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Comparing the summer diet of stone martens (*Martes foina*) in urban and natural habitats in Central Bulgaria

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Understanding whether and how carnivores can adapt to urbanised environments is becoming increasingly important, as human populations grow and undeveloped landscape is lost. The stone marten (*Martes foina*) is often found in urban habitats across continental Europe, due to its flexible foraging behaviour. We compare the utilisation of food types for martens living in villages in a more populated region with that of martens living in a less populated mountainous forest region, over the summer fruiting season (May–July) of 2013, inferred from the analysis of 310 faecal samples. Fruits were the primary food for martens in both regions, but comprised a significantly greater proportion of the diet in villages. Invertebrates and rodents were utilised significantly more in the natural habitat. Garbage and domestic animals were rarely exploited in either region; however, village-dwelling martens appeared to rely heavily on being subsidised by cultivated fruits grown in gardens and orchards, and along the streets. We conclude that the stone marten is able to succeed in urbanised regions of Central Bulgaria by exploiting cultivated food resources, attributable to its flexible and adaptable generalist diet.

KEY WORDS: cultivated fruits, faecal analysis, food habits, urban adaptation, *Martes foina*.

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INTRODUCTION

As human populations grow and undeveloped landscape is lost, understanding whether, and how, carnivore species can adapt to urbanised environments is becoming increasingly important, not only from the standpoint of conserving these species, but also for avoiding human–wildlife conflict (Gehrt 2004). Furthermore, due to this habitat encroachment, more carnivores are increasingly using urban areas (e.g. Beckmann & Lackey 2008; Gehrt et al. 2011), where some are tolerated (e.g. foxes, raccoons, coyotes) more than others (e.g. bears, wolves; Bateman & Fleming 2012).

Many medium-sized carnivore species can adapt to urban environments, particularly those with flexible, generalist diets, able to consume non-natural food sources such as waste from households and restaurants, or able to exploit novel foraging opportunities (McKinney 2002; Bateman & Fleming 2012). To succeed, these species must also be able to find suitable shelter within human settlements without being overly conspicuous or causing disturbance, often also benefitting from reduced inter-specific competition (Gehrt et al. 2010). Species with a versatile, broad, generalist diet, that can use prey switching to optimise foraging efficiency, also have an advantage (Rosalino et al. 2014). By contrast, mesocarnivores avoiding urban areas tend to rely more exclusively on natural prey, being more strictly carnivorous ('urbanophobes', sensu Witte et al. 1985; 'urban avoiders', sensu McKinney 2006), where large and potentially dangerous carnivores provoke antagonistic responses from local residents (e.g. polar bears, lions; Saberwal et al. 1994; Clark 2003).

Few mustelids are adaptable enough to succeed in urban areas, many species being limited by exclusive carnivory. While omnivorous representatives, such as generalist and opportunistic badger species (*Meles* sp.), can live in semi-urban conditions (e.g. Kaneko et al. 2006, 2014; Davison et al. 2009), ultimately they become limited by suitable sites to construct dens (Davison et al. 2009). By contrast, the denning requirements of the stone marten (*Martes foina*) are less demanding (Newman et al. 2011), and due to their more flexible foraging behaviour than other Holartic martens (Zhou et al. 2011a), they are often found in urban habitats across continental Europe (Herr 2010). The stone marten is an opportunistic feeder (e.g. Rödel & Stubbe 2006), able to shift its diet from predominantly small rodents in winter to exploit the seasonal availability of fruit in summer (Baghli et al. 2002; see also Zhou et al. 2011b). In this study, we contrast the diet and utilisation of each main food category of stone martens living in and around larger villages in a more populated region in Central Bulgaria with those of stone martens living in forested habitat in a less populated region, focusing on the summer (fruiting) season, to complement previous work examining their winter diet (Hisano et al. 2013, 2014).

We use faecal analysis to examine the relative frequency and dry-weight distribution of prey species consumed (see Lanszki 2003; noting that faeces tend to become obscured by snow storms in this area, preventing this method from being used year-round; Hisano et al. 2013, 2014 used stomach contents for winter diet analysis). Our survey objective was simply to collect as many faecal samples as possible, representative of both habitat types, to permit analytical power in comparisons.

We predict that martens utilising anthropogenically modified habitats will exhibit the ability to exploit food-types uniquely available to them in villages, such as orchards and refuse, contrasting with the wild-type diet recorded contemporaneously for martens in natural, wooded, mountainous habitats.

MATERIALS AND METHODS

Study areas

In order to investigate the extent to which human activity affected marten summer diet, we undertook this study in two regions of contrasting population density, settlement type and extent of human modification of the landscape in Central Bulgaria (Fig. 1). The climate here is transitional between moderate–continental and continental–Mediterranean (Köppen climate classification: Cfa).

