# High breeding performance of European Rollers *Coracias garrulus* in a heterogeneous farmland habitat of southern Hungary

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Summary

**Capsule** Rollers showed slightly higher breeding performance in farmland mosaics than in natural grasslands in southern Hungary, where both habitats were supplied with nest-boxes.

**Aim** To establish which factors affect Rollers' breeding success in agricultural and their more traditional grassland habitats.

**Methods** Rollers' reproductive success in farmland mosaics and grassland habitats were compared. Laying date, clutch size, feeding rate, as well as prey abundance and diversity, as estimated by sweep netting and pitfall trappings, were evaluated. Their effects on breeding performance were analysed by generalized linear models.

**Results** In the agricultural habitat Rollers showed an even higher reproductive output than in their traditional habitat of natural grassland. Prey composition showed differences between the two habitats, with the lower abundance of orthopterans in farmland mosaics being substituted by the higher abundance of coleopterans and the diversity of arthropods (Orthoptera, Coleoptera, Heteroptera, Arachnida, Hymenoptera, Lepidoptera, Diptera, Homoptera, Mantidae, Myrmeleonidae and Odonata) .

**Conclusions** This species can thrive where good quality resources are available, even outside of their typical habitat, where nest box erection schemes may benefit this threatened species.

## Introduction

In the last three decades, the populations of many farmland and grassland bird species have declined throughout Europe (Siriwardena *et al*. 1998a; Donald *et al.* 2001; Donald *et al.* 2002; BirdLife International 2004). This trend has been attributed to widespread intensification of agricultural practices (Tucker & Heath 1994; Donald *et. al* 2001), such as reduction and fragmentation of semi-natural grasslands (Söderström *et al.* 2001). Large areas of meadows and pastures have been abandoned or transferred to arable fields (Vickery *et al.* 2001), and the use of insecticides have increased (Boatman *et al.* 2004; Hart *et al.* 2006). Donald et al. (2006) showed that among 58 avian species classed by an independent assessment as being primary birds of farmland, 41 showed negative trends across Europe between 1990 and 2000, of which 19 proved to be significant. Agricultural intensification may negatively affect birds' survival rate (Siriwardena *et al.* 1998b), and their reproductive output (Siriwardena *et al.* 2000; Hart *et al.* 2006). In insectivorous species, one of the reasons for these changes is a decline in food supply. For example, arthropod diversity and abundance can be lower on intensively managed areas and this may result in less diverse nestling diet (Britschigi *et al.* 2006).

Variation in the abundance and quality of food supply is thought to be an important determinant of life-history traits of birds. As an ultimate factor, food availability may affect breeding time, clutch size, offspring quality (Martin 1987; Tortosa et al. 2003) and reproductive success (Goławski & Meissner 2008). Consequently, the composition of food resources and the annual fluctuation of prey are some of the main factors determining population breeding parameters and density (Korpimäki 1984; Korpimäki & Norrdahl 1991; Arroyo & Garcia 2006).

The European Roller (*Coracias garrulus*) is a threatened bird species in Europe. It suffered from a serious population decline during the 1970's, disappearing as breeding species from Finland, Denmark, Germany and the Czech Republic (Cramp *et al.* 1993). The Hungarian population was also affected by this process, Rollers disappeared from the western part of the country, and the larger population of the eastern region also showed a serious decline (Hungarian Checklist and Rarities Committee 1998). The likely reasons for this decline are the lack of nest-sites and food availability due to changing agricultural practices (Tucker & Heath 1994). Nest-box installation proved to be an efficient method to replace natural nesting places (Avilés *et al.* 2000). Other studies reported less success with nest-box programs for Rollers (Sosnowski and Chmielewski 1996), or even identified that nest-boxes may serve as ecological traps and reduce reproductive success of Rollers having lower individual quality (Rodríguez et al. 2011). Decreases in the extent and/or quality of feeding sites (grasslands) still cause conservation problems for Rollers and other insectivore avian species, such as Lesser Grey Shrikes (*Lanius minor*) (Giralt *et al.* 2008) and Red-backed Shrikes (*Lanius collurio*) (Golawski & Golawski 2008). According to Donald et al. (2001) the Roller was one of the 19 primary farmland species which showed negative trend as a consequence of agricultural intensification in Europe. Furthermore, its breeding success and egg productivity are affected by farming practices (Avilés & Parejo 2004).

