Freemark 2004, Winter et al. 2006). Nest predation has been found to grow with an increasing proportion of surrounding farmland (Andrén 1992, Bayne & Hobson 1997, Chalfoun et al. 2002, Storch et al. 2005) as well as with the amount of urban habitat (Wilcove 1985, Marzluff & Restani 1999).

In addition, several studies investigating nest predation have revealed that decreasing size of habitat fragments may negatively affect nest survival (Wilcove 1985, Weinberg & Roth 1998, Pasinelli & Schiegg 2006, Winter et al. 2006). However, the results obtained from urbanized areas have been ambiguous and often have shown no significant effect of patch size (Huhta et al. 1996, Matthews et al. 1999, Zanette & Jenkins 2000). This inconsistency may stem from the different scales upon which the experiments have been designed. Paton (1994) reviewed previous studies and concluded that patches smaller than 10 ha usually suffer from higher predation rate. Therefore, only studies encompassing both small patches and sufficiently large patches ($\gg 10$ ha) may reveal a significant size effect. As the ratio of edge length to interior area increases with decreasing fragment size (Villard 1998, Brand & George 2001), the explanation

for increased predation risk in small fragments can be due to the edge effect (Andrén & Angelstam 1988, Batáry et al. 2004, Storch et al. 2005, Hoover et al. 2006, Schiegg et al. 2007). Many previous studies have shown that edge habitats are attractive for generalist predators (e.g. Andrén 1992, Paton 1994, Ries & Sisk 2004, Chace & Walsh 2006). Therefore, the size of habitat patches should be considered in predation studies.

While idle fields embedded in urban zones may function as attractive nesting refuges for some bird species, they may, at the same time, provide only weak protection against nest predation. This may depend on the fragment area, nest position within it, as well as on urbanization rate or other habitat characteristics of the surroundings. The inconsistent findings to date, however, do not allow for predicting predation risks to bird nests in these specific habitats and for recommending conservation practices, such as what size and surrounding habitat structure might effectively support bird diversity in suburban zones. More detailed studies from various conditions and regions are thus needed to reveal the main factors driving nest predation risk in suburban zones worldwide.

In this study, we examined possible effects of patch size, extent of surrounding urbanization, habitat structure and heterogeneity on predation risk to ground bird nests on patches of idle fields in suburban areas of Prague, Czech Republic. Based on previous findings described above and our observations during study on grey partridges in the area (Šálek et al. 2004) we predicted higher vulnerability to predation on the nests located (1) within small patches (up to 10 ha), and (2) at the edges of large patches (> 10 ha) due to edge effect, as well as (3) in patches embedded within less diverse habitat mosaic, and (4) in patches with more urbanized surroundings due to more diverse food resources including those for nest predators at these stands.

Study Area

The study was conducted around Prague, Czech Republic (50°1'-50°6' N, 14°4'-14°8' E; Fig. 1), in a transition zone between farmland-dominated landscape and urbanized areas of the capital city. We selected 103 unmanaged patches (51 in 2008 and 52 different ones in 2009) of various sizes (1 ha to 40 ha – see Fig. 2 for size distribution of the patches) using orthophotomaps and JanMap 2.3.0 software (www.janitor.cz). We established 1000 m as the minimum distance between any two neighbouring patches to