'Region 1' was sited around the large city of Stara Zagora with a population of 159,537 as of 2012 (42°24–34′N, 25°16–56′E). This encompassed an area of ca 190 km^2, comprised of hilly terrain with an elevation of 240–440 m above sea level (a.s.l.); mean annual temperature was 13.6 °C with a mean summer (May–July) temperature of 21.7 °C (data from Plovdiv; 185 m a.s.l.), mean annual precipitation was 544.8 mm with summer (May–July) precipitation of 103.5 mm (data from Sliven;

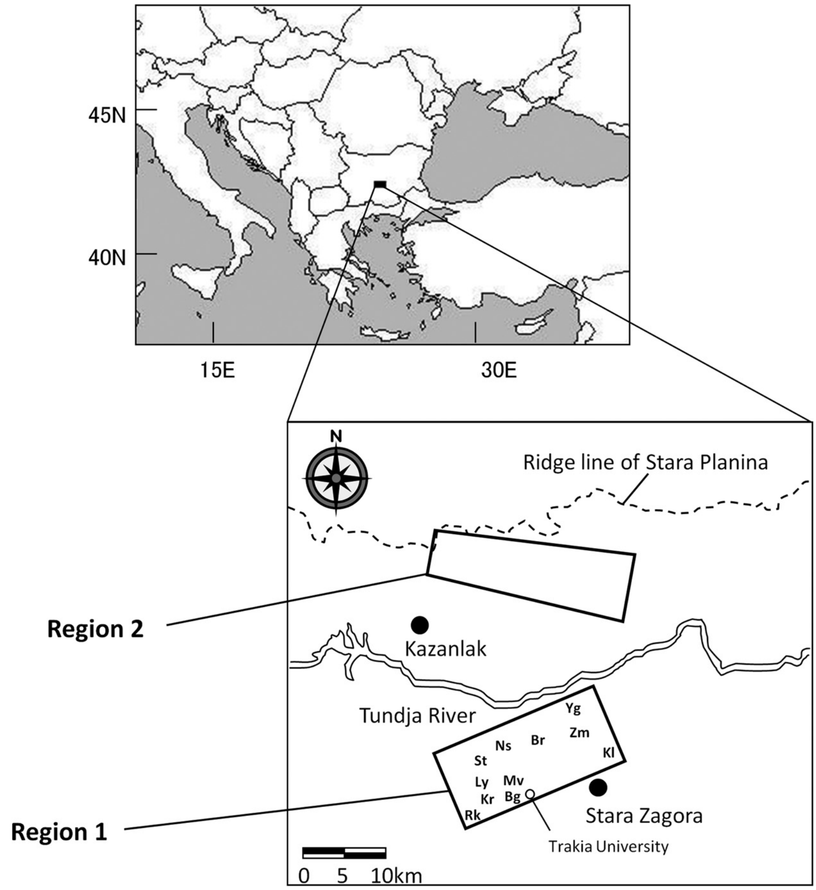

Fig. 1. — The study areas in Central Bulgaria. Habitat proportions were assessed from aerial photographs of the regions.
Location of the villages where samples were collected in Region 1: Bg – Bogomilovo, Kr – Kirilovo, Mv – Malk Vereya, Ns – Novo Selo, Rk – Rakitnitsa, Ly – Lyaskovo, Br – Borilovo, Yg – Yagoda, St – Sulitsa, Kl – Kolena and Zm – Zmeyovo.

Table 1.

The numbers of stone marten faeces collected in each region, listing the villages sampled in Region 1.

	Villages	May	June	July
Region 1	Bogomilovo	7	3	0
	Kirilovo	28	16	9
	Malka Vereya	0	44	18
	Lyaskovo	0	14	2
	Zmeyovo	2	0	0
	Kolena	1	1	1
	Novo Selo	4	9	0
	Borilovo	2	0	0
	Yagoda	0	0	1
	Rakitnitsa	0	1	5
	Sulitsa	0	0	2
	Trakia University	4	3	0
Region 2		37	65	31

257 m a.s.l.). Cultivated land covered 51.6% of this region (from quantitative assessment of aerial photographs with a scale of 1 to 150,000, using 1-km^2 grids), farming cereal crops and orchard fruit, with secondary oak (*Quercus* spp.) forests (31.8%). Village settlements occupied 16.6% of this region, and resident populations ranged from 88 to 1540, spaced, on average, at 4.5 km (SD = 1.88); in total, 6784 people inhabited this region, and population density was ca 36/km^2 as of 2012. We undertook scat collection in and around seven villages in this region, as well as on the campus of Trakia University (Fig. 1; Table 1).

