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Habitat selection in foraging European Rollers (*Coracias garrulus* L.) in Eastern Austria

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Abstract. The population of the European Roller in northern and central Europe has suffered a dramatic decline during the late 20th century. This decline has often been attributed to changes in land use negatively affecting breeding success, mainly due to degrading quality of foraging habitats. However, so far empirical studies determining the habitat quality for Rollers in the context of foraging are missing. We studied the selection of foraging habitats by Rollers in eastern Austria. Habitat preferences were quantified by data on the use of two important artificial perch types, power lines and wooden poles, by hunting Rollers in the years 2002+2004 and 2002, respectively. All perches included in our analyses were located within a distance of less than 1.2 km to nearest breeding sites. Structural parameters, reported to play an important role for habitat choice in the Roller, were measured within a predetermined range of 25 m around all perches. Within this distance range, ca. 85 % of all hunting strikes from perches could be observed. The use of 50 m power line sections and wooden poles for perching was negatively related to the distance to nearest breeding sites, particularly during breeding season. Furthermore, the number of hunting Rollers was negatively affected by decreasing distance to settlements during breeding and post-breeding seasons in both artificial perch types. During breeding season, the attractiveness of power line sections as perches for hunting Rollers significantly increased with increasing meadow area, most likely caused by the high abundance of suitable prey (with body size >10 mm) in this habitat type. In contradiction, the proportion of maize area proved to be an important explanatory variable for perch use in the post-breeding season by negatively affecting foraging habitat quality. An increasing habitat diversity and/or habitat edge density improved perch attractiveness for hunting Rollers during breeding season (wooden poles) and post-breeding season (power line sections: 2002+2004; wooden poles).

Future conservation plans aiming to protect remaining Roller populations in Central Europe should consider that ongoing loss of meadows, the decline of habitat heterogeneity due to land consolidation and agricultural intensification, in combination with an uncontrolled rural development, represent crucial threats for this highly endangered species.

Key words. Artificial perches, conservation, foraging habitat, habitat preferences, land use, meadows, prey availability, rural development

Zusammenfassung

Die Bestände der Blauracke in Nord- und Mitteleuropa erlitten im Laufe des späten 20. Jahrhunderts einen drastischen Einbruch. Dieser Rückgang wird im Wesentlichen schwerwiegenden Veränderungen in der Landnutzung zugeschrieben, welche sich maßgeblich durch eine Verschlechterungen der Jagdhabitate negativ auf den Bruterfolg auswirkten. Jedoch existierten bislang keine empirischen Studien, die eine quantitative Bewertung der Habitatqualität im Zusammenhang mit dem Furagierverhalten der Blauracke ermöglichen. Diese Studie untersuchte die Habitatwahl jagender Blauracken in Ostösterreich in den Jahren 2002 und 2004 anhand der Nutzungshäufigkeiten der zwei meistgenutzten Ansitzwartentypen, Niederspannungsleitungen (beide Jahre) und Sitzkrücken (nur 2002). Dabei wurden nur potentielle Ansitzwarten berücksichtigt, die nicht weiter als 1,2 km vom nächstgelegenen Brutplatz entfernt waren. Für alle Ansitzwarten (50 m lange Abschnitte der Niederspannungsleitungen und Sitzkrücken) wurden als wichtig für die Habitatselektion der Blauracke beschriebene Habitatparameter für einen Aktionsradius von 25 m quantifiziert. Innerhalb dieses Aktionsradius konnten ca. 85 % aller von Ansitzwarten durchgeführten Jagdflüge beobachtet werden. Vor allem während der Brutzeit stieg die Nutzungshäufigkeit von Niederspannungsleitungen und Sitzkrücken zur Ansitzjagd mit zunehmender Nähe zum nächstgelegenen Brutplatz signifikant an. Unabhängig von Sitzwartentyp und Jahreszeit (Brutzeit vs. Nachbrutzeit) nahm die Anzahl der von Warten aus jagenden Blauracken mit zunehmender Siedlungsnähe deutlich ab. Während der Brutzeit wurden Abschnitte von Niederspannungsleitungen mit einem hohen Anteil an Wiesenflächen deutlich häufiger zur Ansitzjagd genutzt als Bereiche mit anderer Vegetationsbedeckung. Dies

lässt sich mit großer Wahrscheinlichkeit auf die relativ hohen Abundanzen geeigneter Beutetiere (mit Körpergröße >10 mm) in diesem Vegetationstyp zurückführen. Für die Nachbrutzeit zeigte sich, dass sich die Habitatqualität für jagende Blauracken durch einen zunehmenden Anteil an Maisflächen deutlich verschlechterte. Eine zunehmende Habitatdiversität und/oder Habitatrandliniendichte erhöhte die Attraktivität von Ansitzwarten für Blauracken während der Brutzeit (Sitzkrücken) und Nachbrutzeit (Niederspannungsleitungen: 2002+2004; Sitzkrücken). Zukünftige Schutzkonzepte zur Sicherung der letzten Populationen der Blauracke in Mitteleuropa müssen versuchen, den fortschreitenden Rückgang von Grünlandflächen und die Abnahme der Habitatheterogenität durch Flurneuordnung und Intensivierung der Landwirtschaft zu bremsen, sowie mögliche negative Auswirkungen einer unkontrollierten ländlichen Entwicklung (z.B. durch Zersiedlung) zu minimieren. Nur durch die Berücksichtigung solcher wichtiger Gefährdungsursachen wird ein langfristiger Schutz dieser hochgradig gefährdeten Vogelart möglich sein.