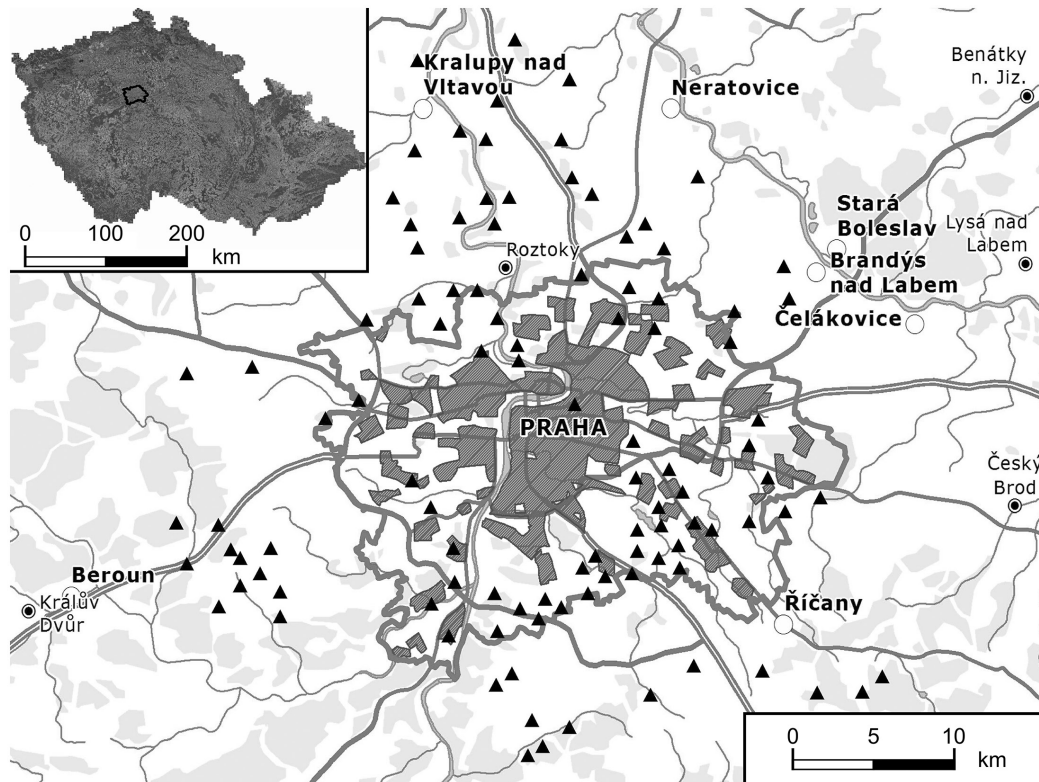


Fig. 1. All 103 study sites around Prague (large map) and position of Prague within the Czech Republic (small map). Legend: black triangles = study sites. Source: GIS.

avoid overlaps of their habitat surroundings and minimize cumulative effect of individual predators. We selected only early successional sites (up to 10 years after initiation) dominated by pioneer herbs and grasses (*Urtica dioica*, Apiaceae, Poaceae), and sparsely broken by shrubs or tree seedlings (*Robinia pseudacacia*, *Rosa* sp., *Malus* sp., *Sambucus nigra*). The bird species inhabiting the area include common farmland species (e.g. yellowhammer *Emberiza citrinella*, Eurasian skylark *Alauda arvensis*, whitethroat *Sylvia communis*, common pheasant

Phasianus colchicus) but also scarcer species appearing in idle fields where they are under the pressure of nest predation, such as grey partridge, whinchat, crested lark, and wheatear (Fuchs et al. 2002, Šálek et al. 2004, Šťastný et al. 2006). Idle fields around Prague are characterized by high diversity of weed plants and associated invertebrates which provide various types of food for the aforementioned species (Fuchs et al. 2002, Šálek et al. 2004).

Using the JanMap 2.3.0 software, we measured the area of each patch (m²) and proportions of its surrounding habitats (specified in Table 1) in a circle up to 500 m distant from the patch margins by combining digitized photomap information with that from subsequent field inspection. In addition, the surrounding habitat heterogeneity was then calculated using the Shannon diversity index (Krebs 1989) where particular habitat attributes were included as proportions.

Material and Methods

Nest predation

During May-June 2008 and 2009, which corresponds to the main breeding period for the bird species in our climatic conditions (Hudec & Šťastný 2005, Šťastný et al. 2006), we placed two artificial ground nests in each patch in a manner to include possible variation

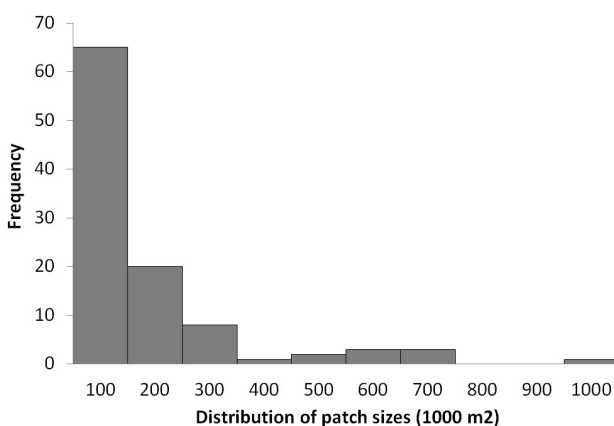


Fig. 2. Distribution of patch sizes.