In Hungary, extended pastures and meadows were the most typical historic habitats for Rollers (Szijj 1958), where they mainly bred in old patches of white poplars (*Populus alba*) and oak (*Quercus robur*) woods, in the holes of the Green Woodpecker (*Picus viridis*) and also in the holes of the rarer Black Woodpecker (*Dryocopus martius*) (Kalotás 1998). In southern Hungary the breeding population of Rollers decreased rapidly in the second half of the 20th century, parallel with the reduction of the natural oak forests and the disappearance of old poplar woodland patches. In the second half of the 20th century the disappearance of cottages with old orchards also reduced suitable breeding sites, and the remaining young and premature black-locust (*Robinia pseudoacacia*) woodlands had no suitable nesting holes for Rollers. Fig. 1 shows population changes of Rollers in the last three decades in Hungary. Rollers totally disappeared from southern Hungary in the 1980'sand in the 1990's they gradually disappeared from ca. 1/3 of the country, mainly from the western parts (Transdanubia) (Kalotás 1998). After installation of nest-boxes, Rollers recolonized dry grasslands in southern Hungary and became a relatively frequent breeding species in grasslands and the mosaics of agricultural areas as well.

In the present study we aimed to compare breeding performance of Rollers in two presently favoured breeding habitats of this species, where the missing natural holes are provided artificially. One of these habitats is the farmland mosaics, which seems to be dominant in the countryside of southern Hungary. The other habitat is the traditional Roller habitat in Hungary, the dry grassland ("steppe") with scattered trees or woodland patches. As the breeding population of Rollers has increased recently in both habitat types, we hypothesized that breeding performance of Rollers would be similar in these habitats, and predict similar values in clutch size, hatching success fledging success and reproductive success. We also hypothesized that food supply was also similar in these habitats, which is a critical factor for reproductive success. We also compared the main types of food that Rollers delivered to their nestlings, and also surveyed the abundance and diversity of these main prey items available in the field. We predicted similar food supply and similar prey selection of rollers in the two habitats, if our hypothesis is true. Alternatively, these habitats differ for Rollers, which may have consequences on their reproductive performance.

## Methods

### Study area

The study was conducted near the town of Szeged, southern Hungary, in two sites (Fig. 2): (i) "Natural grassland" habitat at the village Baks (46°32'N; 20°03'E). This habitat was alkaline natural grassland (often called "steppe"), which was characterized by salt and dry grassland patches. Due to the lack of natural holes available for breeding, nest-boxes (approx. height: 30 cm, width: 20 x 20 cm, diameter of the entrance hole: 6-6.5 cm) were installed in the area in previous years. With the help of this nest-box program we made dry grasslands available for Rollers. Originally, they used to occupy grassland areas with scattered trees or where nearby woodland patches were available with natural tree holes (Szijj 1958). The installation of nest-boxes started in 1990 (Molnár 1998) and continued until 2008. Altogether 80 nest-boxes were placed into this area, from which about 57-61% of them were occupied by Rollers during any one year of the study. All nest-boxes were fixed on trees, mostly on black locusts or poplars (*Populus* sp.). In this habitat breeding density of Rollers was about 0.255-0.235 pairs/10 ha in 2009 and 2010, respectively. (ii) "Farmland mosaics" at the village Szatymaz (46°24'N; 19°57'E). The second site is an agricultural area, which is the mosaic of salt grassland patches (23% of the whole area) and extensive cereal cultures (3%), arable fields (53%) and artificial forest monocultures (4% of the whole area). The size of the grassland patches within this habitat was about 14 ha. Nest-boxes were placed into the grassland patches, from the year of 1988 (Molnár 1998). During the study period 65 nest-boxes were available for Rollers and about 45% of them were occupied. We placed the next-boxes on trees (lone trees and treelines) and electric pylons. In this habitat density of the breeding Roller population was about 0.32-0.362 pairs/10 ha in 2009 and 2010, respectively.