Introduction

The European Roller *Coracias garrulus* is widely distributed across the Palearctic region (Cramp and Simmons 1988). Since the late 19th century, the range and population size of the species dramatically declined in western and northern Europe, leading the species to extinction in southern Sweden, Denmark and Germany. Scattered remnants of its formerly continuous central and eastern European distribution range remained in the Baltic States, eastern Poland and Slovakia (Glutz von Bolzheim and Bauer 1980, Samwald and Štumberger 1997, Bohuš 2002). In the southern and eastern provinces of Austria the species was still widespread and common up to the 1950s below an altitude of 400 m asl. For example, for the province Styria the breeding population was projected at more than 350 breeding pairs in 1953 (Samwald and Samwald 1989). However, most likely as result of the large-scale agricultural intensification after the Second World War (Sackl *et al.* 2004), range and population size of the Austro-Slovenian meta-population collapsed during the 1960s and 1970s (Braćko, 1986, Samwald and Samwald 1989). Since the mid 1980s the remaining Austrian population became stable at a low level of 10–18 breeding pairs (Samwald 1996, Sackl and Tiefenbach *in press*., M. Tiefenbach *unpubl*.), whereas the Slovenian continuously declined until a population size of 1–5 breeding pairs was estimated for 1998–2004. The last brood was recorded in 2005 (B. Štumberger *pers.comm*.). Currently, the breeding ground of the European Roller in Austria is restricted to the valleys of two tributaries of the river Mur in south-eastern Styria between Bad Gleichenberg and the Slovenian border.

The decline of bird populations can be caused by many factors. However, in many European bird species habitat loss is the major driver (Tucker and Heath 1994, Hagemeijer and Blair 1997, Verhulst *et al.* 2004, Donald *et al.* 2006). Insectivorous bird species feeding predominantly on large insects, such as the Roller, Lesser Kestrel *Falco naumanni* and Lesser Grey Shrike *Lanius minor*, appear to suffer particularly from large-scale habitat loss mainly caused by changing agricultural practices (Samwald and Samwald 1989, Donazar *et al*. 1993, Lefranc 1995, 1997, Franco *et al*. 2004).

Several local and regional studies across the Roller's range reported population declines (Creutz 1964, Lovari 1975, Creutz 1979, Samwald and Samwald 1989, Sosnovski and Chmielewski 1996, Bohuš 2002). While for populations at the northern edge of the species´ former range, climatic changes were discussed as main driver for extinction (Durango 1946, Niethammer 1951, Glutz von Blotzheim and Bauer 1980), declines in central and southern Europe have often been attributed to effects of changing agricultural practices, although no empirical evidence was provided. Merely one study documented that the decline of Roller populations is closely linked to agricultural intensification, which negatively affected breeding success (Avilés and Parejo 2004). However, it has not been shown which habitat attributes accounted for the decreasing breeding success. This would not only be a precondition to estimate the remaining area suitable for the species, but also to predict potential population responses to habitat changes and to successfully implement effective conservation measures. Without such knowledge on habitat requirements, it is either possible to develop nor to modify or adjust, for instance, agro-environmental schemes and conservation plans targeting a sustainable protection of the threatened Roller.

Our study quantified habitat requirements of the small remaining population of Rollers in Styria in the behavioural context of foraging. Foraging efficiency in birds can be directly related to breeding success (Fournier and Arlettaz 2001, Johst *et al*. 2001, Barbaro *et al*. 2008) and, therefore, is an important indicator for habitat quality. To study habitat selection in Rollers during foraging, we used two different approaches. First, habitat use was analyzed for Rollers perching on electric wires crossing all habitats within the breeding area. This will allow identifying major habitats types used by the species for hunting insects. Subsequently, patterns of habitat use were studied using data on another artificial perch, wooden poles, erected within the entire breeding area of the Austrian population.

Ties with the breeding site may spatially limit the use of potentially high-quality perching sites for foraging to a certain distance around the breeding holes, as long as the adult birds have to return frequently to the nest to feed their young (e.g. Johst *et al*. 2001). Therefore, we analyzed patterns of habitat selection during foraging separately for breeding and post-breeding season. Our data not only help identifying high quality foraging habitats but also can provide information on how to improve the spatial distribution of artificial perches, thereby providing a better access to relevant food sources for Rollers. Both have important implications for the conservation of the last highly threatened population of Rollers in eastern Austria.

Methods

Study area

Since the mid-1980s the breeding distribution of European Rollers in Austria is restricted to a few narrow river valleys in the lowland (220-345 m asl) of south-eastern Styria (Samwald and Samwald 1989, Samwald 1996). This region is predominantly characterized by an intensive cultivation of maize, and, less important, of pumpkin and cereal crops. These annual cultures are interspersed with patches of 2-3 times mown meadows. Forest is mainly restricted to hillsides and ridges. Merely small patches of deciduous woodland (<1ha) can be found at the valley floors.

The presence of the last Austrian breeding population of the Roller, in combination with the occurrence of several other species listed in Annex 1 of the European Directive on the Conservation of Wild Birds (Black Stork *Ciconia nigra*, White Stork *Ciconia ciconia*, Honey Bussard *Pernis apivorus*, Common Kingfisher *Alcedo atthis*, Eagle Owl *Bubo bubo*, Middle Spotted Woodpecker *Dendrocopos medius*, Grey-headed Woodpecker *Picus canus*, Black Woodpecker *Dryocopus martius*, Collared Flycatcher *Ficedulla albicollis*) led to the nomination as Special Protected Area (SPA). The area includes all known breeding sites of Rollers in Austria since the late 1990s. Since 1998, efforts are being made to reduce intensive land use, respective to enhance the portion of meadows, by implementation of aids for environmentally compatible agriculture (ÖPUL – Österreichisches Programm zur Förderung einer umweltgerechten Landwirtschaft). Within this program, farmers were bound to put up wooden poles (artificial perches) on their land, mainly along meadow edges, thereby increasing the availability of perches for hunting Rollers.