Table 1. Habitat types.

Description of measured habitat attributes
Fields (“field”)
Forests (“forest”)
Other idle fields (“weed”)
Orchards and gardens (“gard”)
Meadows (“mead”)
Baulks and field paths (“path”)
Water bodies and flows (“wat”)
Railways outside of cities and villages (“rail”)
Buildings and structures, including integrated roads and railway (“hous”)
Bare fallow, sand and gravel grounds and newly established building sites (“bare”)
Managed lawn areas such as playgrounds, stadiums or airports (“airp”)

in edge effect and nest position in the patch depending on patch size. One nest was placed at the immediate patch edge (up to 5 m in from the edge) while the second nest was put into a patch’s interior (i.e. 50-60 m from the edge) to reveal the possible edge effect. The nests were constructed as small depressions in the ground strewn with dry grass (Angelstam 1986). Each nest was baited with a pair of hen eggs, one fresh and one filled with a wax-oil mixture. Using two types of eggs, we were able to better identify the nest predators by the marks of their mouths/bills. Eggs filled with a wax-oil mixture are commonly used as well as clay balls (Green 2004) but resemble real eggs even better. The wax-oil eggs were tied to the ground using a nail to prevent them from being carried away by a predator. Nest position was marked with short scraps of florist streamer 3 to 5 m apart. In order to minimize inadvertently attracting predators, nests were exposed for 14 days with no check in the interim period (Villard

& Pärt 2004). Any nest was considered as depredated if at least one egg disappeared or had marks indicating a predator’s visit. A similarly designed method using artificial nests has been previously applied in many nest predation studies (e.g. Yahner & Mahan 1996, Rangen et al. 2000, Martin & Joron 2003).

Analyses

Prior to analysing nest predation, we used principal components analysis (PCA) to find the correlated explanatory variables representing the composition of habitat surroundings and reduced their numbers for further analysis. When PCA axes represented two or more explanatory variables, they were used as substitutional explanatory variables. A mixed-effects model was applied to analyse multiple effects of selected predictors on nest predation risk (Crawley 2005), which was expressed as a binomial response (a nest was either depredated or untouched). The predictors included (a) nest position (edge vs. interior), (b) scores of the main principal components (with eigenvalue $\lambda > 1$) as underlying factors of mutually intercorrelated environmental variables, and (c) other remaining (non-correlated) particular variables (see Table 2 for interrelationships among the variables and principal components). In addition, all first-order interactions of these variables with nest position (categorical variable) were included into the model. As two nests were treated at each patch, patch identity together with year were stated as random factors.

We applied the full-model multiple logistic regression method to test the effects of particular terms (Whittingham et al. 2006). In this analysis, we first assessed the contributions of first-order interactions

Table 2. Correlation coefficients between particular environmental variables and principal components PC1-PC5 (with $\lambda \geq 1$). Variables strongly associated with a particular principal component ($r > 0.6$) are in bold.

Variable	Particular axes of principal components				
	PC1	PC2	PC3	PC4	PC5
Patch area	0.40	0.08	-0.13	-0.05	0.61
Distance to city centre	-0.65	-0.11	0.27	-0.09	0.35
Fields	-0.91	-0.10	>> -0.01	0.03	-0.02
Forests	0.43	-0.59	-0.06	0.01	0.31
Buildings and structures	0.71	0.39	-0.23	-0.27	-0.02
Weeds	0.51	0.61	0.13	0.06	-0.01
Airports and playgrounds	0.14	<< 0.01	0.34	0.29	0.44
Gardens and orchards	0.37	-0.41	0.33	0.06	-0.43
Meadows	0.36	-0.64	0.21	-0.14	-0.09
Water bodies	0.35	-0.21	-0.07	0.65	0.08
Paths	-0.61	0.03	0.27	0.20	0.16
Bare soil	-0.02	0.21	0.67	0.13	-0.19
Railway	0.04	0.23	-0.22	0.74	-0.15
Surrounding habitat heterogeneity	0.82	-0.15	0.30	0.02	0.06

considering all predictors together, stating the tested factors as the last in the model (Type 3 test). After removal of the interactions from the model, we tested the contributions of particular fixed effects in a similar way. Statistica 9.0 and R 2.8.0 were used in all statistical analyses. Proportions of eggs predated by mammalian and avian predators were tested using a homogeneity test.