'Region 2' (42°36–42′N, 25°25–46′E) was an area of ca 210 km^2 on the southern slopes of central Balkan Mountains (Stara Planina), north of Kazanlak (Fig. 1). Here the terrain was steep and cut by a multitude of short, steep valleys, with elevation ranging between 400 and 1370 m a.s.l. The mean annual temperature depended on the elevation; for example, – 0.1 °C was recorded from a summit 1200 m a.s.l. with annual precipitation of 980.9 mm (data from Shipka). More typically, at an elevation of 750 m, mean summer (May–July) temperature was 20.8 °C, with mean summer (May–July) precipitation of 196.7 mm (data from Borushtitsa). The mountains were covered with secondary forests of oak up to around 1000 m a.s.l., with primary forests comprised of European beech (*Fagus sylvatica*) at higher elevations (96.2%). There was also a small proportion of alpine grassland (3.5%) above the tree-line, around mountain summits. This region included no cultivated land, with only three hamlets (population ranging from 13–28) which comprised only 0.3% of the area; in total 59 people were resident and population density was ca 0.3/km^2 as of 2007. These two regions lie on opposite sides of the Tundzha River valley, approximately 14 km apart.

Sample collection

Faecal samples were collected during the fruiting season from May to July of 2013. From power analysis (see below), our objective was to attempt to collect at least 30 samples per month in each region; thus, we used collection protocols in each region appropriate for optimising the number of samples that could be collected per unit survey effort. Note that the distribution of scats in each region and how this might relate to local marten density was not an objective of this study.

Due to the extensive private ownership of land in Region 1, we collected faecal samples opportunistically from all villages listed in Fig. 1, 3 times a week. We systematically surveyed abandoned houses/barns, attics, churches, cemeteries, gardens and along village streets as well as on the Trakia University campus. Faeces were also collected from orchards and forests adjacent to these villages (within ca 500 m); however, none were found on pastures, grasslands or arable land.

In order to collect substantial samples of faeces in Region 2, we surveyed natural habitat over 5 m adjacent to four paved (tar-macadam and gravel) forest roads as well as non-paved forest small paths/trails twice a week, each transect averaging ca 15 km; both sides of each roads were surveyed.

Although the accuracy of the visual identification of marten scats has been questioned (e.g. Birks et al. 2005), surveys for martens based on visual and olfactory diagnostics have been used reliably (e.g. O'Mahony et al. 2006), and for other generalist mustelids as well (e.g. Zhou et al. 2015a, 2015b). We were confident in this technique, assisted by an expert marten hunter (co-author Evgeniy Raichev), and did not feel that recourse to genetic methods was necessary for this study (see Davison et al. 2002). Importantly, marten scats smell 'sweet' (i.e. like fermenting fruit mixed with soy sauce/sour wine), leading to the historical distinction between 'sweet-cats/martens' and 'foul-cats/martens'; the latter being the origin of the linguistic corruption to pole-cat (i.e. those similar but rank-smelling mustelids; see Encyclopædia Britannica [Internet] c2014).

We thus identified stone marten faeces according to diameter, shape, texture and their characteristic sweet odour, taking secondary support from nearby tracks, foraging signs and the presence of marten hair in exceptional cases (following the general methods of Zhou et al. 2008, 2011b; Virgós et al. 2010).

Both red fox (*Vulpes vulpes*) and European polecat (*Mustela putorius*) were sympatric with stone martens in these regions; however, the faeces of both species smell rank, a key diagnostic feature supplemented by differences in typical faecal diameter [faeces of martens (diameter: ca 10–15 mm) were smaller than those of red fox but usually larger than those of European polecat], which allowed us to differentiate scats with confidence. Additionally, samples are misidentified more often when target species are less abundant (Prugh & Ritland 2005; Kelly et al. 2012). In this study area, the stone marten was one of the most common carnivores, further enhancing our sampling accuracy. Faeces that could not be attributed absolutely to martens were excluded from the analysis.

In addition to the sympatric mesocarnivores listed in Region 1, the pine marten (*M. martes*) also occurred in Region 2 (being absent in Region 1). In order to minimise the potential for misidentification (where visual and olfactory diagnostic criteria are hard to disambiguate), we collected faeces only from an elevation below 400–1000 m a.s.l., where there was no evidence of pine marten populations. In Central Bulgaria, pine martens inhabit the zone of beech forests to the upper forest boundary over 1500 m a.s.l. on Balkan Mountain summits (Popov & Sedefchev 2003).

Faecal analysis

Following the methods of Jędrzejewska and Jędrzejewski (1998; modified by Zhou et al. 2011b), faecal samples were washed through a sieve (0.5-mm mesh) with water. We sorted faecal items under a 10× magnifying lens and identified contents to at least the level of order, usually family or species (each termed as a food 'item'), using morphological criteria (Zhou et al. 2008) such as teeth, vertebra, hairs, feathers, elytra, fruit cuticles and seeds, with reference to collections of specimens from the study area and the Laboratory of Zoology and Anatomy at Trakia University. Faecal items were air-dried at room temperature for at least 2 weeks, and then weighed.