All breeding sites known in Austria since 1996 are located within our study area, which covers 27.4 km² in the middle reach of a northern tributary of Mur river, the Sulzbach. It is situated at an altitude of 240–300 m asl in the districts of Feldbach and Bad Radkersburg between N 46°51´−46°45´ and E 15°51´−15°57´.

Bird survey

To study habitat requirements in the behavioural context of foraging, we conducted roadside-counts of Rollers between the last decade of April and the second decade of September in intervals of 10–14 days in the years 2002 and 2004. Selected routes covered the complete study area. The area was surveyed for foraging Rollers by driving a car at low speed, stopping every 200 m. The relative openness of the landscape and the predominantly flat terrain most likely prevented that identical individuals were counted frequently more than once during the same survey. Large blocks of continuous forests were omitted from surveys, due to the fact they are not used by foraging Rollers. Birds were observed with binoculars (10x42) and a telescope (40x80). Surveys started one hour after dawn at the earliest and finished one hour before dusk at the latest in order to encompass the whole foraging activity period of the species. Order of sites visited on the same day changed randomly between surveys in order to avoid an influence of day time on sampling results. Each time a Roller was detected, it was observed for a maximum of 10 min using a telescope to ensure that the perch was used for foraging. Perching sites used by Rollers were located on aerial photographs. Additionally, perch type and hunting behaviour were noted. When an individual changed its perching site during the observation, only the first perching site was taken into account for analyses in this study. Also birds showing no hunting activities or perching behaviour during the observation unit were excluded. Nesting sites of Rollers were located during the breeding season by tracing feeding adults and checking potential breeding sites. All data were digitalized by using ArcView.

Perch types

Because Rollers in our study area predominantly used wires of 30kV high-voltage power lines (36% of total records) and wooden poles (41%), only these two perch types were used for analysing habitat use during foraging. The average height of power lines was 10 m, of wooden poles 2–4.5 m. Due to their different spatial distribution, patterns of habitat use were analyzed separately for both perch types. Within our study area power lines with a total length of 7.3 km are running “randomly” across most major habitat types. In contradiction, artificial perches erected to support foraging Rollers are not randomly distributed, but were placed in arrangement with the local farmers mainly at the edges of meadows to avoid conflicts with agricultural land-use activities. A total of 217 artificial perches were erected within the entire study area; 63 of them did not remain during the whole study, thus they were excluded from all analyses.

Habitat survey

In the years 2002 and 2004 habitat composition of the entire study area was mapped using a GIS approach. Therefore, all habitat types were initially classified in 70 categories, but afterwards reduced to the following ten main habitats: meadow, maize field, pumpkin field, cereal field, other annual crops, woodland patches, waterbodies, buildings/settlement, asphalt roads, and non-asphalt roads. Additionally, potential perching sites (such as wires, other artificial perches, trees, bushes) within the study area were mapped.

Habitat composition was measured within predetermined ranges around perches. Observations of foraging Rollers (n = 835) showed that more than 85 % of all recorded hunting events occurred within a distance of 25 m from the perch (Figure 1). Therefore, due to the linear structure of power lines, habitat composition was quantified for sections of 50 m length within a band of 50 m width (25 m to both sides). For wooden poles, habitat measures were taken within a radius of 25 m.

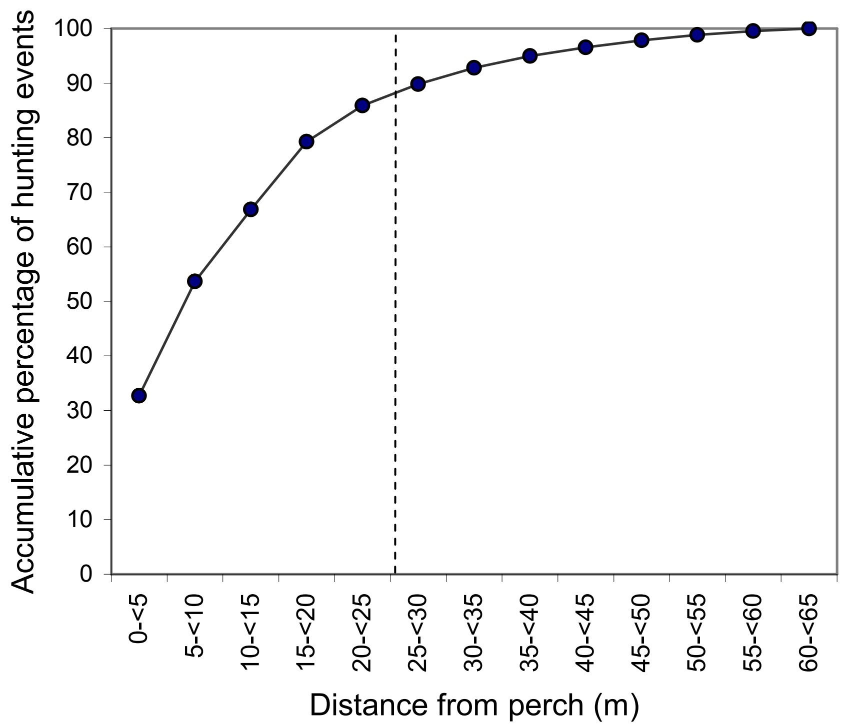

Figure 1. Accumulative percentage of total number of observed hunting events (n = 835) from low towards larger distances from perches. A total of 85 % of all hunting events occurred within a distance range of 0-25 m (indicated by broken line) from perches.

To study effect of perch selection, six habitat variables were quantified for both perch types: (1) Nearest distance (m) to next occupied breeding site; (2) nearest distance (m) to next human settlement; (3) habitat edge density measured as the sum of edge lengths (m) of all habitat patches (e.g. Heikkinen et al. 2004); (4) habitat diversity quantified by Shannon-Wiener Index (e.g. Heikkinen et al. 2004); (5) relative area of maize fields (%); (6) relative area of meadows (%).