Number of nest-boxes did not change in the years of our study. No pairs of Rollers bred in natural holes in our study areas. In nest-boxes no competitors were observed, except a pair of Western Jackdows (*Corvus monedula*) bred in a nest-box. A few attempts at nest-box occupation were observed by Eurasian Scops Owls (*Otus scops*) and Starlings (*Sturnus vulgaris*), but Rollers won in these cases. Previously we also observed a few successful nesting attempts of Red-footed Falcons (*Falco vespertinus*) in Rollers' nest-boxes, but not in the years of the study.

The study was conducted in 2009 and 2010, during the breeding season of Rollers (from late April to early August). We also sampled prey of Rollers in the first year of the study.

Arthropod abundance

We studied the availability of prey on 12 and 14 plots at the Baks and Szatymaz sites respectively, in 2009. At both sites plots were established in grassland patches of the habitat, within the breeding territories of Rollers (average territory size was 4.83 ha, Molnár 1998). Rollers preferred to collect food from grassland patches (our unpubl. results). The dry short-grass steppe habitat offers high visibility of prey for sit-and-wait predators, like Rollers and Lesser Grey Shrikes (Lovászi et al. 2000), when they are perching on trees or power lines. Only one plot per Rollers' territory was used to avoid pseudoreplication in data. Our sampling plots were established within 150 m radius around the nest-boxes, because Avilés et al. (2000) reported about 165-170 m foraging radius of Rollers in the nesting period.

Although Rollers sometimes catch small vertebrates, they typically forage on terrestrial invertebrates and slowly flying arthropods (Cramp *et al.* 1993; Avilés & Parejo 2002). We used pitfall traps and sweep-net sampling to estimate arthropod abundance and potential prey species diversity. In each study plot we randomly placed five pitfall traps of plastic cups with the diameter of 65 mm in a line, 1 m apart from each other. Ethylene glycol (30-50%) was used as killing-preservative solution. We also sampled potential prey by sweep netting in three transects within a territory, under good weather conditions (above 15 Celsius degree temperature on a windless day, e.g. below 2 on the Beaufort scale). Pitfall-traps were active for two weeks between 16 June and 20 July, which overlapped the feeding period of nestlings. This resulted in two samples from pitfall traps and three samples from sweep netting. Rollers usually feed on arthropods larger than 1 cm (Cramp et al. 1993) hence we selected the food items larger than 1 cm from the collected samples for further analyses. We identified arthropods to families, then dried (72 hours, 60 °C) and their biomass was measured (accuracy: 0.001g) (see Table 2a for main taxa of arthropods determined).

Breeding parameters and feeding behaviour

From the end of April to August we checked nest-boxes weekly to monitor the breeding attempts of Rollers. Nest-boxes were monitored weekly through all the breeding cycle, but in the case when we found a clutch larger than one or two eggs, we rechecked it in the next 1-2 days during the egg laying period or if the clutch was considered complete we monitored it every 4-5 days until the first egg hatched. Incubation begins before clutch completion, usually just after the third egg has been laid, and the mean clutch size is 3.8 (Cramp *et al.* 1993). Start of laying was estimated by backward calculation, assuming that an egg was laid in every second day and the incubation period was about 18 days (Cramp *et al.* 1993). We calculated hatching success as the percentage of hatched eggs in a clutch and fledging success as the percentage of hatchlings that fledged. The number of 20-23 days old nestlings was accepted as the number of fledglings produced by a pair, because fledging time is 26–27 (25–30) days (Cramp *et al.* 1993). Reproductive success was calculated as the number of fledglings per pair that laid at least one egg. We documented feeding rates and prey composition delivered by Rollers to their nestlings by video recordings (Sony DCR-HC53E camera). We positioned the video camera about 5 m from the nest-boxes on a tripod, and left it in place for 5-10 minutes, before recording started to allow habituation of the parents. Recording sessions typically lasted one hour (mean 64.7 min ± 1.1 SE).We recorded Rollers between 0600 and 1200 hours in the morning, because Poole (2006) reported the frequency of Rollers' feeding activity was similar within this period. We recorded Rollers' chick feeding twice at each nest, first during the first week of the nestling period and the second recording during the third week of the nestling stage in 2009; Roller nestling period is at least 3 weeks long (Cramp *et al.* 1993).