These contents were divided into 11 predominant categories: rodents, hares, domestic mammals, wild birds, domestic birds, hen's eggs, invertebrates, reptiles and amphibians, fruits, grasses and artificial materials (that is, the 'items' comprised 'categories'). We then calculated marten diet composition according to three indices:

(1) The percentage frequency of occurrence [PFO (%): (the number of occurrences of each faecal item/the total number of faecal items) × 100];
(2) The percentage of dry weight [PDW (%): (dry weight of each faecal item/dry weight of the one faeces) × 100]; and
(3) The percentage of total consumed biomass [TCB (%): (the sum of the estimated consumed biomass of a given faecal item in all faeces/total estimated consumed biomass of all faecal items) × 100].

For PDW and TCB indices, we weighed the dry matter for each category (but not each item separately, except for fruits, due to the quantities involved). We acknowledge that scats collected in series can contain common contents from a single large meal, or similar locally common small items, but small commonly eaten items can be overestimated (Atkinson et al. 2002; Zhou et al. 2011b). We therefore interpret our results accordingly.

To estimate consumed biomass, we multiplied dry weights of each faecal item (except artificial materials such as plastic food wrappings and aluminium foil) by coefficients of digestibility provided for martens by Jędrzejewska and Jędrzejewski (1998); small rodents × 23, medium-sized mammals (hares) × 50, domestic ungulate carcasses × 118, birds × 35, reptiles and amphibians × 18, insects × 5, fruits × 33 [modified for this study: using the average fresh weight of edible flesh per cherry (the main fruit species consumed)/average dry weight per cherry, derived from stone marten faeces] and grasses × 14 (see also Lanszki et al. 2009). We also calculated trophic niche breadth among the 11 main faecal categories using Levins' standardised equation (Krebs 1989) and Pianka's similarity index (Pianka 1973).

Statistical analysis

To establish that adequate sample sizes had been attained per region, per month, we calculated the diversity of prey in faeces using the Brillouin index (adopted from Glen & Dickman 2006; Hass 2009), according to the equation:

$$H_b = \ln N! - \Sigma \ln n_i!/N$$

where H_b represents the diversity of prey in the sample, N represents the total number of individual prey taxa in all samples and n_i represents the number of individual prey taxa in the ith category (Brillouin 1956; Magurran 1988). Following Hass (2009), the 11 main food categories substituted for 'taxa' in this calculation. By simulating sampling over a range of one to 80 samples (in increments of three), a curve was plotted from which the adequacy of sampling effort could be assessed from whether an asymptote was reached, indicating that the addition of three more samples conferred < 1% incremental improvement. The equation was run 10,000 times to calculate a median and 95% confidence interval.

To detect differences per main food category between the two regions, we applied a G-test with Yates' correction to the PFO data and Mann–Whitney U test to the PDW. To assess the overall differences in the PFO and the PDW between Region 1 and Region 2, as well as among months, we then conducted a permutational multivariate analysis of variance (PERMANOVA) using the Adonis function of R package vegan (Oksanen et al. c2015) with "Chao index". All the statistical analyses were performed using R 2.13.2 (R Development Core Team 2011).

RESULTS

Adequacy of sample size

We analysed 177 faeces from Region 1 and 133 from Region 2. Diversity curves reached an asymptote and the incremental change declined to less than 1% from 39 samples onwards for Region 1 and at 36 for Region 2 (Fig. 2); our sample sizes per

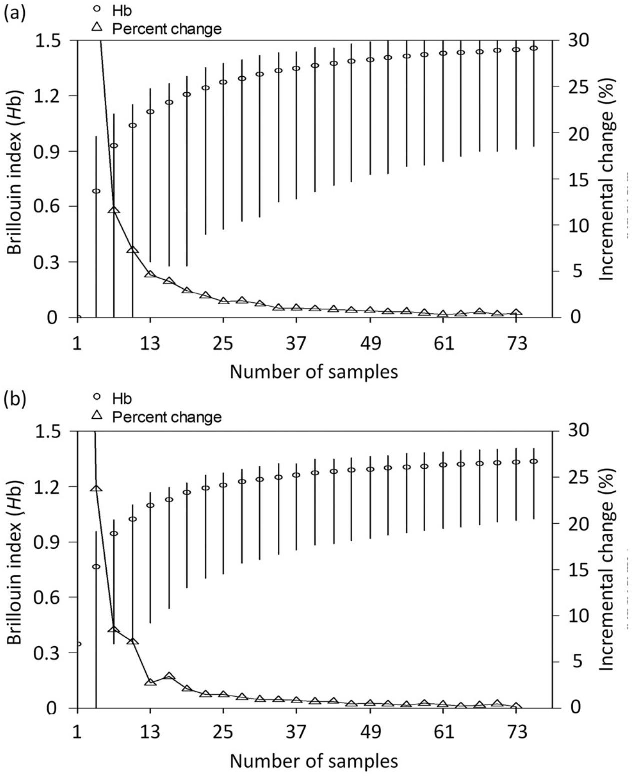

Fig. 2. — Diversity (H_b: Brillouin index) curves and incremental change curves for faecal samples in (a) Region 1 and (b) Region 2. Median and 95% confidence intervals obtained by re-sampling with replacement 10,000 times.