Results

Overall nest predation rate was 57.8 % for the two years together (62.7 % in 2008 and 52.9 % in 2009). Whereas the eggs from 59.7 % (n = 71) of all 119 depredated nests were removed by an unidentified predator, we detected marks of nest predators on egg remains in 48 nests (40.3 %) and specified either avian or mammal predator at eggs in 45 nests (Table 3). We found that 70.0 % of detected egg predations were exclusively due to avian predators (homogeneity test, $\chi^2 = 6.4$, $df = 1$, $p = 0.011$, total n = 40 eggs).

“Patch area” correlated with only PC5 and then with lower eigenvalue ($\lambda = 1.1$), we decided to include this variable also as a single predictor instead of its PCA that was an ambiguous representative.

We revealed significant effects of two terms (PC2 and PC4) on nest predation risk (Table 5). PC2 (Fig. 3) positively correlated with the amount of early successional weed habitats around houses and other constructions while being negatively correlated with proportions of meadows and forests representing later successional (long-lasting and established) stands outside of urbanized segments. PC4 (Fig. 4) was most strongly correlated with the proportions of water bodies and railways. In addition, interaction of nest position to PC4 and to the portion of gardens were also significant (Table 5); however, a detailed insight into the relationship patterns revealed that this interaction consisted only in stronger predation with increasing PC4 in interior than edge nests. Fixed effects of patch area and nest were not

Table 3. Predator prints of nests with depredated eggs and total counts of nests with removed eggs.

Type of nest depredation		Count of depredated nests	% in overall count of depredated nests
Nests with eggs marked by predator prints	bird	28	23.5
	mammal	12	10.1
	combined	5	4.2
	undetermined	3	2.5
Nests with eggs totally removed with no marks		71	59.7
Total		119	100

PCA reduced the set of 15 particular environmental variables representing patch surroundings to five principal components (PC1 to PC5) with eigenvalues $\lambda > 1$ for each. The sum of the eigenvalues for PC1-PC5 $\lambda_{sum} = 9.35$, and these variables together explained 62.4 % of the total variance in relationships among the variables. Scores of the first four PC axes representing 11 particular variables (listed in Table 4) we used as predictors to the model. The variables “Airports and playgrounds” and “Gardens and orchards” did not correlate with the considered principal components and were included as single predictors. Because

significant as well as all remaining interactions (fixed effects: both $\chi^2 < 1.4$, $df = 1$, $p > 0.20$, interactions: all $\chi^2 < 3.0$, $df = 1$, $p > 0.06$, Table 5).

Table 4. Eigenvalues of correlation matrix, and related statistical values.

Value number	Eigenvalue (λ)	% of total variance	Cumulative eigenvalue	Cumulative %
PC1	3.84	25.59	3.84	25.59
PC2	1.86	12.39	5.70	37.98
PC3	1.33	8.89	7.03	46.87
PC4	1.23	8.23	8.27	55.10
PC5	1.09	7.24	9.35	62.34

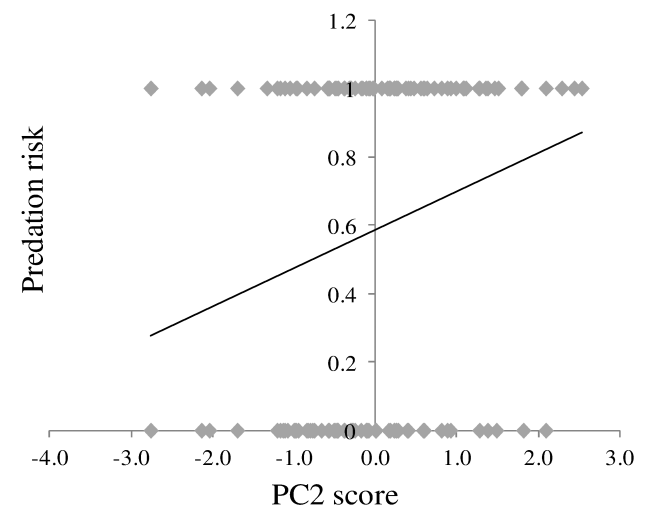


Fig. 3. Correlation of predation risk in patches and PC2 scores referring to proportions of early successional stages at the expense of forest and meadows in the surroundings (see Table 2 for interrelationships between the principal components and particular variables).