Statistical analyses

We tested three sets of models to determine if there were differences across habitats. (1) How reproductive success (number of hatchlings per clutch size, expressed as percentage; the response variable in the model) was affected by the nesting parameters, such as feeding rate, date of the first egg laid and clutch size, prey availability as covariates, including habitat type as a fixed factor. Two model derivates were compared by multi-model inference (see details below): the first variant was the simple effect model where only the main effects among the studied variables were considered, while in the second variant, clutch size was added as a correction term for dispersion parameter (Bolker et al. 2009) due to control the effects of different clutch sizes on the response variable. This means that the arc sine transformed clutch size was added as a known coefficient to the linear predictor to avoid any potential biases in the model estimates caused by the difference in clutch sizes.
(2) How feeding rate was affected by the nesting parameters, such as date of the first egg laid, clutch size and prey availability, and including habitat types as a fixed factor. Two model derivates were compared by multi-model inference: the first model was the simple effect

model, while in the second variant the linear predictor was corrected by clutch size, similarly to model (1).

(3) Three models were built (to avoid collinearity) to describe how food resources (mean for orthopterans, coleopterans and the total abundance of prey as response variables) vary between habitat types and collection methods (including their interactions).

For models (1) and (2) we used information criterion (AICc) to rank the models in terms of their ability to explain the responses (Burnham and Anderson 2002). In this way parameters of the "best approximating" model were selected for the most parsimonious explanation of the data.

We used generalized linear models to reveal the relationships between the assumed explanatory and response variables using Gaussian error term. The response variable reproductive success was arc sine transformed, while feeding rate and food resources variables were log(x+1) transformed to allow linear fitting of the models (c.f. Bolker 2009). We applied multi-model inference to select the most parsimonious model in the case of models 1 and 2. The analyses were carried out in R 3.0.1 (R development team 2013), using the package MuMIn for multi-model inference (Barton 2013). Box-and-whisker plots were generated by SPSS ver. 17.

## Results

We found similar clutch sizes of Rollers in the two study sites (mean clutch sizes were 3.94 ± 0.98 SE and 3.72 ± 1.22 SE in the grassland and mosaic habitats, respectively; Mann-Whitney U-test, $U_{83,54} = 2030.0$, $P = 0.42$). Hatching success (81% in the grassland and 85% in the mosaic habitats; $U_{72,51} = 2065.0$, $P = 0.95$) and number of hatchlings was also similar between the two habitats (mean number of hatchlings was 3.27 ± 1.57 SE in the grassland

and 3.26 ± 1.59 SE in the mosaic habitats; $U_{77,54} = 1661.0$, $P = 0.35$). Fledging success (percentage ratio of hatchlings that fledged) also showed similar values in both of the habitats (82.9% and 90% in the grassland and mosaic habitats, respectively; $U_{68,49} = 1428.5$, $P = 0.16$). The only habitat-related difference in reproductive performance was found in breeding success (percentage of eggs that fledge per pair that laid at least one egg) that proved to be higher in the mosaic than in the grassland habitat (64.2% and 77% in the steppe and mosaic habitats, respectively; $U_{76,52} = 1487.5$, $P = 0.019$; Table 1).

