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Diet of *Sorex coronatus* in the western Pyrenees

Enrique CASTIÉN and Joaquim GOSÁLBEZ

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The diet of *Sorex coronatus* (Millet, 1828) was studied by the analysis of digestive tracts from 178 individuals collected in Quinto Real Massif, western Pyrenees (north of the Iberian Peninsula). In total, 28 different types of food were determined. The most important prey species, as determined by numerical presence (N) and Simpson's dominance index (D"), were *Chilopoda* (%N = 12.8; D" = 21.4), *Diptera* larvae (%N = 22.0; D"= 17.7), *Oligochaeta*: *Opistopora* (%N = 11.3; D" = 12.2), *Gastropoda* (%N = 7.0; D" = 8.7), adult *Coleoptera* (%N = 6.9; D" = 8.0) and *Hemiptera* (%N = 6.0; D" = 5.3). Diets of both sexes were similar. The diet of *S. coronatus* in the study area was similar to the diet of *S. araneus* described in the literature.

Servicio de Medio Ambiente, Gobierno de Navarra, C./ Alhóndiga 1, 31002 Pamplona. Navarra, Spain (EC); Dept. de Biologia Animal, Fac. de Biologia, Univ. de Barcelona, Avgda. Diagonal 645, 08028 Barcelona, Spain (JC).

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Introduction

Since *Sorex coronatus* (Millet, 1828) was discovered as a sibling species of *Sorex araneus* (Meylan 1964, Meylan and Hausser 1978, Catzeflis *et al.* 1982, Hausser 1984, Hausser *et al.* 1985), research efforts have focused on discovering the ecological strategies of each species. Recently some information has appeared on habitat usage in parapatric contact areas (Handwerk 1987, Neet and Hausser 1990, Brünner and Neet 1991). Neet (1989, quoted by Brünner and Neet 1991) showed that in contact zones both species occupy the same trophic niche. However, studies on the diet of *S. coronatus* are rare. Kischnick (1984, quoted by Hausser 1990) studied the contents of 8 stomachs of *S. coronatus* from Germany. This study analyzed the diet of *S. coronatus* from the northern Iberian Peninsula. Our data were also compared with those of *S. araneus* from central Europe.

Material and methods

The diet of *Sorex coronatus* was studied by the analysis of 178 digestive tracts (106 males, 72 females) captured in the Quinto Real Massif (western Pyrenees, Iberian Peninsula) from September 1984 until August 1986. The area is dominated by an acidophilus *Fagus sylvatica* forest. Areas without arboreal vegetation are dominated by *Erica cinerea* and *E. vagans*, and bramble patches with a preponderance of *Rubus* sp. Captures took place between 660 m and 1000 m above sea level (a.s.l.). Average annual precipitation is about 2138 mm, with the highest levels in spring and autumn. The annual average temperature is 8.8°C. The highest average temperature is in August (16.6°C) and the lowest in January (2.9°C).

In order to establish a reference collection of virtual prey, monthly sampling was carried out during the year on the invertebrate community in the study area. Invertebrate samples were obtained from humus layers (0.25 m^2) for the forest and heath-groves by Berlese funnel, from forest ground surface by means of pit-fall traps and also by colection of invertebrates from the surroundings and below forest fallen logs.

Digestive tracts were preserved in 60% alcohol, whilst awaiting analysis. The minimum numbers of consumed prey for each tract were estimated from the remains identified in the stomach and intestines. Contents of the digestive tracts were identified by use of a stereoscopical microscope at 10× and 40× magnification.

The Ruiz and Jover (1983) method was used to determine the importance and variation of the different trophic components. This develops the model defined by Pielou (1966a, b, 1975), Hurtubia and Di Castri (1973) and Hurtubia (1973). The method requires a matrix with rows representing different food types, and columns the distinct variables: appearance frequency in number (N) and percentage (%N), percentage of stomachs with a determinate type of food (%P) and Simpson's dominance ratio ($D = \Sigma P_i^2$)($1 \leq i \leq z$, z – total number of digestive tracts). P_i is the probability of a food unit from stomach i belonging to a certain type of food. $D' = D / z \times 100$ compares the different matrix indices. $D'' = D' / \Sigma D' \times 100$ expresses the value of D' as a percentage.