Arthropod availability

Prior studies quantifying arthropod prey availability for Rollers used pitfall traps (Avilés and Costillo 1998). However, the abundance of non-soil dwelling taxa, like *Orthoptera*, non-soil dwelling *Coleoptera* etc., which represent an essential proportion of the Rollers´ prey (Szijj 1958, Sosnowski and Chmielelewski 1996), may not be adequately recorded by this method. Therefore, we made transect counts in the five most representative habitat types (meadows, maize fields, pumpkin fields, unpaved road margins, stubble fields) from 2004 to 2007 to study differences in prey availability. Transect counts were conducted from April to September in intervals of 15 days thereby accounting for seasonal changes of vegetation height and prey abundance. Transects had a length of 50 meters and a width of two meters and were scanned for arthropods at a slow pace of one minute per 10 meters. Observed arthropods were identified at the level of orders and were assigned to one of four size classes (0-10 mm, 10-20 mm, 20-40 mm, >40 mm) in the field.

Existing studies on prey preferences of Rollers showed that prey size is the decisive factor for selection. The taxonomic affiliation of caught prey seems to play only a minor role, indicating that the Roller is an opportunistically foraging species (Szijj 1958, Klausnitzer 1963, Heansel 1966, Sosnowski and Chmielelewski 1996, Fry and Fry 1999). Rollers prefer prey with a size of more than 10 mm (Klausnitzer 1960, Haensel 1966, Fry 2001). Accordingly, we only used the following two arthropod size classes 10-20 mm and >20 mm to quantify prey abundance in different habitat types.

Data analysis

As measure for perch preferences of foraging Rollers, we used the number of observations per wooden pole and power line section, respectively. Because the bonding to nesting sites during the breeding season might affect the spatial patterns of perch use, habitat selection of foraging Rollers was separately analysed for the two time periods breeding season and post-breeding season. The start of the breeding season was defined by the first observations of displaying Rollers. The start of the post-breeding season was determined by the occurrence of the first fledged chicks.

An examination of our data indicate, that encounter frequency of foraging Rollers declined highly beyond a radius of 1.2 km from the nearest breeding site. Thus, potential perching sites out of this range were excluded from all analyses. Hence, 154 wooden poles and 100 power line sections remained for analysis.

Statistical analyses were performed using Statistica 7.1 (StatSoft Inc 2005). Results were considered significant if $P < 0.05$. Map-based analyses were conducted using the software ArcGIS/ArcView 9.2.

To assess effects of categorical and continuous habitat variables on the total number of observations per perch (wooden pole or 50 m power line section) generalized linear models (GLMs) were used. By using a Poisson error term and a log-link function a log-linear model was fitted. In all cases, the count data model was not seriously over-dispersed indicating that the Poisson distribution was appropriate for these data. To identify which habitat variables had the strongest influence on the number of Roller observations per perch, we determined a minimum adequate model by using a 'step down' approach (Crawley 1993). Therefore, first, all predictor variables were included in the GLM and, subsequently, each predictor variable was excluded in turn. The excluded variable that caused the least influence on the overall model deviance, determined by Akaike's Information Criterion (AIC; Crawley 1993), was removed and the process repeated again. Finally, the most parsimonious model, included all habitat variables that had a significant effect (according to Wald statistics) on the perch-use frequency.

Effects of habitat type on arthropod abundance were tested by calculating a Kruskal-Wallis ANOVA. Subsequent post hoc tests were used to detect significant differences between habitats. Analyses of habitat-specific differences in prey availability were made separately for breeding season and post-breeding season.

Results

Habitat selection

A total of 100 power line sections were included in the analysis, with Rollers recorded at 49 in 2002 and 54 in 2004. Furthermore, data of 154 wooden pole perches were used for analysis, with Rollers recorded at 136 in 2002. For both perch types we tested effects on perch use frequency for the following six predictor variables: Distance to nearest breeding site, distance to nearest settlement, habitat diversity, habitat edge density, maize area and meadow area.

The step-down minimum adequate model selection with the number of Roller observations per 50 m power line section as response variable detected distance to the nearest breeding site and proportion of meadow area as the most important predictor variables during the breeding season of both years (Table 1). The observation frequency of hunting Rollers was highest for power line sections in distances of up to 200 m to the nearest breeding site and then declined rapidly (Figure 2a). Furthermore, Rollers preferred perching on power line sections crossing areas with a high proportion of meadow cover of >50-75%, although similar perch use frequencies were reached in sections with a >25-50% (in 2004) and a >75-100% meadow cover (Figure 2b).

The use of power line sections for hunting during the post-breeding season 2002 was best predicted by the minimum adequate model including proportion of maize area, habitat edge density, distance to nearest settlement and distance to breeding site. In 2004 only maize area and distance to nearest settlement remained in the minimum adequate model, while habitat edge density was “replaced” by habitat diversity, which represents another measurement for habitat heterogeneity (Table 1). In both cases, the number of Roller observations per power line section increased with increasing habitat heterogeneity (data not shown). Increasing maize area proved to negatively affect the occurrence of Rollers perching on power line sections during foraging (Figure 2c).

Table 1. Step-down minimum adequate model selection for detecting variables important for the use of 50 m long power line sections as perches during foraging in breeding and post-breeding seasons of two different years.

