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What's for dinner? Diet and trophic niche overlap in two sympatric carnivores in agricultural and near-natural habitats in Bulgaria

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Abstract. The feeding behavior and trophic niche overlap between Stone Marten (*Martes foina* Erxleben, 1777) and Red Fox (*Vulpes vulpes* Linnaeus, 1758) in two regions of Bulgaria with different human influence were determined. A total of 1,440 fecal samples were collected from agricultural area in the Upper Thracian Plain and from near-natural habitat in Central Stara Planina Mts. In agricultural area, both predators preferred fruits in all seasons, while rodents dominated in winter diets in the mountain area. Our results showed that the Stone Marten and the Red Fox had high trophic niche overlap in both habitats.

Key words: *Vulpes vulpes, Martes foina*, agricultural region, mountainous region, trophic niche.

Introduction

Excluding the first mechanism for overcoming competition between species - habitat separation, they are forced to either change their diets or feeding time (Schoener, 1974). Feeding behavior is one of the most important research topics in the ecology of mammalian predators, having in mind that food utilization is considered to influence their population dynamics, social organization and inter-species relationships (Lodè, 1993; Padial et al., 2002; Balestrieri et al., 2011; Verdade et al., 2011), even the displacement of a species from its habitat (Remonti et al., 2012). Trophic resources, habitat characteristics and season were assumed the most important ecological niche dimensions in resource partitioning between species (Pianka, 1969; Prigioni et al., 2008). Thus coexisting species could reduce potential competition by utilizing different diets or changing daily activity patterns (Carvalho & Gomes, 2004; Hayward & Slotow, 2009; Karanth et al., 2017; Tsunoda et al., 2018, 2020). The more diverse diet based on the available food in the habitat is exploited, the better survival rate for carnivores is ensured (Wierzbowska & Skalski, 2010).

The Red Fox (*Vulpes vulpes*) and the Stone Marten (*Martes foina*) are among the most widespread medium-sized generalist carnivores (Prigioni et al., 2008; Bakaloudis et al., 2012; Main et al., 2020). They have different body size and social organization (Verdade et al., 2011; Zhou et al., 2008, 2010), but often they have sympatric distribution, with habitat and trophic spectrum overlap (Petrov et al., 2016; Lanszki et al., 2019). This suggests possible competition between the two species. Unfortunately, there aren't enough comparative studies, dealing with this issue. The researchers are mainly focused on one of the two species – the Stone Marten (Kyurkchiev, 2005, 2008; Georgiev & Raichev, 2009; Bakaloudis et al., 2012, 2015; Georgiev, 2013; Hisano et al., 2013; Peeva et al., 2018) or the Red Fox (Seebeck, 1978; Rosa et al., 1991) and rarely involve both sympatric predators (Vasileva et al., 2005; Prigioni

et al., 2008; Kirkova et al., 2011; Petrov et al., 2016). Rodents, insects and fruits were reported as the most preferable food for the two predators, while birds, small mammals or recourse to carrion were document-ted at lower rates.

Only few studies focused on the seasonal comparison of the diet of the Red Fox and the Stone Marten in different habitats (Prigioni et al., 2008; Papakosta et al., 2010; Petrov et al., 2015). In Bulgaria both species are widespread and co-exist in various habitats (Popov & Sedefchev, 2003). The present study aims to determine how their diet differ between agricultural region and mountainous region, among seasons, and if there is a trophic niche overlap.

Our hypothesis is that the Stone Marten and the Red Fox, utilizing anthropogenically modified habitats (agricultural regions), will show the ability to exploit food-types uniquely available around villages: fruit from orchards, grape and debris, contrasting with the diet recorded for these generalist carnivores in natural mountainous regions.

Materials and Methods

Study area

Two different habitats in Bulgaria were studied - agricultural and mountainous (Fig. 1). The agricultural regions were located at an altitude between 306-580 m a.s.l. and around different villages in the Upper Thracian Plain - Liaskovo, Malka Vereia, Parvenets and Hrabrino (Penin, 2007).