The cumulative diversity curve H_z was drawn by arranging the stomachs according to their diversity in increasing or decreasing order. This was used to estimate the representativity of the sample studied. To calculate the diversity of the diet the Brillouin expression was used: $H = 1 / N \times (\log N! - \log N_i!)$. This equation is better suited to this kind of data than others (Pielou 1966a, 1975, Hurtubia 1973, Ruiz 1985). The value of H_z corresponded to the last value of the cumulative diversity function. $H_p = 1 / (z - t) \Sigma hk$, ($t + 1 \leq k \geq z$). $hk = (M_k \times H_k - M_k - 1 \times H_k - 1) / (M_k - M_k - 1)$, M_k – number of prey of the k digestive tract, H_k – diversity of the k digestive tract, t – point at which H_k / k curve becomes stabilized. The average diversity value [$\bar{H} = \Sigma H_i / z$ ($1 \leq i \leq z$)] and the equitability (E) were also compared. The similarity of diets in each season were evaluated by Spearman's correlation coefficient. The diets of both sexes were compared with the Kolmogorov--Smirnov test and Spearman's correlation coefficient.

A comparisons between field availability and diet inclusion of prey species was calculated using the similarity coefficient defined as follows $C = 2w / (a + b)$ (Ryan 1986), being w the sum of the lower of the two pair percentage values for each type of invertebrate, a the sum of all the percentage values for invertebrates of the diet and b the sum of all the percentage values for the invertebrates of the field.

Results

Annual diet

Figure 1 shows the cummulative diversity, in which tracts are ordered according to their diversity, in increasing and decreasing order. In the case of decreasing order, diversity stabilization is considered after the accumulation of the contents of 25 alimentary tracts. Therefore, it is possible to assess that the sample is representative of the species' diet. However, to calculate H_p it was considered that the definitive stabilization took place after the accumulation of 146 tracts.

Table 1. Trophic matrix of the annual diet of *Sorex coronatus* (n = 178). N – appearance frequency in number, %N – appearance frecuency in percentage, %P – percentage of stomachs with a determinate type of food, D – Simpson's dominance ratio ($D = \Sigma P_i^2$, P_i – probability of a food unit from stomach i belonging to a certain type of food, $1 \le i \le z$, z – total number of digestive tracts), $D' = D/z \times 100$, $D'' = D' / \Sigma D' \times 100$.

Prey type	N	%N	%P	D	D'	D"
Oligochaeta						
Plesiopora	7	0.7	2.2	0.32	0.18	0.54
Opistopora	113	11.3	55.0	7.22	4.06	12.18
Gastropoda	70	7.0	38.8	5.15	2.89	8.68
Crustacea						
Isopoda	34	3.4	19.1	1.64	0.92	2.76
Myriapoda						
Chilopoda	128	12.8	60.7	12.70	7.13	21.41
Diplopoda	26	2.6	14.0	1.03	0.58	1.73
Arachnida						
Araneae	36	3.6	19.7	1.10	0.62	1.86
Opiliones	33	3.3	18.5	1.62	0.91	2.74
Pseudoscorpiones	3	0.3	1.7	0.13	0.07	0.22
Acarina	40	4.0	20.2	1.53	0.86	2.58
Insecta						
Collembola	4	0.4	2.2	0.12	0.07	0.21
Thysanura	2	0.2	1.1	0.04	0.02	0.07
Diplura	2	0.2	1.1	0.27	0.15	0.45
Coleoptera adult	69	6.9	35.9	4.73	2.66	7.97
Coleoptera larvae	57	5.7	30.9	2.47	1.39	4.17
Diptera adult	20	2.0	11.2	0.95	0.53	1.60
Diptera larvae	220	22.0	41.6	10.49	5.90	17.70
Lepidoptera larvae	29	2.9	14.6	2.61	1.47	4.40
Hemiptera	60	6.0	23.6	3.15	1.77	5.31
Orthoptera	4	0.4	2.2	0.25	0.14	0.43
Hymenoptera	25	2.5	4.5	0.65	0.37	1.10
Dermaptera	3	0.3	1.7	0.14	0.08	0.23
Anoplura	1	0.1	0.6	0.04	0.02	0.07
Siphonaptera	5	0.5	2.8	0.31	0.17	0.52
Ephemeroptera adult	2	0.2	1.1	0.13	0.07	0.22
Trichoptera larvae	4	0.4	2.2	0.10	0.06	0.17
Vertebrata	2	0.2	1.1	0.28	0.16	0.47
Plants	1	0.1	0.6	0.11	0.06	0.19