Explanatory variables included	df	AIC	χ^2	*p*
Breeding season 2002				
Distance to breeding site, distance to settlement, habitat diversity, habitat edge density, maize area, meadow area	6	183.04	23.26	0.0007
Distance to breeding site, distance to settlement, habitat diversity, habitat edge density meadow area	5	181.04	23.26	0.0003
Distance to breeding site, distance to settlement, habitat edge density, meadow area	4	179.06	23.23	0.0001
Distance to breeding site, distance to settlement, meadow area	3	177.06	23.23	< 0.0001
Distance to breeding site, meadow area [a]	2	178.03	20.27	< 0.0001
Meadow area	1	184.51	11.79	0.0005
Post-breeding season 2002				
Distance to breeding site, distance to settlement, habitat diversity, habitat edge density, maize area, meadow area	6	233.34	89.05	< 0.0001
Distance to breeding site, distance to settlement, habitat diversity, habitat edge density, maize area	5	233.92	86.47	< 0.0001
Distance to breeding site, distance to settlement, habitat edge density, maize area [a]	4	233.31	85.08	< 0.0001
Distance to settlement, habitat edge density, maize area	3	246.70	69.70	< 0.0001
Habitat edge density, maize area	2	255.81	58.59	< 0.0001
Maize area	1	268.80	43.59	< 0.0001
Breeding season 2004				
Distance to breeding site, distance to settlement, habitat diversity, habitat edge density, maize area, meadow area	6	273.83	68.70	< 0.0001
Distance to breeding site, distance to settlement, habitat edge density, maize area, meadow area	5	271.84	68.68	< 0.0001
Distance to breeding site, distance to settlement, habitat edge density, meadow area	4	270.00	68.53	< 0.0001
Distance to breeding site, distance to settlement, meadow area [a]	3	271.35	65.18	< 0.0001
Distance to breeding site, meadow area	2	287.37	47.16	< 0.0001
Distance to breeding site	1	293.39	39.14	< 0.0001
Post-breeding season 2004				
Distance to breeding site, distance to settlement, habitat diversity, habitat edge density, maize area, meadow area	6	183.90	87.09	< 0.0001
Distance to breeding site, distance to settlement, habitat diversity, habitat edge density, maize area	5	183.17	85.82	< 0.0001
Distance to settlement, habitat diversity, habitat edge density, maize area	4	183.59	83.40	< 0.0001
Distance to settlement, habitat diversity, maize area [a]	3	185.05	79.93	< 0.0001
Habitat diversity, maize area	2	215.75	47.23	< 0.0001
Maize area	1	233.48	27.51	< 0.0001

[a] Final model (all variables significant according to Wald statistics).

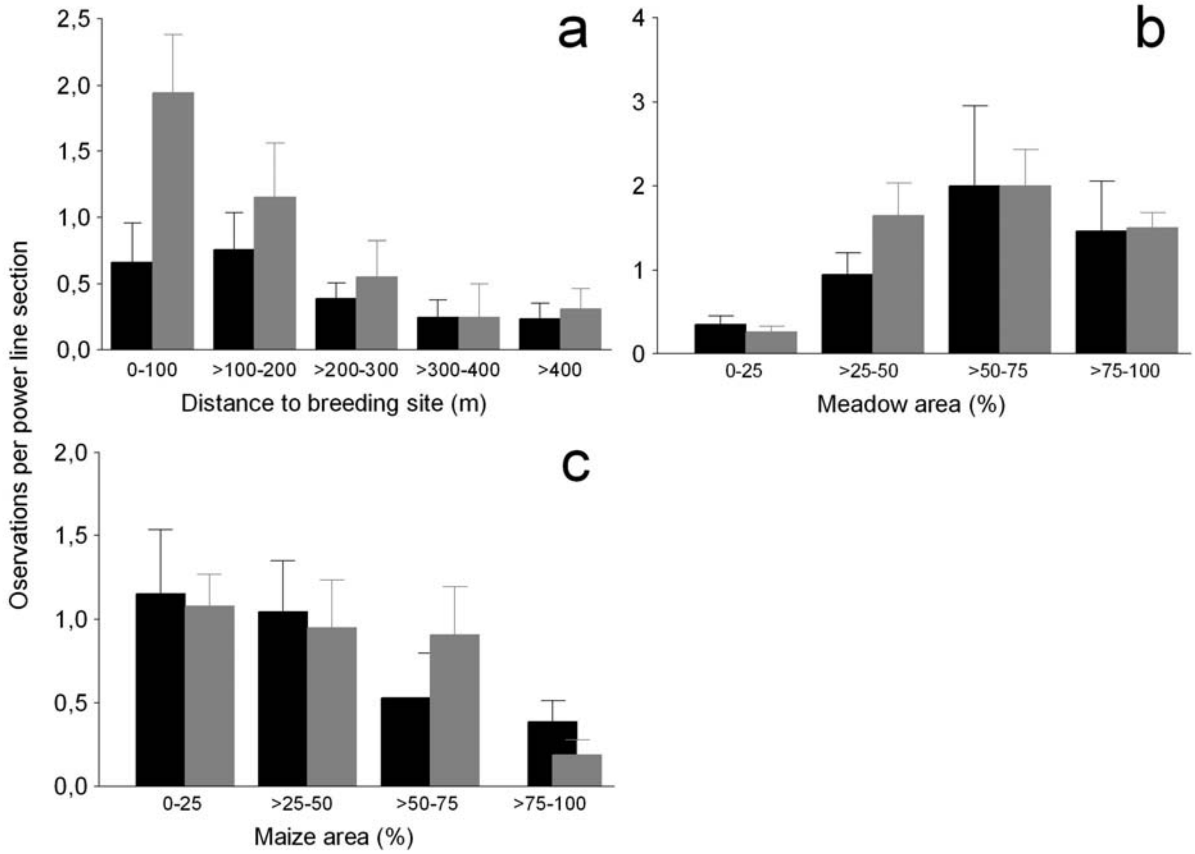

Figure 2. Effects of distance to the nearest breeding site during breeding season (a), proportion of meadow area during breeding season (b) and proportion of maize area during post-breeding season (c) on the mean number of Rollers observed per power line section (n=100) in 2002 (black bars) and 2004 (grey bars). Whiskers indicate standard errors.