We collected a total number of 8816 arthropods larger than 1 cm (67.6 g dry biomass) were collected by pitfall trapping and sweep-net sampling (Table 2a). Sweep-netting proved to be sensitive for orthopterans, as about 87% of the caught specimens and 82.2% of the dry biomass belonged to this prey type. Beetles were represented in only 1.8% of specimens and 4.3% of the dry biomass. Conversely, pitfall traps caught similar proportion of orthopterans (47.2% of specimens and 58.4% of the dry biomass) and coleopterans (31.8% of specimens and 30.6% of the dry biomass). The total amount of dry biomass of orthopterans collected by sweep-netting was highest in the natural grassland than in the mosaic habitat ($U_{12,13} = 39000$, $P = 0.035$). For pitfall trapping we found no difference in the arthropods collected in the two habitats ($U_{24,30} = 317.5$, $P = 0.46$). Shannon's diversity of the arthropod families, when it was calculated from sweep-net samplings, was significantly higher in the mosaics than in the grassland ($U_{12,14} = 162000$, $P = 0.001$; Fig. 3a), but these values were similar in the two habitats if it was calculated from pitfall traps ($U_{12,14} = 58000$, $P = 0.19$; Fig. 3b). We video-recorded Rollers when they were delivering food for their nestlings in the nest-boxes (Table 2b). These videos revealed that rollers typically fed their nestlings insects, mainly orthopterans (in 40.1% of feeding) and coleopterans (23.3%), but other insects were also important (25.3%). Although the frequency of delivered vertebrates was only 9.3%, their contribution to nestling diet by mass was more important. No difference was found between the two habitats regarding some of the prey types (coleopterans: $U_{28,39}$ = 489.5, $P$ = 0.46; vertebrates: $U_{28,39}$ = 440.5, $P$ = 0.13), but rollers delivered more orthopterans in the grassland ($U_{28,39}$ = 358.0, $P$ = 0.015) and more prey from small mammals (rodents and shrew-mice) ($U_{28,39}$ = 452.0, $P$ = 0.044) in the farmland mosaics.

Reproductive success of Rollers was affected by egg laying date and habitat type, showing higher reproductive success in the farmland mosaics (Table 3). However, feeding frequency did not affect reproductive success. Including clutch size in the model improved it (weight=0.624, AICc=27.6, logLik=-5.128, df =8) suggesting that differences due to habitat were probably not restricted to adult quality and reflected the quantity or quality of food provided to the chicks. Feeding rate was however the same across habitats and only depended on clutch size (Table 4) suggesting that differences across habitats were likely to reflect quality of food provided. The simple effect model provided the better fit than the model including clutch size as offsetting factor (Table 3). Clutch size affected the feeding rate of Rollers, as individuals with larger clutches showed higher feeding rate.

Food availability varied significantly across habitats controlling for collection method (Table 5). Orthopterans seems to be the most important group in prey availability, as shown by the sweep netting methods. Coleopterans have more importance in the farmland mosaics (Table 5).

## Discussion

Our results showed that Rollers’ reproductive success in southern Hungary was higher in mosaic farmland habitats than in the dry natural grassland ("steppe") habitat. This habitat type is known as the most important original habitat for Rollers in this area (Szijj 1958;

Molnár 1998), although this species cannot be regarded as a specialist on grasslands (Batáry *et al.* 2007). The decrease in the availability of natural nesting holes for this species in the second half of the last century drove this breeding population close to extinction (Kalotás 1998; Molnár 1998), but offering suitable nest boxes for Rollers seems to be an effective way to help their survival. Our study revealed high diversity of potential prey types in both habitats, and the dominance of orthopterans when preys were collected by sweep netting. Sweep netting revealed higher abundances of orthopterans and more taxa than pitfall trappings, suggesting the usability of this method for surveying prey availability for Rollers. Reproductive performance of this species in farmland mosaics was slightly higher in the farmlands than in natural grasslands. Although the main prey type of this species, the orthopterans were less numerous in farmland mosaics than in grasslands, Rollers compensated for this by collecting other insects and small vertebrates in the mosaic habitat. Although the abundance of the main prey types somewhat differed in these two habitats, Rollers were able to compensate this difference with the preference for coleopterans in farmlands. This shift did not reduce their breeding success, even it was higher in farmland mosaics than in grasslands. Despite of the difference in food supply in the two habitats, video records revealed that orthopterans dominated in their prey selection when Rollers fed their nestlings. We suggest that Rollers utilized the available resources successfully in both habitats and so both of them seem to be suitable for this species.