region and per month were thus adequate to investigate differences in the metrics of dietary composition, except for July in Region 2, where we were only able to find 30 samples. This was still > 80% of the required number, and thus we retain modest confidence in the veracity of this monthly pairing.

Categorical comparison of marten diet between regions

During these summer months, martens consumed predominantly fruits in both regions (Region 1: PFO = 48.6%, PDW = 64.6%; Fig. 3, TCB = 80.4%; Region 2: PFO = 37.0%, PDW = 57.7%; Fig. 3, TCB = 89.4%). Both the PFO and PDW indices indicated, however, that fruit contributed a significantly greater proportion of the diet in Region 1 (*G*-test: $G = 6.92$, df = 1, $P < 0.01$; Mann-Whitney *U* test: $z = 2.12$, $U = 9360$, $P < 0.05$; Fig. 3), although this tendency was not apparent from TCB. In both regions, the principal fruit consumed was cherries (*Cerasus* spp.), followed by mulberries (*Morus nigra* and *M. alba*) and plums (*Prunus cerasifera*) (see Tables 2 and 3). The PFO, PDW and TCB indices also showed that invertebrates were important in both regions (Tables 2 and 3), although overall invertebrate consumption was significantly

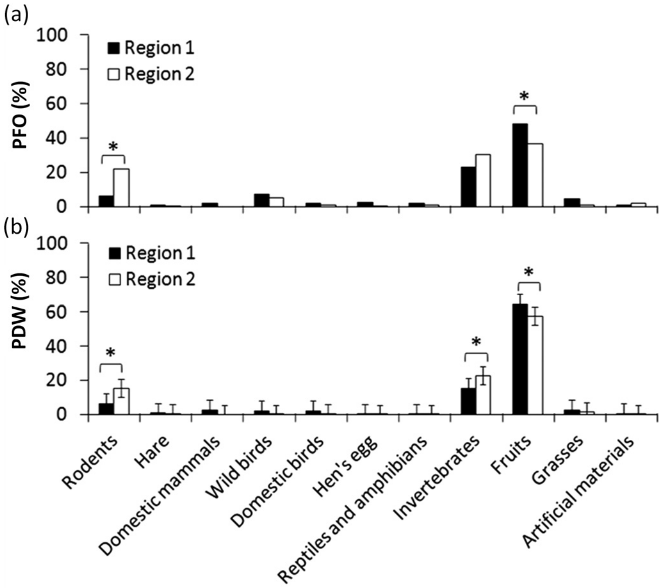

Fig. 3. — Food categories from stone marten faeces collected in villages (Region 1) and in mountainous forest habitat (Region 2) in Central Bulgaria, pooled across the study period (May–July, 2013): (a) the percentage frequency of occurrence (PFO), and (b) the percentage of dry weight (PDW). $^*P < 0.05$: G-test for the PFO and Mann–Whitney U test for the PDW.

greater in Region 2 (G-test: $G = 3.8$, df = 1, $P = 0.05$; Mann–Whitney U test: $z = -2.45$, $U = 9124$, $P < 0.05$; Fig. 3), particularly for the PFO of Coleoptera (mainly nocturnal Carabidae spp. inhabiting forest habitat; G-test: $G = 7.6$, df = 1, $P < 0.01$). Based on the PFO and PDW indices, significantly more rodents were eaten in Region 2, from both quantitative and frequency indices (G-test: $G = 28.6$, df = 1, $P < 0.01$; Mann–Whitney U test: $z = -3.53$, $U = 8323$, $P < 0.01$; see Fig. 3).

Overall comparison of marten diet between regions

The extent to which marten diet differed overall between the two regions was the product of the specific diet category differences detailed above. When analysed as a gross mean measure, a marginal difference was evident in the PFO (PERMANOVA: df = 1, $F = 6.04$, $R^2 = 0.42$, $P = 0.09$), although this was not significant in the PDW (PERMANOVA: df = 1, $F = 2.45$, $R^2 = 0.46$, $P = 0.22$). Analysing each month separately, dietary differences were implied in the PFO (PERMANOVA: df = 1, $F = 5.38$, $R^2 = 0.37$, $P = 0.09$), while not significant in the PDW (PERMANOVA: df = 1, $F = 0.45$, $R^2 = 0.17$, $P = 0.54$). Trophic niche breadths, pooled across month, were 3.31 for Region 1 and 3.53 for Region 2, and dietary similarity between the two regions was high at 0.91.