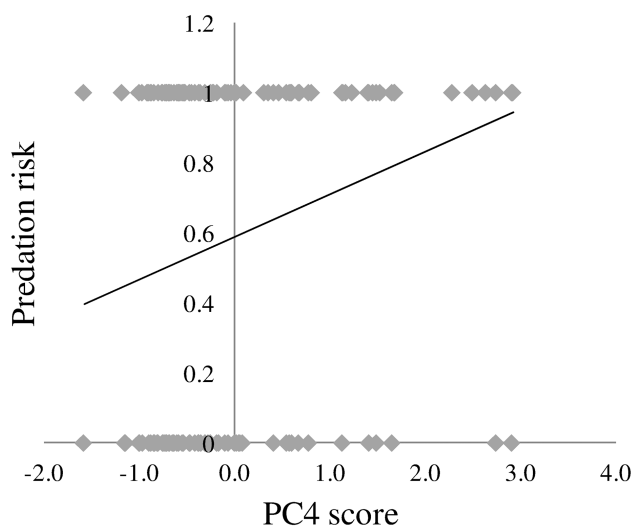


Fig. 4. Correlation of predation risk with PC4 scores referring to amount of water bodies and railways (see Table 2 for interrelationships between the principal components and particular variables).

Table 5. Results of the mixed-effects model ($n = 103$). Df includes values for both numerator and denominator. Effects of two significant predictors were tested as controlled for the effect of one another.

Factor	Estimate	SE	χ^2	df	p
PC4	0.06	0.05	7.52	1	0.006
PC2	0.12	0.06	9.64	1	0.002
Nest position: proportion of gardens	-0.02	0.01	4.58	1	0.03
Nest position: PC4	0.10	0.06	3.87	1	0.05
Proportion of gardens	0.02	0.01	0.85	1	0.36
Nest position	0.77	0.73	1.25	1	0.26
Nest position: PC1	0.10	0.07	1.37	1	0.24
Nest position: PC2	-0.07	0.07	1.14	1	0.29
PC3	-0.08	0.06	0.29	1	0.60
Proportion of airports	0.02	0.01	3.18	1	0.07
PC1	-0.14	0.06	1.20	1	0.27
Patch area	0.02	0.11	0.35	1	0.56
Nest position: patch area	-0.11	0.14	0.19	1	0.67
Nest position: proportion of airports	-0.004	0.02	0.52	1	0.47
Nest position: PC3	0.02	0.08	0	1	0.99

Discussion

Idle fields represent an important part of the suburban habitat mosaic which creates opportunities for threatened openland bird species. Our findings on nest predation risk in these habitats may provide important information for landscape management with a view to supporting avian diversity in suburban zones.

Overall high nest predation risk of our experimental nests can be attributed to the locally specific increased density of generalist predators in the proximity of the urban border because some of other studies from similar habitats showed lower rates (e.g. Danielson et al. 1997, Pärt & Wretenberg 2002). In addition, in contrast to highly urbanized zones, our previous results showed much more reduced nest predation

rate in the pristine landscape (only 32 %; P. Suvorov, unpubl. data).

Our results did not reveal significant effect of patch size on the predation of our experimental nests. Thus, the conclusions of other, previous studies describing the effects of patch size may have resulted from correlativeness with other factors or may have been derived on different scales than we investigated in this study.

Edge effect appears to be significant only in combination with particular types of surrounding habitats such as portion of water bodies, railways and gardens (see below for further explanation). However, detailed insight and reliable interpretation would be possible only with larger data set from various combinations of the targeted variables under interaction.

