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Conference paper

Available versus used prey – Combined methods reveal the breeding diet of the European roller (*Coracias garrulus*) in Serbia

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Summary. The European roller (*Coracias garrulus*) is a threatened species, and over the last few decades population recovery has been achieved via installation of nest boxes as a substitute for lost natural nesting sites. However, lack of available food acts as a second limiting factor for the roller. Thus, in the present study, the dietary requirements of rollers were investigated to provide necessary data to guide conservation measures that encourage the return of rollers to their breeding sites. Field work was carried out within roller breeding territories in the Central Banat region (Serbia). Prey availability and preferences were determined by comparing available and consumed prey over five breeding seasons. Different proportions of main prey categories within the roller's diet were detected, comparing available prey and consumed prey, which led to negative Ivlev index values. Consumed prey remains found in nest boxes constituted larger amounts of coleopterans, while orthopterans were more numerous in the available prey. This finding is not surprising as orthopterans, unlike coleopterans, are soft-bodied and swallowed as whole specimens leaving less detectable body parts among food remains, which could lead to their underestimation in the roller diet. Apiaries were found near the research plots, resulting in a higher proportion of hymenopterans among the available invertebrate prey. In contrast, we only found one bee specimen in the nest box. This confirms that rollers avoid hunt-ing fast flying insects. The low percentage of orthopterans within the pitfall traps has been complemented by sweep net catches. Therefore, this combination of methods resulted in a composition of available prey that corresponds to the observed food remains. A variety of prey groups were found to be part of the roller diet composition. Most of these were arthropods, while 5% of vertebrates were detected (amphibians, reptiles and small mammals). Because of this, we propose that the European roller is an opportunistic predator that can survive near poor, overgrazed, and dry pastures.

Keywords: arthropod, Ivlev index, pitfall trap, sweep net.

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INTRODUCTION

During recent decades, rapid changes in agricultural practices associated with habitat loss, crop homogenization, high insecticide application, and intensive farming (Benton et al. 2003; Flohre et al. 2011) have affected biodiversity in many European countries (Donald et al. 2006; Emmerson et al. 2016). Over the last few decades, over 400 million individuals of common bird species have vanished, of which 57% are farmland birds. This loss is related to changes in agriculture practices (Billeter et al. 2008; Inger et al. 2015; PECBMS 2020). Lack of nesting and foraging sites are the most obvious factors associated with this decline. However, reductions in the quality and amount of food are also a significant threat to bird survival (Taylor et al. 2006; Paquette et al. 2013; Lopez-Antia et al. 2018). Global reductions of arthropod populations (Sánchez-Bayo and Wyckhuys 2019; Wagner 2020) coupled with an over 60% decline in biomass over the last three decades (Hallmann et al. 2017; Seibold et al. 2019) has directly impacted the breeding success of birds, for which arthropods are an essential dietary component (Holland et al. 2006; Tallamy and Shriver 2021). The European roller (hereafter roller), a farmland bird, has suffered a steep global decline over the last decades of the 20th century, caused by large scale changes in agricultural practices (Kovács et al. 2008). Installation of nest boxes is an active conservation measure that has helped stimulate the recovery of roller populations in some countries, including Serbia (Ružić et al. 2017; Tokody et al. 2017).

In order to design effective conservation measures, detailed knowledge on species ecology is essential (Ramírez et al. 2016). Data related to foraging dynamics and trophic ecology is still lacking in some regions of the roller's breeding distribution (Sutherland 2004; Kovács et al. 2008). Although some studies of roller diet have been reported (Avilés and Parejo 2002; Kiss et al. 2014; Catry et al. 2019), research based on comparisons between available and used prey are relatively scarce. Because prey availability varies throughout the roller range across Europe (Hebda et al. 2019), and dietary data on breeding populations in Serbia are lacking, the present study focuses on dietary composition analysis and determination of whether available prey within the breeding territory actually corresponds to consumed prey based on remains found in nest boxes.