A step-down minimum adequate model selection indicated distance to the nearest human settlement, habitat diversity and distance to nearest breeding site as most important variables for predicting the number of observed Rollers per wooden pole perch in both breeding and post-breeding season (Table 2). The minimum adequate models for the breeding and post-breeding season additionally included habitat edge density and proportion of meadow area, respectively (Table 2). The frequency of hunting Rollers observed on wooden poles increased more or less continuously with increasing distance to the nearest settlement and increasing habitat diversity during breeding and post-breeding season (Figure 3a-d). While observation numbers per perch decreased with increasing distance to nearest breeding sites during the breeding season, in contradiction, afterwards the smallest number of Rollers per perch was recorded in vicinity (0-250 m) to the formerly used breeding sites (Figure 3e-f).

Table 2. Step-down minimum adequate model selection for detecting variables affecting observation frequency of hunting Rollers on wooden pole perches in breeding and post-breeding season.

Explanatory variables included	df	AIC	χ^2	p
Breeding season 2002				
Distance to breeding site, distance to settlement, habitat edge density, habitat diversity, maize area, meadow area	6	463.86	114.88	< 0.0001
Distance to breeding site, distance to settlement, habitat edge density, habitat diversity, maize area	5	510.62	117.24	< 0.0001
Distance to breeding site, distance to settlement, habitat edge density, habitat diversity[a]	4	507.56	119.16	< 0.0001
Distance to settlement, habitat edge density, habitat diversity	3	509.93	114.79	< 0.0001
Distance to settlement, habitat diversity	2	514.18	108.54	< 0.0001
Distance to settlement	1	514.85	105.87	< 0.0001
Post-breeding season 2002				
Distance to breeding site, distance to settlement, habitat edge density, habitat diversity, maize area, meadow area	6	622.62	155.14	< 0.0001
Distance to breeding site, distance to settlement, habitat diversity, maize area, meadow area	5	621.24	154.52	< 0.0001
Distance to breeding site, distance to settlement, habitat diversity, meadow area [a]	4	620.48	152.36	< 0.0001
Distance to breeding site, distance to settlement, habitat diversity	3	681.94	141.98	< 0.0001
Distance to settlement, habitat diversity	2	696.39	125.54	< 0.0001
Habitat diversity	1	737.23	82.70	< 0.0001

[a] Final model (all variables significant according to Wald statistics).

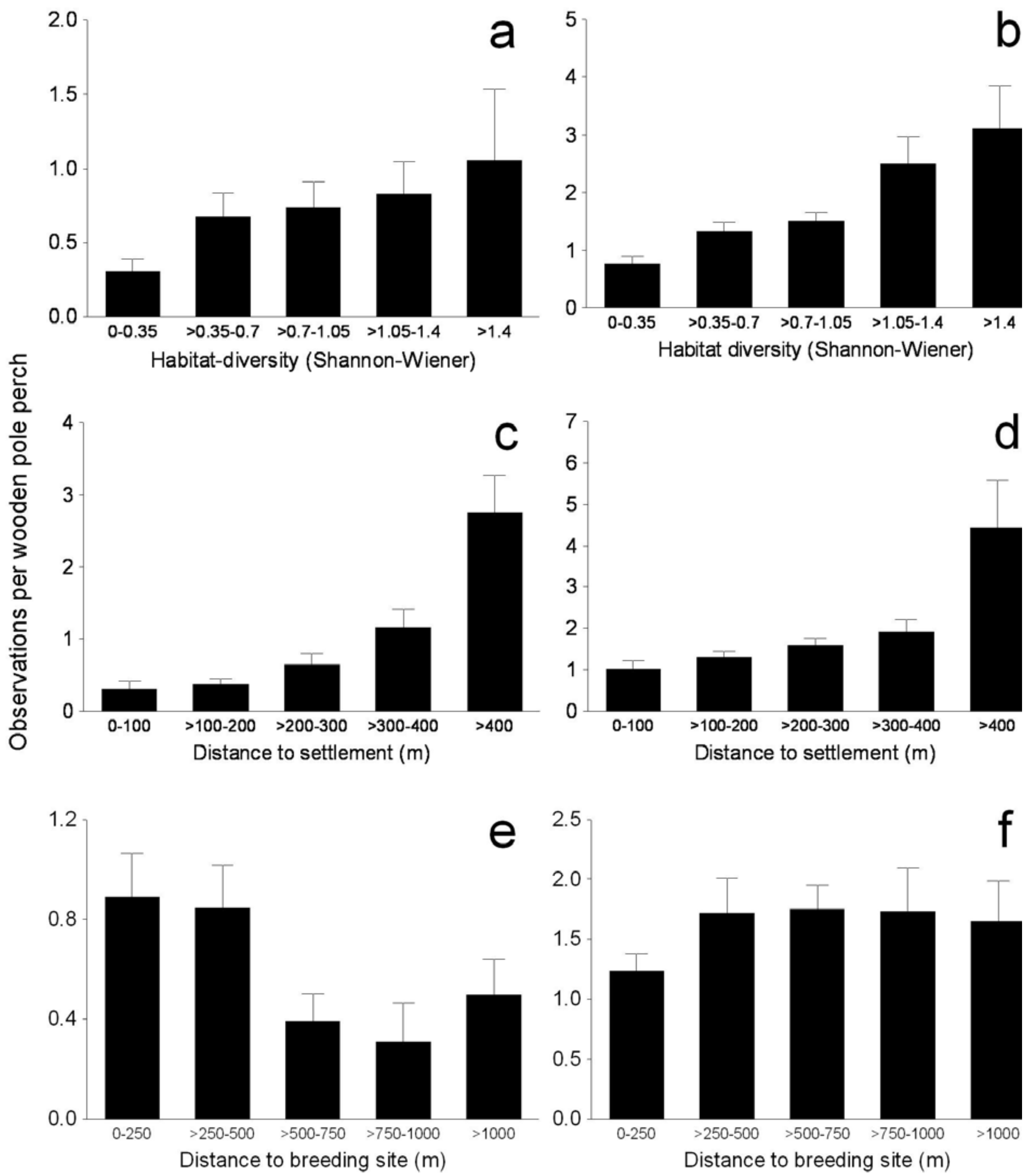

Figure 3. The relationship between mean number (± SE) of rollers recorded per wooden pole perch (n = 154) and habitat diversity (Shannon-Wiener-Index) (a: breeding season, b: post-breeding season), distance to the nearest settlement (c: breeding season, d: post-breeding season), and distance to the next breeding site (e: breeding season, f: post-breeding season), respectively.