The mountainous habitat was located in the central part of Stara Planina Mts. as a part of southern slopes of "Central Balkan" National park. The limited road network in the beech forest between 800 and 1200 m a.s.l. served as a sampling transect. The conservation status of this territory implies a weak human presence. Only tourism, logging and hunting activities are carried out in it, which characterizes the region as "near-natural" habitat.

Sample processing

A total of 1440 fecal samples were collected - 360 per species from the two regions between September 1st 2021 and August 31st 2022. Each month 30 scats from the Red Fox and 30 from the Stone Marten were collected and placed in plastic bags.

After that each sample was placed in 70% ethyl alcohol for 24 hours, then washed through a sieve (0.5-mm mesh) and get to air-dry condition. After processing, the macro components were separated to determine the species composition of each sample by reference collection (Seebeck, 1978; Jedrzejewska & Jedrzejewski, 1998).

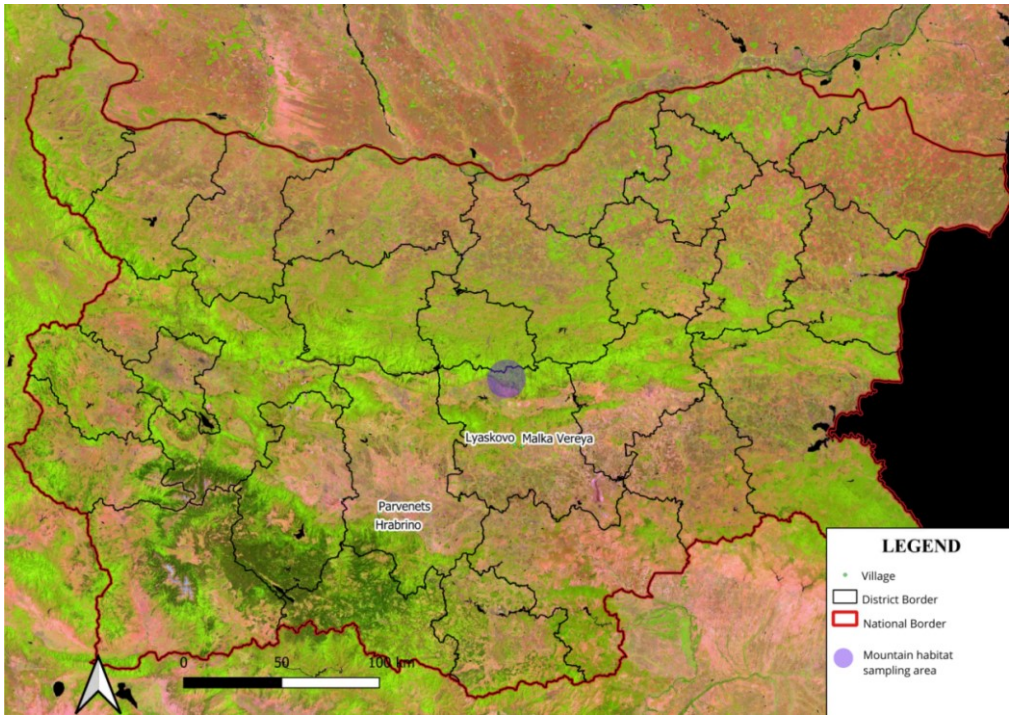

Fig. 1. Sampling areas in Bulgaria.