MATERIALS AND METHODS

Fieldwork was conducted on European roller breeding territories within the Central Banat area in Vojvodina, in northern Serbia. Nest boxes (research plots) were placed within Novi Bečej, Kumane, Melenci, Taraš, Bašaid and Novo Miloševo municipalities. The entire area is mainly covered by crop fields that surround grassland fragments used for grazing. Roller diet analysis included available prey collected using pitfall and sweep net sampling, with some modifications according to Kiss et al. (2014) and consumed prey determined through identification of food remains collected from nest boxes according to Tidmarsh (2003). We chose twenty nest boxes for prey availability analysis. The study was conducted over a period of five consecutive years, starting in 2015. Each nest box was considered the center of a circular research plot (with a 200 m radius) which was divided into 20 × 20 m quadrants. Within each research plot three sides of different quadrants were randomly chosen by the QGIS (QGIS Development Team 2012) software to represent the transects (each 20 m in length) along which sweep net sampling was conducted. Pitfall traps (2 dl plastic cups) were placed in the ground along the same transects, following sweep net sampling: 5 pitfall traps filled with preservative (vinegar) were placed at a distance of 5 m apart. Therefore, a total of 15 pitfall traps were stored within each research plot. The traps remained active for one week at the beginning of July during high brood feeding rates. Rollers prefer larger arthropods (Cramp et al. 1993), therefore only specimens that exceed 1 cm in body length were included in the following analyses. Used prey was analyzed for three consecutive breeding seasons, starting in 2015. Due to unequal frequency of inhabiting nest boxes, we randomly chose the occupied ones that contained food remains (22 nest boxes per each season). We collected prey remains once, during the ringing of chicks in the beginning of July, so unnecessary disturbance was avoided. All specimens were identified taxonomically to the lowest possible level with the help of expert consultation and online databases, such as Alciphron for invertebrates (HabiProt ©2014-2021). Arthropods were mostly determined by wing characters, whereas identification of small mammalian specimens was based on cranial and dental characters. The species of small mammals were determined according to identification keys (Barčiová and Macholán 2009; Balaž et al. 2013). Vertebrate samples mostly consisted of whole specimens within available and used prey. Some samples of prey remain contained different body fragments of arthropods, therefore counting specimens was obtained by combining easily identifiable and unique body parts to complete one individual (e.g. four back legs of orthopterans were counted as two individuals) according to Tidmarsh (2003). Additionally, reference collection of whole specimens helped through the process of combining body parts. Most of the samples were identified to the species level, while some were identified to the genus, subfamily or family level.

Counting the specimens of available prey differed between applied methodologies. In the case of sweep net samples, the total number of specimens per plot was used.

Because some cups went missing as a result of cattle disturbances, the number of specimens captured within the plot was divided by the number of cups actually found in the field. Therefore, each nest box was represented by the sum of the total number of specimens (sweep method) and the average number of specimens per cup. Used prey was represented as the total number of counted specimens per nest box. Due to the different representation of counted specimens per plot (nest box) between applied methods, the numbers of specimens within prey categories were converted into percentages. Derived percentages of prey groups sampled by each method were equalized for the purpose of statistical analysis. For the following analyses, available and used prey were distributed between four main groups: Coleoptera, Orthoptera, other invertebrates, and vertebrates.

One-way permutational multivariate analysis of variance (PERMANOVA) using Bray-Curtis dissimilarity matrices was applied to distinguish whether there were differences in the composition of the available prey between the applied methods (Anderson 2001). Percentages of the main groups of prey (Coleoptera, Orthoptera, rest invertebrate and vertebrate) were used for analyses. Non-metric multidimensional scaling (NMDS) analysis based on Bray-Curtis dissimilarity was used to ordinate samples acquired using pitfall traps and sweep catches. The stress coefficient (s) evaluating the goodness of applied NMDS, was used to assess the quality of ordination: $s < 0.05$ indicates excellent representation, while $s < 0.2$ may indicate some misleading ordination (Clarke and Warwick 2001). All analyses were conducted in R version 3.5.3 (R Core Team 2019), package vegan (Oksanen et al. 2020).

Selection of each prey group was expressed as the relationship of used and available prey, calculated using Ivlev's electivity index (E):

$$E_i = (r_i - p_i)/(r_i + p_i)$$

where r_i is the percentage of prey i found in the nest box; p_i is the percentage of available prey i in the environment and E_i is the electivity index. Positive values indicate a prey preference while negative values indicate avoidance of prey (Ivlev 1961).