The analysis of the digestive tracts determined 1000 different preys items. The average number of prey items for each digestive tract was $\bar{x} = 5.6$ (n = 178, SE = 0.325).

In total, 28 different types of food were determined. *Diptera* larvae are the most abundant prey taxa (Table 1). *Chilopoda* are the second in numerical importance.

However, their presence in the digestive tracts was habitual constant, and they were considered the dominant prey in the diet according to Simpson's index. From the 128 *Chilopoda* detected, 99 (77.3%) belonged to *Lithobiomorpha*, 28 (21.9%) to *Geofilomorpha* and 1 (0.8%) to *Scolopendromorpha*.

The *Oligochaeta*: *Opistopora*, all of them *Lumbricidae*, made up a high proportion of the diet. Sixty out of 113 specimens found were small species of *Lumbricidae* mostly *Dendrobaena*. The frequent presence of earthworms in the digestive tract increases the importance attributed by the Simpson's index (D") in relation to their numerical percentage.

Gastropoda were scanty in number, but they appeared in a high proportion of the tracts analyzed. They could thus be considered an important source of food according to Simpson's index. Adult *Coleoptera* were also a prominent food. There were 60 *Hemiptera*, 40 of them (66.7%) were identified as *Aphididae*.

There were also *Coleoptera*, *Acarina*, *Araneae*, *Isopoda* and *Opilionida* larvae, all of which had lower numerical importance. Among *Acarina* (n = 40) at least 18 belonged to *Oribatidae*.

Fourteen percent of the total diet (%N) was composed by 17 different types of food: *Lepidoptera* larvae, *Diplopoda* (4 *Polidesmidae*, 17 *Glomeridae*, 5 *Julidae*), adult *Diptera*, *Hymenoptera* (19 *Formicidae*, 3 *Ichneumonidae*), *Siphonaptera*, *Oligochaeta*: *Plesiopora*, *Collembola*, *Orthoptera*, *Trichoptera* larvae, *Pseudoscorpionida*, *Dermaptera*, *Thysanura*, *Diplura*, adult *Ephemeroptera*, *Anoplura*, vertebrates and plants.

In total 871 invertebrates were captured on the ground's surface by means of pit-fall traps, 742 collected from the surrounding area and under fallen trunks, and 746 from humus layer samples. Table 2 shows that almost all captured invertebrates from different samples appear in the diet of *Sorex coronatus*. Nevertheless, the similarity coefficient between diet and the list of invertebrates available from each habitat sampled changes considerably, being greater in comparison with humus layer samples and lower in comparison with surface samples.

Table 2. Number of invertebrate ecological types found in the diet of *Sorex coronatus*, number of invertebrate types collected from the different sampling mediums, percentage of invertebrate types found in the diet of collected specimens in each sampling medium and the similarity coefficient (C) between diet and samples from each medium.

	Diet of *S. coronatus*	Ground surface samples	Forest fallen trunks samples	Humus layer samples
Number of invertebrate types	26	17	19	20
Number of invertebrate types found in the diet		16	19	19
Percentage		94.1	100.0	95.0
C		0.27	0.43	0.51

Trophic niche amplitude

Figure 1 shows the interval of variation for *Sorex coronatus* trophic diversity curves. The values obtained for each different kind of diversity are the following: $\bar{H} = 1.131$ (SE = 0.036, $n = 178$); $H_p = 3.773$ (SE = 0.203, $n = 31$); $H_z = 3.690$, E = 0.768.