Original breeding habitats of Rollers have also changed in Spain, and there they now use different agricultural habitats for breeding sites such as cereal fields, irrigated crops, pastures, holm oaks, olive groves or scrub fields, as well as more traditional habitats (Avilés *et al.* 1999; Avilés *et al.* 2000; Avilés & Parejo 2004). Though Avilés & Parejo (2004) revealed that farming practices had a negative effects on Rollers' breeding performance, they also suggested that the decrease in natural nest-sites that resulted from agricultural intensification is probably the main effect responsible for the decline of Roller populations. In France, Rollers also breed in farmland mosaics, but prefer sites with higher density of orthopterans (Bouvier et al. 2014).

Although the food composition of Rollers in our study site appears to be similar to that of in their European range (Cramp *et al.* 1993; Avilés & Parejo 2002), our study revealed differences in nestling food composition in different habitat types. Fragmentation may have complex effects on insect density and movement (Hunter 2002) and probably provides variable hunting possibilities for insectivorous species. Hunting success of the sit-and-wait predator Roller is affected by several factors besides food availability, such as perch type and vegetation (Cramp *et al.* 1993). The Roller is a polyphagus species, foraging on a wide range of prey (Szijj 1958), and our findings showed that Rollers can effectively switch between prey species based on their availability. We also found higher frequencies of small mammals and lizards in the mosaic site than in the natural grasslands. Avilés & Parejo (2002) showed that small mammals significantly contributed to the biomass of the nestling diet in Rollers, therefore their abundance may have a positive effect on breeding success. Video-recordings revealed that Rollers fed their nestlings with easily-available large insects, mainly orthopterans, but when availability of this prey was reduced in the farmland habitat they collected more coelopterans. Other studies have pointed to the potential importance of vertebrates in Rollers' food, but vertebrates never dominate as prey, and can best be regarded as only occasional elements (Szijj 1958; Sosnowski & Chamielski 1996). Only one exceptional case is known where anurans comprised 70% of Roller diet (Barthos 1906). Small mammals, birds, snakes, lizards, and anurans might represent valuable food types because of their  higher biomass, but in Hungarian samples small mammals and reptiles were detected only at a relatively low frequency.

In the present study we show an example where a new man-made habitat type can be suitable for breeding and survival for a vulnerable bird species as long as critical limiting factors are addressed (i.e. nest site availability). The farmland mosaics in southern Hungary seem to be offering a high-quality breeding habitat for Rollers, if supplied with artificial nest boxes. These large-sized nest boxes are also necessary in the traditional breeding habitat of this species, where there is now a shortage of natural holes for breeding. In southern Spain nest boxes had a negative impact on Rollers' reproduction (Rodríguez et al. 2011). The variation in the importance of nest boxes in helping Roller populations clearly needs further research in different parts of Rollers' breeding range, as several factors may influence their usability. For example, snake predation is an important factor which reduces the applicability of nest boxes for Rollers in Spain (Parejo & Avilés 2011), but no snake predation was observed in Hungary. These results suggest that geographical variations may possible be explained by regional factors affecting nest-box suitability, and the importance of evaluating population effects of conservation actions on a case by case basis.  Our study probably provides an example of how nature conservation practices – provision of nest boxes - may help in the survival of a threatened generalist species in new habitats, if there is sufficient food availability.