RESULTS

Total counts of all specimens sampled by pitfall traps and sweep net catches were used to compile the complete composition of available prey during the research period (Table 1). From the total number of specimens (1623), 39.4% were caught by sweep net sampling and 60.5% specimens were detected by pitfall traps.

As expected, prey sampled using pitfall traps contained higher amounts of Coleoptera specimens compared to sweep net catches, which contained significantly higher proportions of Orthoptera specimens (PERMANOVA: $P = 0.001$). The distribution of main prey types between the applied methods is shown in Table 2. Fully separated ellipses within the ordination plot (Fig. 1) confirmed significant differences in the proportions of available prey between the two applied methods. The stress score ($s = 0.001$) indicated excellent ordination representation.

Within the prey remains found in roller nest boxes, we identified 501 specimens (Table 3). Our results indicate that both available and consumed prey mostly consisted of arthropods within which Orthoptera and Coleoptera orders were dominant, compared to other invertebrate or vertebrate prey.

Ivlev's index values indicated prey preferences in the case of Coleoptera ($E = 0.41$) and vertebrates ($E = 0.22$). The other two groups, orthopterans and other invertebrates, showed negative values ($E = -0.23$ and -0.49, respectively).

DISCUSSION

During July, vegetation within the breeding territories is poor, due to grazing regimes and long periods of drought. However, the variety of prey found within the research plots during the short sampling period might indicate that prey availability is not limiting the reproductive success of rollers. Pitfall trapping resulted in a low proportion of orthopteran specimens, but sweep net catches complemented this deficiency. Therefore, both methods are important for assessing the complete composition of available prey within the breeding territory.

Based on our samples, Orthoptera and Coleoptera specimens were the most dominant prey compared to other groups within the roller's diet. These findings are in agreement with results of other studies (Sosnowski and Chmielewski 1996; Avilés and Parejo 2002; Kiss et al. 2014; Catry et al. 2019; Hebda et al. 2019). Although index value indicates negative selectivity for orthopterans, we assume that this type of prey is not negatively selected, but due to its easy digestibility the actual number of specimens within used

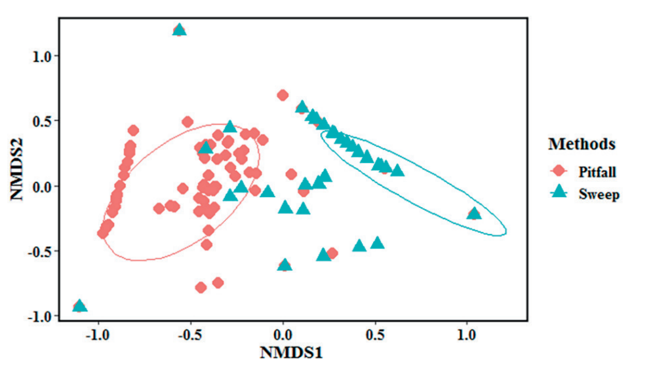

Fig. 1. Nonmetric multidimensional scaling (NMDS) graph showing differences in sampling methodologies for the available prey.

Table 1. Available prey items of European roller (*Coracias garrulus*) collected using pitfall traps and sweep net catches during five-year (2015–2019) period in Central Banat region (Serbia).