Character of the surrounding landscape appeared to be the driving factor affecting the nest predation

rate in our idle fields. Even though such mutually intercorrelated attributes as proportion of urbanized areas, farmland-to-city-centre gradient, and habitat heterogeneity indicated the highest variation among all treated variables, these did not contribute significantly to nest predation rate. Instead, we found that increasing proportion of early successional stages in the surroundings of the studied patches negatively influenced nest survival. Early successional stages with stronger human disturbances in urbanized areas and accompanied by higher nest predation contrasting with more stable ecosystems (meadows or forests) together with higher nest success extend the findings of Jokimäki & Huhta (2000) and López-Flores et al. (2009), who had found that some components of

urban environment negatively affected survival of their artificial nests. Medium-urbanized landscapes such as suburban zones at city borders usually produce highly heterogeneous environments attractive for generalist predators (Donovan et al. 1997, Chiron & Julliard 2007), which are sometimes termed “urban exploiters” (Chace & Walsh 2006). On the other hand, nest predation does not seem to increase more in highly urbanized areas closer to city centres (Donovan et al. 1997) because breeding and food opportunities for both birds and predators are not increasing more along this gradient.

Proportions of water bodies and railways also negatively influenced the survival of our experimental nests. Close surroundings of water bodies can be linked to occurrence of such nest predators as marsh harrier (*Circus aeruginosus*) or grey heron (*Ardea cinerea*) (Hansson et al. 2000, Opermanis et al. 2001, Teunissen et al. 2008), which might occasionally depredate the nests placed in nearby surroundings.

Presence of a railway as a linear structure itself may increase the nest predation rate (Wallander et al. 2006). Moreover, railway body can be, due to its shape, perceived as a certain form of the edge habitat. Its increasing portion in the surrounding landscape in the interaction with the nest distance from the edge of our patches may, then, strengthen the nest predation rate. Moreover, railway is often surrounded by wide belts of shrub which can attract mammal predators, using them as travel corridors while searching for prey (Wegner & Merriam 1979), as well as avian predators (corvids), using the stands for nesting (Wallander et al. 2006). All these predators may contribute to increased nest depletion near water bodies and railways. Nevertheless, as railway represented only a minor part of the landscape and the correlation with presence of water bodies may be only accidental as well as the interaction of both above mentioned variables with the nest position, any generalizations are probably of minor importance.

Gardens create an important feature of the suburban zones. Their vegetation structure differs from other nature-like stands such as idle fields, forests or meadows due to specific management (mowing, planting with exotic plants etc.). Their contrast with the above mentioned stands can be, then, strong. In addition, supplemental resources (compost, waste from the kitchen etc.) are very frequent close to the gardens. These factors may attract generalist predators to gather in the surroundings of gardens and increase the nest predation rate nearby. As a consequence,

the survivorship of bird nests in idle fields may be, paradoxically, negatively affected by the proportion of gardens in the surroundings.

Two-thirds of the eggs in depredated nests contained marks by avian predators. This result corresponds to other, similar studies which determined birds to be the principal nest predators in (sub)urban zones (Matthews et al. 1999, Jokimäki & Huhta 2000, Thorington & Bowman 2003). Mammals were also found to be regular nest predators, and this shows a diverse predation community and more complex predation pattern from site to site. The prevalence of bird nest predators in our sample can, however, be due to a methodological artefact that mammal predators might more often carry away large hen eggs. In addition, we would expect mammal predators to prefer habitats with shorter and sparser vegetation than occurs in idle fields, because dense and tall vegetation hinders movement and orientation (DeLong et al. 1995, Dion et al. 2000). Finally, we cannot exclude that our human-installed artificial nests without concealment by an incubating parent were more easily detectable by visually oriented avian predators (Söderström et al. 1998, Yahner & Piergallini 1998, Burke et al. 2004, Villard & Pärt 2004).

Conclusion

Nest predation risk in idle fields spread out across suburban zones of cities varies particularly with the presence of individual habitat types in the surroundings regardless of those patches' size within the farmland-to-city-centre gradient and with a minor contribution of edge effect. From the general standpoint of nature conservation in suburban areas, we nevertheless highlight the importance of diverse nature-like stands such as meadows or forest fragments in the vicinity of idle fields. Although the early successional stands themselves would generally be prone to increased nest predation particularly by avian predators they play an important role as breeding habitats for several uncommon or endangered bird species and should therefore be of interest to conservationists.

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