Statistical analysis

We defined 9 main food types in our analysis: fruits, domestic mammals, wild mammals, rodents, wild birds, domestic birds, amphibians and reptiles, insects and others (waste, grass, etc.). Determination of components was done to the lowest possible taxon. We calculated the relative frequency of occurrence (RFO %) of all food components and food groups by dividing the number of occurrences of a certain food component by the sum of occurrences of all food components. Trophic niche breadth (B) was calculated in accordance with Levins (1968):

$$\boldsymbol{B = 1/p_i^2},$$

where p_i is the relative frequency of occurrence of the i^{th} food component; and standardized across food types:

$$\boldsymbol{B_A = (B - 1)/(n - 1)},$$

ranging from 0 to 1, n is the total number of the resource taxa (Krebs, 1989).

The trophic niche overlap was calculated following Pianka (1973):

$$\boldsymbol{O_{jk} = \sum p_{ij} p_{ik} / \sqrt{\sum p_{ij}^2 \sum p_{ik}^2}},$$

where O_{jk} is the percentage overlap between species j and species k; p_{ij} and p_{ik} are the proportions of resource i in the diets of species j and species k.

The statistical package PAST v.4.0 was used for the statistical processing of the data (Hammer et al., 2001). A Shapiro-Wilk test was used for testing the normal distribution (Shapiro & Wilk, 1965). When comparing the trophic spectrum of the two species in the same region, the nonparametric Mann-Whitney U-test for independent pairs was applied, since the data lacked normal distribution (Fowler et al., 1998). Differences with $p<0.05$ [α=5%] were considered statistically significant.

Results

Diet content

We identified 539 dietary items in 360 Stone Marten's fecal samples from the agricultural areas of Central Bulgaria for the studied year (Table 1). The most common food components were fruits, followed by insects and rodents.

The identified food items in the Red Fox diet in the same region were 572 (Table 1). The predominance of fruit was again considerable, while rodents and insects were with almost equal consumption. We assume the orchards' availability in agricultural areas supply medium-sized carnivores with effortless food. During the cold months, fruits can also be obtained from the dumping grounds near the villages.

Stone Marten used mainly rosehips (*Rosa canina* L., 1753), grapes (*Vitis* sp. L., 1759) and medlar (*Mespilus* sp. L., 1753) among the fruits in the autumn-winter period. Rosehips were also the most consumed fruit from the Red Fox in autumn-winter, but a significant part of its summer diet consisted of the mulberry (*Morus* sp. L., 1753).

Common wood mouse (*Sylvaemus sylvaticus / flavicollis* Linnaeus, 1758), house mouse (*Mus musculus / macedonicus* Linnaeus, 1758) and Common vole (*Microtus arvalis / mystacinus* Pallas, 1778) were the rodents with highest occurrence in the Stone Marten's diet through the whole year. Rodents were more common in winter's diet when other used groups such as fruits and insects were with low availability. The same species of rodents presented in the Red Fox's diet throughout the year, but there was also a high rate of occurrence of edible dormouse (*Glis glis* Linnaeus, 1766).

Both carnivores consumed Coleoptera and Orthoptera insects during the spring-summer period. Remnants of Coleoptera were also found in the samples in February, which could be explained by the early warming in the beginning of 2022.

Similar results were found for the mountainous region. Fruits were again the most used food throughout the year for both species, followed by rodents and insects (Table 2). As expected, the appearance of fruits and rodents typical for mountainous regions was noticed. Medlar (15.72%), cherry (*Prunus avium/cerasus* Linnaeus, 1755; 11.59%) and blackberry (*Rubus* sp. Linnaeus, 1753; 7.07%) were the most consumed fruits in mountains by the Stone Marten through the year. The Red Fox used medlar (11.95%), rosehips (8.05%) and blackberry (5.75%). The most common rodents in the food of both species were wood mouse, common vole and the typical for forest mountain habitats bank vole (*Myodes glareolus* Schreber, 1780).

Coleoptera was again the most used insect order by both species. The beetles among other insects were consumed probably due to their abundance and the wide range of habitats they can be found (Mollov, 2008).

Table 1. Number of cases (n) and relative frequency of occurrence of food items in the faeces (180 for each period) of *Martes foina* and *Vulpes vulpes* in the agricultural regions of Central Bulgaria.