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Table 1. Clutch size, hatching success, fledging success and breeding success of Rollers, observed in natural grasslands and farmland mosaics in southern Hungary (means ± SE; sample sizes are in parentheses).

| | Clutch size | Hatching success | Fledging success | Breeding success |
|---|---|---|---|---|
| Natural grassland | | | | |
| 2009 | 4.27 ± 0.129 (51) | 95.8 ± 1.70 (40) | 80.4 ± 5.05 (41) | 73.4 ± 5.06 (44) |
| 2010 | 3.41 ± 0.148 (32) | 62.6 ± 7.74 (32) | 86.7 ± 5.09 (27) | 51.4 ± 7.43 (32) |
| Farmland mosaics | | | | |
| 2009 | 4.26 ± 0.169 (23) | 92.5 ± 4.87 (22) | 82.3 ± 6.4 (22) | 77.7 ± 7.02 (23) |
| 2010 | 3.32 ± 0.234 (31) | 79.8 ± 6.85 (29) | 97.5 ± 1.71 (27) | 78.7 ± 6.8 (29) |

Table 2. Potential prey supply in Rollers' territories and prey selected for chick feeding in natural grasslands and farmland mosaics in southern Hungary. (a) Mass of dry biomass (g) of the main groups of arthropods collected by sweep-netting and pitfall traps (means ± SE). (b) Frequency of main prey types in Roller nestling diet identified from video recordings (number of observations and percentages of all feedings).

(a)

| | Natural grassland | | Farmland mosaics | |
|---|---|---|---|---|
| | Sweep-netting | Pitfall traps | Sweep-netting | Pitfall traps |
| Orthoptera | 0.691 ± 0.66 | 0.135 ± 0.17 | 0.43 ± 0.044 | 0.141 ± 0.152 |
| Coleoptera | 0.05 ± 0.22 | 0.061 ± 0.068 | 0.011 ± 0.003 | 0.079 ± 0.128 |
| Heteroptera | 0.0389 ± 0.17 | 0.0004 ± 0.001 | 0.037 ± 0.006 | 0.002 ± 0.0035 |
| Arachnida | 0.0108 ± 0.037 | 0.0822 ± 0.1 | 0.0095 ± 0.002 | 0.017 ± 0.025 |
| Hymenoptera | 0.0104 ± 0.05 | 0.0009 ± 0.002 | 0.004 ± 0.001 | 0.0036 ± 0.006 |
| Lepidoptera | 0.036 ± 0.17 | 0.0005 ± 0.0015 | 0.0054 ± 0.0015 | 0.0001 ± 0.0001 |
| Diptera | 0.01 ± 0.04 | 0.0003 ± 0.0009 | 0.01 ± 0.002 | 0.0015 ± 0.0027 |
| Homoptera | 0.0002 ± 0.0009 | - | 0.0005 ± 0.0003 | - |
| Mantidae | 0.0011 ± 0.006 | - | 0.064 ± 0.036 | - |
| Myrmeleonidae | - | - | 0.0016 ± 0.0007 | - |
| Odonata | 0.0001 ± 0.0004 | - | 0.02 ± 0.00018 | - |

(b)

| | Natural grassland | Farmland mosaics |
|---|---|---|
| Orthoptera | 77 (41.62%) | 56 (35.44%) |
| Coleoptera | 32 (17.3%) | 43 (27.22%) |
| Other insects | 68 (36.76%) | 36 (22.78%) |
| Reptiles | 7 (3.78%) | 16 (10.13%) |
| Mammals | 1 (0.54%) | 4 (4.43%) |

Table 3. Results of the best model for the reproductive success of Rollers (i.e. the number of fledglings per pair that laid at least one egg; dependent variable) in southern Hungary with habitat (fixed factor), feeding rate, laying date, abundance of coleopterans and orthopterans (covariates) and clutch size (as offset).

| Parameters | d.f. | Estimates | S.E. | t | P |
|---|---|---|---|---|---|
| Intercept (farmland) | | -1.79 | 0.37 | -4.77 | <0.001 |
| Habitat (grassland) | 1,112 | -0.54 | 0.06 | -8.53 | <0.001 |
| Feeding rate | 1,111 | 0.00 | 0.00 | 0.22 | 0.82 |
| Laying date | 1,110 | 0.06 | 0.00 | 8.39 | <0.001 |
| Coleoptera mean abundance | 3,113 | -0.11 | 0.42 | -0.25 | 0.79 |
| Orthoptera mean abundance | 3,107 | 0.08 | 0.1 | 0.78 | 0.43 |
| Total mean abundance | 3,107 | 0.04 | 0.07 | 0.53 | 0.59 |