Prey item	N	Prey item	N	Prey item	N
COLEOPTERA	444	ORTHOPTERA	633	*Gnaphosa lucifuga*	4
Carabidae total	**240**	**Acrididae total**	**564**	*Gnaphosa muscorum*	1
Agonum sp.	3	Acrididae*	72	**Lycosidae total**	**126**
Anchomenus dorsalis	1	*Acrida ungarica*	22	*Hogna radiata*	79
Brachinus crepitans	2	*Aiolopus* sp.	2	*Hogna* sp.	43
Broscus sp.	2	*Aiolopus thalassinus*	74	*Pardosa palustris*	1
Carabus cancelatus	134	*Caliptamus italicus*	31	*Trochosa* cf. *ruricola*	1
Chlaenius festivus	13	*Chorthippus dichrous*	2	*Trochosa robusta*	1
Harpalus sp.	17	*Chorthippus dorsatus*	1	*Xysticus kochi*	1
Laemostenus sp.	5	*Chorthippus mollis*	1	HETEROPTERA	15
Laemostenus terricola	22	*Chorthippus oschei pusztaensis*	29	**Coreidae total**	**5**
Pterostichus cylindricus	33	*Chorthippus* sp.	2	*Coreus marginatus*	5
Pterostichus vernalis	8	*Dociostaurus brevicollis*	16	**Pentatomidae total**	**7**
Cerambycidae total	**55**	*Dociostaurus maroccanus*	1	*Dolycoris baccarum*	6
Carinatodorcadion aethiops	11	*Euchorthippus declivus*	267	*Pentatoma rufipes*	1
Carinatodorcadion fulvum	9	Gomphocerinae	7	**Scutelleridae total**	**3**
Neodorcadion bilineatum	31	*Omocestus petraeus*	1	*Eurygaster austriaca*	3
Pedestredorcadion scopolii	4	*Omocestus rufipes*	26	ISOPODA	36
Cetoniidae total	**4**	*Pseudochorthippus parallelus*	10	Isopoda *	11
Cetonia aurata	4	**Conocephalidae total**	**1**	**Armadillidae total**	**10**
Curculionidae total	**12**	*Conocephalus* sp.	1	**Trachelipodidae total**	**15**
*Curculionidae**	8	**Grylllidae total**	**39**	LEPIDOPTERA	11
Mecinus sp.	4	*Gryllus campestris*	37	Lepidoptera*	9
Dynastidae total	**42**	*Oecanthus pellucens*	2	Lycaenidae*	2
Pentodon idiota	42	**Phaneropteridae total**	**2**	GASTROPODA	12
Geotrupidae total	**9**	*Leptophyes albovittata*	2	MYRIAPODA	31
Geotrupes mutator	9	**Tettigoniidae total**	**27**	Lithobiidae	18
Histeridae total	**41**	Tettigoniidae*	15	Eupolybothrus	13
Hister quadrimaculinatus	41	*Platycleis affinis*	5	AMPHIBIA	50
Lucanidae total	**8**	*Roeseliana roeselii*	6	Anura*	5
Dorcus parallellipipedus	8	*Tessellana veyseli*	1	*Bombina variegata*	6
Meloidae total	**6**	HYMENOPTERA	238	*Pelobates fuscus*	33
Meloidae*	2	**Apidae total**	**230**	*Rana ridibunda*	5
Hycleus polymorphus	4	Apidae*	37	*Triturus vulgaris*	1
Rutelidae total	**9**	*Apis melifera*	193	REPTILIA	2
Anisoplia sp.	9	**Scoliidae total**	**8**	*Lacerta viridis*	2
Silphidae total	**15**	*Scolia sexmaculata*	6	MAMMALIA	6
Silpha carinata	3	*Scolia* sp.	2	*Microtus arvalis*	2
Silpha obscura	12	ARANEA	145	*Apodemus flavicollis*	1
Tenebrionidae total	**3**	Araneae*	14	*Sorex araneus*	3
Blaps sp.	3	**Gnaphosidae total**	**5**	**Total specimens**	**1623**

Notes. Sampling was conducted within 20 research plots (nest boxes) per season. Number of specimens (N) represents total number of counts obtained by both methods.

Table 2. Main groups of the available prey of European roller (*Coracias garrulus*) acquired by pitfall traps and sweep net catches during the five-year (2015–2019) research period in Central Banat region (Serbia).

Sampling method	Coleoptera (%)	Orthoptera (%)	Rest invertebrate (%)	Vertebrate (%)
Pitfall traps	44.7	13.83	34.84	6.57
Sweep net catches	4.42	74.04	21.53	/