Dietary items	Autumn-Winter		Autumn-Winter		Spring-Summer		Spring-Summer		Total for the year		Total for the year	
	M. foina		*V. vulpes*		*M. foina*		*V. vulpes*		*M. foina*		*V. vulpes*	
	n	RFO%	n	RFO%	n	RFO%	n	RFO%	n	RFO%	n	RFO%
Fruits	**153**	**49.84**	**112**	**37.97**	**95**	**40.95**	**104**	**37.55**	**248**	**46.01**	**216**	**37.76**
Vitis sp.	40	13.03	25	8.47	3	1.29	3	1.08	43	7.98	28	4.90
Mespilus sp.	32	10.42	13	4.41	12	5.17	16	5.78	44	8.16	29	5.07
Pyrus sp.	1	0.32	2	0.68	0	0	0	0.00	1	0.18	2	0.35
Prunus domestica	3	0.98	12	4.07	5	2.15	12	4.33	8	1.48	24	4.20
Prunus avium	1	0.32	1	0.34	1	0.43	1	0.36	2	0.37	2	0.35
Ficus carica	2	0.65	6	2.03	1	0.43	0	0.00	3	0.56	6	1.05
Rosa canina	40	13.03	34	11.53	17	7.33	6	2.17	57	10.57	40	6.99
Morus sp.	0	0.00	0	0.00	39	16.81	47	16.97	39	7.23	47	8.22
Malus domestica	0	0.00	0	0.00	9	3.88	7	2.53	9	1.67	7	1.22
Rubus sp.	4	1.30	0	0.00	0	0.00	2	0.72	4	0.74	2	0.35
Crataegus monogyna	2	0.65	2	0.68	0	0.00	0	0.00	2	0.37	2	0.35
Unidentified fruits	28	9.12	17	5.76	8	3.45	10	3.61	36	6.68	27	4.72
Domestic mammals	**6**	**1.95**	**16**	**5.42**	**0**	**0.00**	**2**	**0.72**	**6**	**1.11**	**18**	**3.15**
Capra domesticus	6	1.95	7	2.37	0	0.00	1	0.36	6	1.11	8	1.40
Oryctolagus cuniculus	0	0.00	4	1.36	0	0.00	0	0.00	0	0.00	4	0.70
Felis silvestris catus	0	0.00	1	0.34	0	0.00	0	0.00	0	0.00	1	0.17
Ovis aries	0	0.00	4	1.36	0	0.00	1	0.36	0	0.00	5	0.87
Wild mammals	**6**	**1.95**	**36**	**12.20**	**6**	**2.59**	**13**	**4.69**	**12**	**2.23**	**49**	**8.57**
Lepus europaeus	1	0.32	5	1.69	2	0.86	2	0.72	3	0.56	7	1.22
Sus scrofa	4	1.30	20	6.78	0	0.00	0	0.00	4	0.74	20	3.50
Capreolus capreolus	1	0.32	11	3.73	4	1.72	11	3.97	5	0.93	22	3.85
Rodents	**48**	**15.63**	**58**	**19.66**	**14**	**6.03**	**54**	**19.49**	**62**	**11.50**	**112**	**19.58**