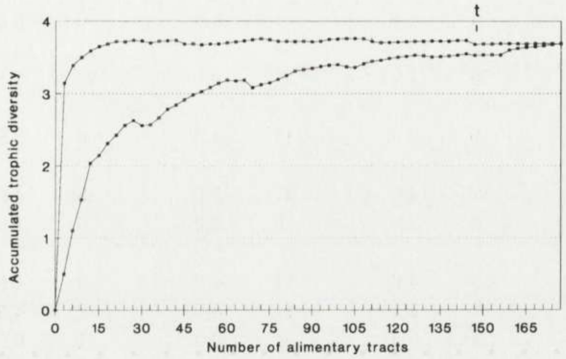

Fig. 1. Cummulative trophic diversity, arranging the digestive tracts (n = 178) according to their increasing (lower curve) and decreasing (upper curve) diversity order. Point t represents the tract where the curve becomes stable.

Seasonal variation in the diet

Table 3 shows the shrew's diet for each season, and its diversity variation. The diet showed high correlation among seasons (Table 4). *Opistopora* (*Lumbricidae*) maintained similar values all year long: between 10.8% (%N) in spring and 13.6% in autumn. *Gastropoda* accounted for 8.9% during winter, decreasing progresively to 4.0% in summer and increasing again in autumn. *Chilopoda* were 10.7% in winter, increasing progressively and maintaining the percentage for the rest of the year between 13.6% and 14.9%.

Adult *Coleoptera* were 3.7% in winter, 6.8% in spring, 10.3% in summer, and decreased in autumn to 5.8%. *Hemiptera* was proportionaly low in winter (4.1%) and spring (1.5%), reaching 8.1% in summer and 9.7% in autumn. *Coleoptera* larvae kept a low but constant count during the whole year. The extreme values were 6.5% in autumn and 4.4% in summer. *Diptera* larvae showed high seasonal variation: in winter their count was 32.8%, in spring 28.9%, in summer 9.9%, and in autum increasing up to 14.3%.

Diet comparison between sexes

Diets of males and females were compared using the Kolmogorov-Smirnov test with a maximum distance observed $d = 0.1785$, $p = 0.99994$. Spearman's correlation coefficients were $r_S = 0.861$, $p < 0.001$, $n = 28$. According to this, diets in both sexes did not differ significantly. Males ($n = 106$) had a trophic spectrum made

Table 3. Seasonal diet for *Sorex coronatus*. N – number of prey items, %N – percentage of N according to the total prey items.

Prey type	Spring		Summer		Autumn		Winter	
	N	%N	N	%N	N	%N	N	%N
Oligochaeta								
Plesiopora	4	1.2	1	0.4	0	0.0	0	0.0
Opistopora	35	10.8	32	11.8	21	13.6	29	10.8
Gastropoda	25	7.7	11	4.0	12	7.8	24	8.9
Crustacea								
Isopoda	9	2.8	11	4.0	6	3.9	10	3.7
Myriapoda								
Chilopoda	47	14.5	37	13.6	23	14.9	27	10.1
Diplopoda	9	2.8	8	2.9	3	1.9	8	3.0
Arachnida								
Araneae	15	4.6	11	4.0	3	1.9	10	3.7
Opiliones	7	2.1	11	4.0	7	4.5	10	3.7
Pseudoscorpion.	1	0.3	0	0.0	1	0.6	1	0.4
Acarina	12	3.7	11	4.0	5	3.2	10	3.7
Insecta								
Collembola	0	0.0	2	0.7	1	0.6	0	0.0
Thysanura	0	0.0	0	0.0	2	1.3	0	0.0
Diplura	0	0.0	2	0.7	0	0.0	0	0.0
Coleoptera adult	22	6.8	28	10.3	9	5.8	10	3.7
Coleoptera larvae	17	5.2	12	4.4	10	6.5	16	6.0
Diptera adult	5	1.5	6	2.2	4	2.6	6	2.2
Diptera larvae	94	28.9	27	9.9	22	14.3	88	32.8
Lepidoptera larvae	10	3.1	11	4.0	5	3.2	4	1.5
Hemiptera	5	1.5	22	8.1	15	9.7	11	4.1
Orthoptera	0	0.0	4	1.5	0	0.0	0	0.0
Hymenoptera	0	0.0	22	8.1	3	1.9	0	0.0
Dermaptera	0	0.0	2	0.7	1	0.6	0	0.0
Anoplura	1	0.3	0	0.0	0	0.0	0	0.0
Siphonaptera	2	0.6	0	0.0	1	0.6	1	0.4
Ephemeroptera adult	1	0.3	1	0.4	0	0.0	0	0.0
Trichoptera larvae	3	0.9	0	0.0	0	0.0	1	0.4
Vertebrata	0	0.0	0	0.0	0	0.0	1	0.4
Plants	1	0.3	0	0.0	0	0.0	1	0.4
n	59		50		25		44	
H_p	3.62		3.81		3.49		3.54	
H_z	3.29		3.71		3.47		3.18	
E	0.76		0.84		0.82		0.78	