prey was underestimated. The apparent avoidance of orthopterans may also be further explained by an underestimated number of specimens within the nest boxes, where chicks consume more orthopterans than coleopterans (Catry et al. 2019). During our ringing campaigns, loud picking chicks were periodically fed with orthopterans, which confirmed that whole specimens have been swollen. Consumption of whole orthopteran specimens resulted in less remains within the nest boxes, and higher amounts of coleopterans being detected. Furthermore, research based on video recordings and stable isotope analysis have confirmed that chicks consumed higher amounts of soft bodied orthopterans compared to coleopterans (Kiss 2014; Catry et al. 2019). During the growth phase, chicks need highly nutritious food, therefore orthopterans are a much better food choice than coleopterans (Beaulieu and Sockman 2014). Some research plots were located near apiaries, which resulted in higher amounts of Hymenoptera specimens within the available prey, compared to used prey. Therefore, the other invertebrate group (available prey) was mainly comprised of arthropods with high proportions of Hymenoptera that resulted in negative Ivlev index values. Although high proportions of hymenopterans were accessible within the field, the case of one Hymenoptera specimen found in one nest box throughout the whole research period confirms the conclusions of previous studies (Cramp 1998), that rollers sit and wait for their prey, avoiding fast flying arthropods. The total prey contained specimens that are considered to be agricultural pests (such as *Cetonia* and *Anisoplia*), indicating the important role of rollers as an ecosystem service (Orłowski et al. 2014). The presence of specimens belonging to Dytiscidae and Hydrophilidae found in nest boxes, but not within

Table 3. Total counts of used prey of European roller (*Coracias garrulus*) sampled throughout three breeding seasons (2015–2017) in Central Banat region (Serbia).

Prey item	N	Prey item	N	Prey item	N
COLEOPTERA	292	*Hydrochara caraboides*	4	*Gryllus campestris*	4
Coleoptera*	75	*Hydrophilus* sp.	8	HYMENOPTERA	1
Carabidae total	**34**	**Lucanidae total**	**9**	Hymenoptera*	1
Carabidae*	10	Lucanidae*	2	ARANEA	1
Carabus sp.	24	*Dorcadion* sp.	6	Aranea*	1
Cerambycidae total	**11**	*Platycerus caraboides*	1	GASTROPODA	43
Cerambycidae *	7	**Rutelidae total**	**28**	Gastropoda*	43
Carinatodorcadion aethiops	3	Rutelidae*	4	BIVALVIA	3
Neodorcadion bilineatum	1	*Anisoplia* sp.	24	Bivalvia*	3
Cetoniidae total	**44**	**Scarabaeidae total**	**8**	AMPHIBIA	14
Cetoniidae*	20	Scarabaeidae*	8	Anura*	12
Cetonia aurata	24	**Silphidae total**	**1**	*Pelobates fuscus*	2
Curculionidae total	**9**	Silphidae*	1	REPTILIA	7
Curculionidae*	4	**Tenebrionidae total**	**1**	Sauria*	1
Mecinus sp.	5	*Blaps* sp.	1	*Lacerta agilis*	2
Dynastidae total	**54**	ORTHOPTERA	135	Serpentes*	2
Pentodon idiota	54	Orthoptera*	16	*Natrix* sp.	2
Dytiscidae total	**5**	**Acrididae total**	**53**	MAMMALIA	5
Colymbetes fuscus	1	Acrididae*	53	*Microtus arvalis*	3
Dystiscus marginalis	4	**Tettigoniidae total**	**55**	*Apodemus flavicollis*	1
Histeridae total	**1**	Tettigoniidae*	55	*Sorex araneus*	1
Hister quadrimaculinatus	1	**Grylllidae total**	**11**	**Total specimens**	**501**
Hydrophilidae total	**12**	Grylllidae*	7		

Notes. Specimens were collected from 22 occupied nest boxes per each season. Number of specimens (N) was estimated from remains found.

available prey, was quite interesting. The life cycles of species from these families are tied to water. During the sampling period, in July, water bodies were lacking in the breeding territories, indicating that rollers travelled further in search of prey (Yee 2014; Kaboré et al. 2016). Longer search distances from breeding territories were made probably due to bad weather conditions (rainy days), when the activity of ground beetles and orthopterans was minimal. In agreement with our results, a small proportion of vertebrates in the roller's diet was also registered in other studies as well (Sosnowski and Chmielewski 1996; Catry et al. 2019; Hebda et al. 2019). The overlapping dominance of amphibian specimens within used and available vertebrate prey was caused by their activity during rainy days, when the consumption of arthropods was smaller. The wide range of prey comprising the roller's diet is proof that the roller is an opportunistic predator. That characteristic enables successful breeding within the poor, overgrazed, and dry pastures of Central Banat.

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