Sylvaemus sylvaticus/flavicollis	7	2.28	12	4.07	5	2.15	7	2.53	12	2.22	19	3.32
Mus musculus/macedonicus	26	8.47	25	8.47	5	2.15	34	12.27	31	5.75	59	10.31
Arvicolinae	11	3.58	9	3.0	1	0.43	7	2.53	12	2.23	16	2.80
Glis glis	4	1.30	12	4.07	3	1.29	5	1.81	7	1.30	17	2.97
Rattus norvegicus	0	0.00	0	0.00	0	0.00	1	0.36	0	0.00	1	0.17
Wild birds	**21**	**6.84**	**3**	**1.02**	**16**	**6.90**	**14**	**5.05**	**37**	**6.86**	**17**	**2.97**
Passeriformes	18	5.86	0	0.00	16	6.90	14	5.05	34	6.31	14	2.45
Unidentified birds	3	0.98	3	1.02	0	0.00	0	0.00	3	0.56	3	0.52
Domestic birds	**0**	**0.00**	**0**	**0.00**	**4**	**1.72**	**3**	**1.08**	**4**	**0.74**	**3**	**0.52**
Gallus gallus domesticus	0	0.00	0	0.00	4	1.72	3	1.08	4	0.74	3	0.52
Amphibians and reptiles	**0**	**0.00**	**0**	**0.00**	**2**	**0.86**	**5**	**1.81**	**2**	**0.37**	**5**	**0.87**
Serpentes undet.	0	0.00	0	0.00	2	0.86	2	0.72	2	0.37	2	0.35
Lacertilia - undet.	0	0.00	0	0.00	0	0.00	3	1.08	0	0.00	3	0.52
Insects	**56**	**18.24**	**38**	**12.88**	**89**	**38.36**	**71**	**25.63**	**145**	**26.90**	**109**	**19.06**
Coleoptera	36	11.73	28	9.49	85	36.64	68	24.55	121	22.45	96	16.78
Orthoptera, Caelifera	1	0.32	0	0.00	0	0.00	2	0.72	1	0.18	2	0.35
Unidentified insects	19	6.19	10	3.39	4	1.72	1	0.36	23	4.27	11	1.92
Other	**17**	**5.54**	**32**	**10.85**	**6**	**2.59**	**11**	**3.97**	**23**	**4.27**	**43**	**7.52**
Waste (Plastic remains)	3	0.98	13	4.41	1	0.43	3	1.08	4	0.74	16	2.8
Pebbles, grass	13	4.23	19	6.44	5	2.15	7	2.53	18	3.34	26	4.55
Egg shell	0	0.00	0	0.00	0	0.00	1	0.36	0	0.00	1	0.17
Others	1	0.32	0	0.00	0	0.00	0	0.00	1	0.18	0	0.00
Total	**307**	**100**	**298**	**100**	**232**	**100**	**277**	**100**	**539**	**100**	**572**	**100**