Table 2.

The percentage frequency of occurrence (PFO), the total consumed biomass (TCB) and the percentage of dry weight (PDW) of food items occurring in the faeces of stone martens collected in Region 1 villages, in central Bulgaria, 2013. A hyphen (-) indicates where TCB and PDW were not calculated to the species level (except for fruits), while vacant cells indicate that no item occurred.

Food items	May (*n* = 48)			June (*n* = 91)			July (*n* = 38)		
	PFO (%)	TCB (%)	PDW (%)	PFO (%)	TCB (%)	PDW (%)	PFO (%)	TCB (%)	PDW (%)
Wild mammals	17.3	22.3	31.5	2.7	2.3	2.5	3.5	3.6	5.3
Rodentia spp.	13.9	17.8	15.7	2.3	2.3	2.5	2.9	3.6	5.3
Lagomorpha									
Lepus capensis	2.5	4.5	15.7						
Domestic mammals	5.3	13.5	8.3	0.6	1.3	1.1	1.5	< 0.1	< 0.1
Artiodactyla									
*Ovis aries**†	1.3	–	–						
Carnivora									
Felis catus and/or *Canis familiaris**†	3.8	–	–	0.6	1.3	1.1	1.5	< 0.1	< 0.1
Wild birds									
Unidentified	6.3	1.5	2.2	8.2	2.9	2.9	1.5	0.8	0.5
Domestic birds									
Galliformes									
*Gallus gallus domesticus**	3.8	3.3	4.2	1.2	0.2	1.2	1.5	2.1	2.6
Hen's egg*	3.8	2.7	2.1	2.3	< 0.1	< 0.1			
Reptiles									
Squamata spp.				1.8	< 0.1	0.1	2.9	1.2	1.2
Invertebrates	22.7	1.3	15.6	25.3	1.4	17.6	17.5	0.9	10.5
Orthoptera									
Gryllotalpa gryllotalpa	1.3	–	–	4.1	–	–			
Unidentified				2.3	–	–	4.4	–	–
Coleoptera									
Carabus and/or *Procerus* spp.				1.2	–	–	1.5	–	–
Lucanus cervus							1.5	–	–
Coccinella septempunctata				0.6	–	–			
Unidentified	17.7	–	–	10.5	–	–	10.3	–	–
Hemiptera									

(*Continued*)

Table 2.

(*Continued*)

Food items	May (n = 48)			June (n = 91)			July (n = 38)		
	PFO (%)	TCB (%)	PDW (%)	PFO (%)	TCB (%)	PDW (%)	PFO (%)	TCB (%)	PDW (%)
Cicadoidea sp. (larvae)				0.6	–	–			
Blattodea spp.				1.2	–	–			
Hymenoptera sp.				0.6	–	–			
Other unidentified insects	2.5	–	–	3.5	–	–			
Fruits	32.0	53.4	40.2	51.4	91.5	73.2	63.2	89.7	75.4
Rosales									
*Prunus cerasifera**							7.4	17.2	11.2
Cerasus spp.*	16.5	34.4	16.3	25.1	60.4	35.7	23.5	44.5	30.1
*Fragaria vesca**	1.3	0.2	0.3				1.5	0.9	0.7
Moraceae									
Morus nigra and *M. alba**	13.9	18.4	16.3	29.2	30.2	35.3	29.4	24.0	27.4
Vitaceae									
Vitis sp.*							7.4	1.7	
Poaceae sp.	1.3	0.1	< 0.1						
Unidentified	2.5	0.3	2.1	1.2	< 0.1	2.3	2.9	1.5	3.4
Grasses									
Monocotyledoneae spp.	5.1	2.0	7.0	2.9	0.3	0.3	5.9	1.8	4.5
Artificial materials	2.7	< 0.1	0.5	0.7	< 0.1	0.1			
Plastic envelope*	1.3	–	–	0.6	< 0.1	0.1			
Human hair*	1.3	–	–						
Levins' index	5.26			2.94			2.28		

* Human-subsidised food; †considered as carcass.

Monthly changes in marten diet in each region

Taking each month in turn, in May the total biomass of fruits consumed in Region 1 (TCB = 53.4%) was slightly greater than that of vertebrate prey, which was the sum of mammals, birds, eggs, reptiles and amphibians (43.3%; Table 2). The TCB of vertebrate prey then declined in June (6.8%) and July (7.6%) in Region 1, while that of fruits increased substantially during the same period (June: 91.5%, July: 89.7%; Table 2). In Region 2, the TCB of fruits was much greater than that of vertebrate prey between May (90.3% for fruits; 8.3% for vertebrate prey) and June (94.2% for fruits;

Table 3.