Food availability

The mean number of medium-sized (10-20 mm) and large arthropods (>20 mm) differed significantly between habitat types for breeding season (Kruskal-Wallis ANOVAs; 10-20 mm: H = 40.59, df = 4, p < 0.0001; > 20 mm: H = 13.62, df = 4, p < 0.01) and post-breeding season (10-20 mm: H = 43.88, df = 4, p < 0.0001; > 20 mm: H = 12.19, df = 4, p < 0.01). For both size classes, the highest mean number of arthropods was found in meadows, significantly differing from maize during breeding season and post-breeding season. Intermediate abundances of medium-sized and large arthropods were found at road margins (Figure 4).

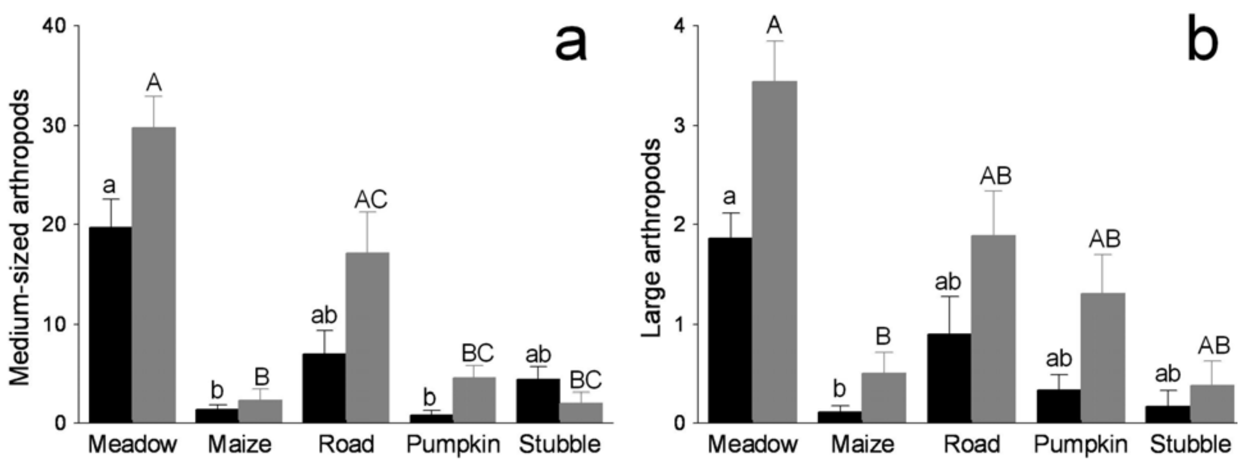

Figure 4. Mean number (+ SE) of (a) medium-sized (body length: 10-20 mm) and (b) large arthropods (> 20 mm) counted per 50 m transect in the five habitat types predominantly used by foraging Rollers during breeding season (black bars; n = 237) and post-breeding season (grey bars; n = 195). Different letters indicate significant differences (post-hoc test) between habitats for breeding (small letters) and post-breeding season (capital letters), respectively.

Discussion

In the framework of the international workshop for preparing the European Species Action Plan for the European Roller in Hungary (22-24 July 2008), the importance to gain more information on habitat requirements of European Rollers was identified as critical step towards developing effective conservation strategies (BirdLife International 2008). We tried to fill part of this gap in our knowledge by studying factors potentially influencing the quality of foraging habitats of Rollers belonging to the last remaining population in Eastern Austria. Due to the small size of this spatially highly restricted population data on habitat use are urgently needed to decrease the risk of local extinction by implementing an adequate land use management.

Due to own observations of individually marked birds from 2002 to 2007, at least 70 % of Rollers observed during the breeding season could be assigned to breeding pairs (M. Tiefenbach, unpublished). Therefore, it was not surprising to find a strong negative effect of distance to the nearest breeding site on perch use for power lines as well as wooden pole perches. Furthermore, Rollers showed a clear preference for a high proportion of meadows during foraging from power line perches during both breeding seasons. This could not be confirmed for Rollers using wooden pole perches. However, wooden poles were predominantly erected at meadow margins. Therefore, the variability of the relative proportion of meadow area within the foraging range of Rollers around individual wooden pole perches may have been too small to detect effects on perch use frequency.

The main reason for a preference of power line sections above meadows for perching may be related to food availability. Meadows in our study area were characterized by the highest abundances of medium-sized and large arthropods, which are the preferred food of Rollers according to Klausnitzer (1960) and Haensel (1966). As indicated by a study on Hoopoes (Fournier and Arlettaz 2001), a decrease in availability of larger insects can hardly be compensated by higher parents´ feeding rates. Also in Rollers a higher provisioning activity may not be as energetically advantageous as a good accessibility to larger prey in meadow areas. Therefore, attention has to be paid to the maintenance of meadows with a high abundance of larger insects e.g. by not applying insecticides in close vicinity to important foraging habitats. The combination of meadows with high food availability in vicinity to adequate breeding sites may be crucial for the survival of the last Austrian Roller population.