Table 2. Number of cases (n) and relative frequency of occurrence of food items in the faeces (180 for each period) of *Martes foina* and *Vulpes vulpes* in the mountainous regions of Central Bulgaria.

Dietary items	Autumn-Winter		Autumn-Winter		Spring-Summer		Spring-Summer		Total for the year		Total for the year	
	M. foina		*V. vulpes*		*M. foina*		*V. vulpes*		*M. foina*		*V. vulpes*	
	n	RFO%	n	RFO%	n	RFO%	n	RFO%	n	RFO%	n	RFO%
Fruits	**130**	**50.39**	**85**	**35.86**	**119**	**47.41**	**63**	**31.82**	**249**	**48.92**	**148**	**34.02**
Mespilus sp.	67	25.97	38	16.03	13	5.18	14	7.07	80	15.72	52	11.95
Prunus sp.	0	0.00	0	0.00	59	23.51	10	5.05	59	11.59	10	2.30
Rosa sp.	15	5.81	24	10.13	14	5.58	11	5.56	29	5.70	35	8.05
Morus sp.	0	0.00	0	0.00	21	8.37	11	5.56	21	4.13	11	2.53
Rubus sp.	0	0.00	1	0.42	0	0.00	0	0.00	0	0.00	1	0.23
Rubus sp.	24	9.30	14	5.91	12	4.78	11	5.56	36	7.07	25	5.75
Prunus spinosa	21	8.14	0	0.00	0	0.00	0	0.00	21	4.13	0	0.00
Prunus domestica	0	0.00	4	1.69	0	0.00	1	0.51	0	0.00	5	1.15
Prunus cerasifera	0	0.00	0	0.00	0	0.00	4	2.02	0	0.00	4	0.92
Ficus carica	1	0.39	1	0.42	0	0.00	0	0.00	1	0.20	1	0.23
Fagus sylvatica	0	0.00	2	0.84	0	0.00	1	0.51	0	0.00	3	0.69
Cornus mas	0	0.00	1	0.42	0	0.00	0	0.00	0	0.00	1	0.23
Unidentified fruits	2	0.78	0	0.00	0	0.00	0	0.00	2	0.39	0	0.00
Domestic mammals	**0**	**0.00**	**0**	**0.00**	**2**	**0.80**	**5**	**2.53**	**2**	**0.39**	**5**	**1.15**
Capra domesticus	0	0.00	0	0.00	2	0.80	5	2.53	2	0.39	5	1.15
Wild mammals	**1**	**0.39**	**18**	**7.59**	**11**	**4.38**	**5**	**2.53**	**12**	**2.36**	**23**	**5.29**
Lepus europaeus	1	0.39	0	0.00	6	2.39	0	0.00	7	1.38	0	0.00
Capreolus capreolus	0	0.00	11	4.64	5	1.99	4	2.02	5	0.98	15	3.45
Sus scrofa	0	0.00	6	2.53	0	0.00	1	0.51	0	0.00	7	1.61
Canis aureus	0	0.00	1	0.42	0	0.00	0	0.00	0	0.00	1	0.23
Rodents	**69**	**26.74**	**93**	**39.24**	**59**	**23.51**	**46**	**23.23**	**128**	**25.15**	**139**	**31.95**
Sylvaemus sylvaticus/flavicollis	13	5.04	29	12.24	13	5.18	12	6.06	26	5.11	41	9.43
Microtus arvalis/mystacinus	0	0.00	51	21.52	0	0.00	26	13.13	0	0.00	77	17.70
Myodes glareolus	15	5.81	8	3.38	6	2.39	5	2.53	21	4.13	13	2.99
Arvicolinae	38	14.73	0	0.00	38	15.14	0	0.00	76	14.93	0	0.00
Glis glis	3	1.16	5	2.11	2	0.80	3	1.52	5	0.98	8	1.84
Wild birds	**12**	**4.65**	**13**	**5.49**	**8**	**3.19**	**12**	**6.06**	**20**	**3.93**	**25**	**5.75**
Passeriformes	12	4.65	13	5.49	8	3.19	12	6.06	20	3.93	25	5.75
Domestic birds	**0**	**0.00**	**0**	**0.00**	**1**	**0.40**	**1**	**0.51**	**1**	**0.20**	**1**	**0.23**
Gallus gallus domesticus	0	0.00	0	0.00	1	0.40	1	0.51	1	0.20	1	0.23
Amphibians and reptiles	**1**	**0.39**	**0**	**0.00**	**0**	**0.00**	**0**	**0.00**	**1**	**0.20**	**0**	**0.00**
Salamandra salamandra	1	0.39	0	0.00	0	0.00	0	0.00	1	0.20	0	0.00
Insects	**43**	**16.67**	**24**	**10.13**	**51**	**20.32**	**64**	**32.32**	**94**	**18.47**	**88**	**20.23**
Coleoptera	42	16.28	24	10.13	51	20.32	62	31.31	93	18.27	86	19.77
Orthoptera, Caelifera	1	0.39	0	0.00	0	0.00	2	1.01	1	0.20	2	0.46
Other	**2**	**0.78**	**4**	**1.69**	**0**	**0.00**	**2**	**1.01**	**2**	**0.39**	**6**	**1.38**
Pebbles, grass	2	0.78	1	0.42	0	0.00	0	0.00	2	0.39	1	0.23
Waste (Plastic remains)	0	0.00	3	1.27	0	0.00	1	0.51	0	0.00	4	0.92
Egg shell	0	0.00	0	0.00	0	0.00	1	0.51	0	0.00	1	0.23
Total	**258**	**100**	**237**	**100**	**251**	**100**	**198**	**100**	**509**	**100**	**435**	**100**