Table 4. Results of best generalized linear models for the feeding rate of Rollers (dependent variable) in southern Hungary with habitat (fixed factor), laying date, clutch size, and abundance of coleopterans and orthopterans (covariates).

| Parameters | d.f. | Estimates | S.E. | t | P |
|---|---|---|---|---|---|
| Intercept (farmland) | | -2.84 | 1.2 | -2.37 | 0.01 |
| Habitat (grassland) | 1,112 | 0.09 | 0.1 | 0.62 | 0.53 |
| Laying date | 1,111 | 0.06 | 0.0 | 3.4 | <0.001 |
| Clutch size | 1,110 | 0.39 | 0.95 | 4.12 | <0.001 |
| Coleoptera mean abundance | 3,113 | -1.26 | 0.96 | -1.3 | 0.19 |
| Orthoptera mean abundance | 3,107 | -0.38 | 0.23 | -1.64 | 0.1 |
| Total mean abundance | 3,107 | -0.31 | 0.18 | -1.74 | <0.001 |

Table 5. Results of generalized linear models describing how food resources (abundance of orthopterans, coleopterans and total abundance of prey as response variables) may vary between habitat types and collection methods (including their interactions).

(a) Shannon's diversity of prey

| Parameters | d.f. | Estimate | S.E. | t | P |
|---|---|---|---|---|---|
| Intercept (farmland, pitfall, farmland: pitfall) | | 0.69 | 0.04 | 14.12 | <0.0001 |
| Habitat (grassland) | 1,36 | 0.17 | 0.06 | 2.62 | 0.01 |
| Source (sweepnet) | 1,35 | 0.035 | 0.06 | 0.51 | 0.61 |
| Grassland: sweepnet | 1,34 | -0.532 | 0.09 | -5.56 | <0.0001 |

(b) Orthopterans

| Parameters | d.f. | Estimate | S.E. | t | P |
|---|---|---|---|---|---|
| Intercept (farmland, pitfall, farmland: pitfall) | | 0.16 | 0.04 | 3.54 | 0.001 |
| Habitat (grassland) | 1,36 | -0.06 | 0.06 | -1 | 0.32 |
| Source (sweepnet) | 1,35 | 0.19 | 0.06 | 2.91 | 0.0006 |
| Grassland: sweepnet | 1,34 | 0.24 | 0.09 | 2.74 | 0.0009 |

(c) Coleopterans

| Parameters | d.f. | Estimate | S.E. | t | P |
|---|---|---|---|---|---|
| Intercept (farmland, pitfall, farmland: pitfall) | | 0.08 | 0.02 | 3.28 | 0.002 |
| Habitat (grassland) | 1,36 | -0.02 | 0.03 | -0.58 | 0.56 |
| Source (sweepnet) | 1,35 | -0.07 | 0.03 | -2.07 | 0.04 |
| Grassland: sweepnet | 1,34 | 0.05 | 0.05 | 1.16 | 0.25 |

(d) Total abundance

| Parameters | d.f. | Estimate | S.E. | t | P |
|---|---|---|---|---|---|
| Intercept (farmland, pitfall, farmland: pitfall) | | 0.25 | 0.05 | 4.341 | 0.0001 |
| Habitat (grassland) | 1,36 | -0.02 | 0.08 | -0.336 | 0.73 |
| Source (sweepnet) | 1,35 | 0.16 | 0.083 | 1.93 | 0.06 |
| Grassland: sweepnet | 1,34 | 0.23 | 0.11 | 2.022 | 0.05 |

Legends to figures

Figure 1 Changes in the number of breeding pairs of Rollers between 1985 and 2013 in Hungary.

Figure 2 A map to show the location of the two study sites in Hungary.

Figure 3 Shannon' diversity of arthropods collected three times by sweep nettings (a), or twice by pitfall trappings (b) from Rollers' territories. (white boxes: natural grassland, grey boxes: farmland mosaics; box-and-whisker plots show median, minimum and maximum values, and quartiles)