The percentage frequency of occurrence (PFO), the total consumed biomass (TCB) and the percentage of dry weight (PDW) of food items occurring in the faeces of stone martens collected in the mountainous forest habitat of Region 2, in central Bulgaria, 2013. A hyphen (-) indicates where TCB and PDW were not calculated to the species level (except for fruits), while vacant cells indicate that no item occurred.

Food items	May (*n* = 37)			June (*n* = 65)			July (*n* = 31)		
	PFO (%)	TCB (%)	PDW (%)	PFO (%)	TCB (%)	PDW (%)	PFO (%)	TCB (%)	PDW (%)
Wild mammals	32.0	8.0	21.3	16.8	4.2	8.3	35.7	21.9	25.9
Rodentia spp.	30.8	8.0	21.3	14.8	4.2	8.3	17.5	14.2	22.9
Lagomorpha									
Lepus capensis							1.8	7.7	3.0
Wild birds									
Unidentified				8.2	0.3	0.2	3.5	< 0.1	< 0.1
Domestic bird									
Galliformes									
*Gallus gallus domesticus**	1.3	< 0.1	< 0.1				1.8	2.2	3.0
Hen's egg*	1.3	0.3	0.1						
Reptiles									
Squamata sp.							1.8	1.0	1.1
Amphibian									
Anura sp.				0.8	< 0.1	0.1			
Invertebrates	28.0	1.4	20.5	27.1	1.3	22.9	43.4	1.9	26.4
Orthoptera									
Gryllotalpa gryllotalpa									
Unidentified				2.5	–	–	7.0	–	–
Coleoptera									
Carabus and/or *Procerus* spp.	1.3	–	–	5.7	–	–	7.0	–	–
Lucanus cervus				0.8	–	–			
Coccinella septempunctata				0.8	–	–			
Cerambycidae spp.							5.3	–	–
Unidentified	20.5	–	–	17.2	–	–	24.6	–	–
Blattodea sp.				0.8	–	–			
Other unidentified insects	3.8	–	–	1.6	–	–	1.8	–	–
Pulmonata sp.	1.3	–	–						

(*Continued*)

Table 3.

(*Continued*)

Food items	May (n = 37) PFO (%)	May TCB (%)	May PDW (%)	June (n = 65) PFO (%)	June TCB (%)	June PDW (%)	July (n = 31) PFO (%)	July TCB (%)	July PDW (%)
Fruits	32.0	90.3	56.9	45.8	94.2	68.5	24.5	72.5	37.0
Rosales									
Prunus cerasifera							7.0	24.3	10.7
Cerasus spp.	32.1	90.3	56.9	29.5	77.7	51.2	7.0	34.7	13.3
Moraceae									
Morus nigra and *M. alba*				17.2	16.5	17.2	10.5	13.4	13.0
Grasses									
Monocotyledoneae spp.							3.5	0.5	6.7
Artificial materials	5.3	< 0.1	1.2						
Plastic envelope*	2.6	–	–						
Fragment of plastic*	1.3	–	–						
Aluminium foil*	1.3	–	–						
Levins' index	3.49			3.12			3.47		

* Human-subsidised food.

4.5% for vertebrate prey). The TCB of vertebrates in Region 2 then increased in July (72.5%), while that of fruits declined (25.1%; Table 3). Dietary similarity between the two regions in July was 0.68, which was notably lower than other combinations between regions and months (0.87–0.97).

DISCUSSION

We discovered that in central Bulgaria, in both wild and human-occupied regions, fruits were the predominant food category in the summer diet of the stone marten, comprising > 80% of TCB, supplemented by invertebrates and rodents. Based on robust statistical power (177 faecal samples in Region 1 and 133 in Region 2), we observed significant differences in distinct food categories between regions, contributing to marginal evidence of overall dissimilarity. Most notably, fruit PFO and PDW were significantly higher in the village-dominated Region 1, compared to the natural habitat of Region 2. The same genera of fruits were eaten in both regions. A similar bias towards fruit has been noted for stone marten populations in other areas of Central Europe, for example Poland (Posłuszny et al. 2007), Germany (Rödel & Stubbe 2006) and Luxembourg (Baghli et al. 2002), although a rodent-biased diet has been observed elsewhere, such as Portugal (Carvalho & Gomes 2004).