Trophic niche breadth and Niche overlap

The trophic niche overlap between the Stone Marten and the Red Fox was high in both habitats, especially in agro-region (0.802; Table 3). We did not detect any significant differences in the diets of the two species in the agricultural region (Mann-Whitney U-test, U=503, z=0.054, p=0.96), as well as in the mountainous region (Mann-Whitney U-test, U=233, z=0.851, p=0.39), which is a result of the high niche overlap. Considerable dietary overlap indicates a high rate of competition, but is not definite proof of its existence (Papakosta et al., 2010).

Both species had wider trophic niche breath in agricultural region than in the mountainous region.

Table 3. Trophic niche breadth and Trophic niches overlap of the Red Fox (*Vulpes vulpes*) and the Stone Marten (*Martes foina*) in agricultural and mountainous region.

Region	Trophic niche breadth						Trophic niches overlap yearly
	M. foina autumn-winter	*M. foina* spring-summer	*V. vulpes* autumn-winter	*V. vulpes* spring-summer	*M. foina* yearly	*V. vulpes* yearly	
Agricultural region	0.36	0.30	0.84	0.37	0.29	0.41	0.80
Mountainous region	0.30	0.35	0.46	0.40	0.24	0.40	0.65

Discussion

In Bulgaria, only one study on the diet of the Stone Marten in the Upper Thracian Plain shows such a high use of fruits throughout the year (Georgiev, 2013). The majority of studies on the trophic spectrum of the two species in Bulgaria show that they use mostly rodents and only in their absence or low numbers they attack other animals or feed on carrion (Vasileva et al., 2005; Raichev & Georgiev, 2008; Kyurkchiev, 2008; Georgiev & Raichev, 2009; Kirkova et al., 2011; Hisano et al., 2013; Petrov et al., 2016). These authors consider insects and fruits as secondary food resources more frequently consumed in the spring to autumn period.

According to Pandolfi et al. (1996) even in the winter, fruits are important food resource for the Stone Marten and the Red Fox in the Mediterranean areas. It's a subject of future studies to determine whether the higher temperatures in winter in recent years lead to high presence of fruits in the food spectrum of both predators in Bulgaria.

Wild birds, wild mammals, domestic birds, amphibians and reptiles, waste, etc. were considered an additional food with significantly lower percentage in the samples of both species in both regions yearly. The wild and domestic mammals (mostly ungulates) found in the samples were considered as a sequence of scavenging. The presence of domestic birds, such as hens is extremely low. We support the opinion of Serafini & Lovari (1993), Coonan et al. (2000) and Jordano et al. (2007), that the so-called "harm" on poorly protected farms is far less than their benefit for the regulation of rodent populations (and endozoohory).

The agro-region offers a greater diversity of food items than mountains (Serafini & Lovari, 1993; Martin, 1994). The trophic niches of both carnivores were broader in the autumn-winter period, than in the spring-summer, more pronounced for the Red Fox's diet, which was previously found in other studies (Storch et al., 1990; Sidorovich et al., 2000; Padial et al., 2002; Papakosta et al., 2010). Overall, our results are consistent with others (Storch et al., 1990; Serafini & Lovari, 1993; Martin, 1994; Sidorovich et al., 2000; Padial et al., 2002, Papakosta et al., 2010).

Conclusions

Our study revealed *Vulpes vulpes* and *Martes foina* as opportunistic omnivores that resort to the most effortless and available food resources in the local environment. Despite the influence of local agricultural activities, the main food groups for both predators do not change. Only the species composition of consumed fruits and rodents switches. Their bad reputation as pests on poultry is not proven.

The possibility of competition between the two species in the studied regions is high. Therefore, we suggest that further studies need to be carried out in this particular area.

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