In contrast to the breeding season, area of maize was included in minimum adequate models testing for effects on the use power line sections as perches during the post-breeding season, while relative meadow area did not enter the model. Maize cover had a strong negative effect on perch selection. This strong negative effect appears to have been overriding the positive influence of meadow cover, which proved to enter the minimum adequate model when excluding maize area (results of GLMs not shown). A negative effect of maize area on Rollers was also emphasized by Samwald and Samwald (1989). They assumed that the increase of the proportion of maize acreage causing a decrease of grassland was a major driver for the decrease of the Roller in Styria during the second half of the 20th century.

According to our own observations, maize plants had a height of 1.4-1.8 m at the beginning of the post-breeding season. Therefore, additionally to a much lower abundance of potential prey, the high vegetation in that time period may have limited the accessibility of medium-sized to large arthropods in maize fields. Samwald and Samwald (1989) estimated the upper vegetation height threshold for fields at least partially still usable for foraging Rollers as 30-40 cm.

Own observations suggest that, in addition to meadow, other habitat types with partially bare ground such as tracks, pumpkin fields, stubble fields and fallows were more frequently used during the post-breeding season, although they were offering a lower food supply (M. Tiefenbach, unpublished). However, these habitat types were too rare to include them as predictor variables in our calculated GLMs. Hence, in addition to prey availability, vegetation structure seemed to be a core factor for habitat selection for sit-and-wait hunting birds, perhaps by influencing prey accessibility. Numerous publications reported a relationship between vertical stratification of vegetation and specific requirements of bird species in the context of foraging (Cyr and Cyr 1979, Wiens and Rotenberry 1981, Oppermann 1990, 1992, Atkinson *et al*. 2004, McCracken and Tallowin 1994). For the pre-alpine lowlands of south-eastern Austria, Trummer (2005) demonstrated by comparing different grassland-types, that Rollers favour dry or poor lowland-hay-meadows (speciose Pastinaco-Arrhenatherethum meadows) with a low vegetation cover for hunting. Furthermore, Trummer (2005) found indications that increased nitrogen input negatively influence meadow quality for the Roller.

A factor not included in our analysis was the periodical mowing of meadows. Freshly mown meadows appeared to attract notably more Rollers and were favoured during the following days (Tiefenbach unpublished), most likely due to improved access to prey. Wirtitsch *et al.* (2001) reported that mowed meadows were also more frequently used than tall grass meadows by hunting Lesser Grey Shrikes. However, Sackl (1985) and Johst *et al*. (2001) reported that after mowing food accessibility decreases again in the progression of vegetation re-growth.

Habitat heterogeneity and richness are two factors assumed to be important for numerous bird species (Tucker and Heath 1994), although empirical evidence is often lacking. In human-dominated landscapes, a mosaic of different annual crops and non-crop habitats, such as fallows, woodland patches and hedgerows, can create a highly diverse vegetation cover characterized by a high density of ecotones. Such landscapes can not only provide a diverse spectrum of prey types for insectivorous birds in space and time, but also offer small-scale structures such as bare ground and low vegetation side by side, particularly at ecotones, with a good accessibility to arthropods dwelling on the ground or within low vegetation. Preliminary analyses of hunting strikes of foraging Rollers showed, that field margins (0–10 m from field edge) were more frequently used, than central parts (> 10 m from field margin) (Sackl *et al*. 2004). Therefore, it is not surprising that several of our resulting minimum adequate models indicate that measurements of habitat heterogeneity (habitat diversity and habitat edge density) positively affected the attractiveness of potential perching sites. For power line sections an increased habitat edge density and habitat diversity increased perch use frequency in the post-breeding seasons 2002 and 2004, respectively. Both habitat variables also had a positive effect on the use of wooden pole perches during both breeding and post-breeding season (habitat diversity) or breeding season only (habitat edge density). Although meadows exhibits the highest availability of arthropods in our study, further enhancement of the ecological value for Rollers could be achieved by actively increasing habitat heterogeneity via sequential mowing. Already Johst *et al*. (2001) reported that sequential (asynchronous) mowing increased breeding success in White Storks *Ciconia ciconia.*

One important limiting factor for spatial patterns of perch selection by Rollers appears to be the distance to the nearest human settlements. This variable proved to negatively affect perch use frequency in all final GLMs largely independent of season (breeding vs. post-breeding season) and perch type (power line vs. wooden poles). In just one case (use of power lines as perches during breeding season 2002) this variable did not remain in the final model. Beside the fact that human settlements and their close vicinity may not provide adequate foraging habitats, the distance to human settlements may be also an important surrogate for the extent of human disturbance. Several studies documented behavioural changes in birds and other wildlife as a result of human disturbance (Cayford 1993, Keller 1995). Our study indicated that human disturbances associated with permanent human settlements may also have a prominent effect on habitat use by Rollers.

Regionally, urbanisation of the countryside has been defined as an important threat for European Roller populations (Birdlife International 2008). Due to the ongoing urban sprawl especially in the current breeding grounds in Styria, urbanisation can cause a significant loss of suitable habitats. Due to the high vulnerability of the small Austrian Roller population and the often uncontrolled rural development further studies have to estimate to which extent human disturbances affect fitness parameters and, consequently, the survival (probability) of the population (Gill *et al*. 2001).

This study on habitat use of foraging Rollers has important implications for the development of future conservation strategies aiming to protect the last remaining Roller population in Eastern Austria. It appears to be crucial for the survival of this small population that the density of settlements will not further decrease the core area available for breeding and foraging, that land use systems will remain patchy and that a further decrease of adequate meadow areas, e.g. through land use intensification, in vicinity of breeding sites can be avoided. When local decision makers and farmers can be convinced to consider the implications of our study in rural development plans and current land use practices, respectively, there is a glimmer of hope for Austrian Rollers, provided that habitat changes in the wintering grounds and negative effects due to global climate change will not increase the mortality of Rollers breeding in Central Europe and elsewhere.

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