Invertebrates made the second highest contribution to overall diet (PFO and PDW) in both regions, although TCB was low for this faecal category (noting that TCB was biased by the water content of food types consumed). This resonates with the findings of Rödel and Stubbe (2006), working in wooded and agricultural area in Germany, who also observed a substantial utilisation of invertebrates in summer. Indeed, these three major food categories fit the profile of marten diets generally, as reviewed by Zhou et al. (2011a). Invertebrates comprised a greater proportion of overall diet in Region 2, attributable to the greater consumption of Carabidae spp. Many carabids are sensitive to habitat fragmentation (Niemelae 2001), which could potentially lead to them be less available in the human-occupied and cultivated Region 1.

The residual balance of diet composition, not comprised by fruits and invertebrates, was derived from wild rodent prey – more so in Region 2 than in Region 1, as evidenced in PFO, PDW and TCB indices.

Maintaining a steady energy supply is crucial for small mustelids, such as martens, because they carry relatively little body fat (to remain agile hunters; Newman et al. 2011) while losing heat rapidly through their elongate bodies (Brown & Lasiewski 1972; King & Powell 2007). This is achieved through trophic adaptability, where Zhou et al. (2011b) highlighted that marten diets often do not simply track primary resource abundance, but are a function of the relative availability of alternative food types. For example, the dietary niche breadth of American marten (*M. americana*) has been found to associate negatively with absolute prey abundance (Thompson & Colgan 1990).

In the absence of environmental food abundance metrics, we speculate on (not mutually exclusive) explanations for how these dietary differences could arise between regions in our study:

(i) Invertebrates and rodents may have been more easily available in Region 2 than Region 1; although circumstantial evidence of the attempts by village residents and farmers to control populations of house mice (*Mus musculus*) and Norwegian rats (*Rattus norvegicus*) implies that, although different species from the natural region, rodents were abundant in Region 1.

(ii) The composition of natural diet may have been skewed towards fruits in Region 1 because of the ready availability of fruit trees grown in gardens and orchards and along the roadsides in villages, compared to the greater dispersion of fruit trees in native forest habitats/Region 2. Further work will, however, be required to relate food categories consumed to food availability, quantitatively (e.g. Zhou et al. 2011b).

(iii) The observed selectivity for fruit, per se, may be a response to its appealing taste (i.e. sweetness), and to nutritional preference (Bermejo & Guitian 2000) – see Zhou et al. (2011b). Thus, fruit would be selected over other prey, preferentially.

(iv) On balance, consuming fruit may prove a less hazardous option than actively hunting rodent prey, where injury could result from chasing and falling, etc., or if larger rodent prey (rats, squirrels) defend themselves (see Zhou et al. 2011b). Consequently, there could be risk avoidance benefits to consuming fruit, preferentially. Linked to this, Kirkova et al. (2011) describe the parasites of stone marten in Bulgaria (especially enzootic *Toxocara* sp. and *Trichinella* sp.), for which rodents are intermediate hosts.

Outside of the summer fruiting season, Hisano et al. (2013, 2014) report from stomach content analysis (scats being concealed by snow storms in the Bulgarian winter) that martens in both regions consumed similar rodent-biased diets, illustrating their dietary flexibility. Zhou et al. (2011b) found a similar seasonal pattern for yellow-throated martens (*Martes flavigula*) in sub-tropical forest, which shifted their diet towards the maximum utilisation of small mammals, with no fruit consumption, when both fruits and small mammals were least abundant in the environment in winter.

Further evidence of how stone martens can modify natural diet in order to succeed in urban environments comes from reports of them scavenging on refuse (Lanszki 2003), or relying upon poultry and eggs (Lanszki et al. 2009). In our study, refuse made very little contribution to their diet; rather, it appears that the subsidy of cultivated fruits was exploited by village-dwelling martens. Szöcs and Heltai (2007) made a similar observation for a stone marten population in Budapest, where they favoured habitat with abundant fruit trees (Tóth et al. 2009). A study of the spatial use of habitats in German villages also found that stone martens preferred orchards (Herrman 1994).

Our observation that stone marten scats tended to be localised in different villages in different months, despite our searching village sites consistently throughout the study, was also intriguing. We have no empirical evidence with which to evaluate this at this time; however, we note that Pulliainen (1984) reports, anecdotally, that martens may congregate temporarily when prey is abundant – a phenomenon he termed 'martelism' (discussed in Newman et al. 2011). Our future research will seek to correlate fruit ripening and harvesting practices in these villages with peak marten presence.

To conclude, our data evidence stone martens to be flexible, adaptable and opportunistic generalist feeders, in Central Bulgaria. In summer they exploit the availability of fruits, especially cultivated fruit in village regions, supplemented by invertebrate and rodent prey, but resume greater reliance upon rodents in winter. This trophic adaptability facilitates their success in human-modified (village) landscapes. Future research will extend the duration over which data are available, although we feel it is unlikely this will expose any major differences in overall regional diet. More importantly, we aim to relate dietary consumption patterns to regional food abundance, as this study continues.

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No potential conflict of interest was reported by the authors.

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