up by 27 types of food, while females (n = 72) had 22 types. The trophic diversity for each one of the sexes was as follows. Males: $\bar{H}$ = 1.111 (SE = 0.048, n = 106),

Table 4. Seasonal diet comparison with the Spearman correlation test. ** – correlation coefficient value significant for $p < 0.001$.

Season	Spring	Summer	Autumn
Winter	0.909 **	0.720 **	0.869 **
Spring		0.711 **	0.801 **
Summer			0.868 **

$H_p = 3.780$ (SE = 0.234, $n = 109$), $H_z = 3.597$, E = 0.755. Females: $\bar{H} = 1.160$ (SE = 0.056, $n = 72$), $H_p = 3.762$ (SE = 0.087, $n = 45$), $H_z = 3.624$, E = 0.815.

Discussion

Kischnick (1984, quoted by Hausser 1990) analyzed 8 *Sorex coronatus* stomach contents from Bonn (Germany), from November to March. He found that numerically the most important prey items were *Coleoptera* and *Diptera* larvae, *Hemiptera*, *Araneae*, adult *Coleoptera* and *Isopoda*. Comparing our results (appearance frequency) with those of Kischnick (1984) for autumn and winter, there was a high correlation between both diets ($r_S = 0.768$, df = 22, $p < 0.001$).

Hausser and Meylan (1984) noted that *S. coronatus* had the same ecological niche as *S. araneus*. Nevertheless, the first species was less adapted to a severe climate. Neet (1989, quoted by Brünner and Neet 1991) considered that in the contact zone, both species occupied the same trophic niche.

Rudge (1968) also found that in Great Britain (Scotland, Wytham Woods and Exeter) the main part of *S. araneus* prey items included *Lumbricidae*, *Mollusca*, *Hemiptera*, *Diptera*, *Coleoptera*, *Lepidoptera* and plants. When our data are compared with those of Rudge (1968) (appearance frequency, except for non identified diets) there was no correlation with the Scottish area ($r_S = 0.200$, df = 22, $p > 0.1$), but a significant correlation in the Wytham Woods ($r_S = 0.358$, df = 26, $p < 0.05$) and Exeter ($r_S = 0.383$, df = 27, $p < 0.05$).

Kischnick (1984, quoted by Hausser 1990) described a *S. araneus* diet around Bonn, from November to March essentially based on *Gastropoda*, *Araneae*, *Isopoda*, *Hemiptera*, *Coleoptera* larvae and *Diptera* larvae. Comparing these results with ours (appearance frequency), we found a high correlation between the two species ($r_S = 0.822$, df = 22, $p < 0.001$).

When our data from *S. coronatus* are compared with different populations of *S. araneus* (Rudge 1968, Pernetta 1976, Butterfield *et al.* 1981, Churchfield 1982, 1984, Kischnick l.c.), both species appear to have similar diets. Different types of prey are common to both species: *Lumbricidae*, adult *Coleoptera*, *Gastropoda*, *Coleoptera* larvae, *Hemiptera* and in some cases *Diptera* larvae. The most remarkable feature of the Quinto Real population of *S. coronatus* was the high occurrence of *Chilopoda* in its diet. This must depend on the characteristics of the study area (Castién 1994). Neet (1989, quoted by Brünner and Neet 1991) indicated that both species occupy a similar trophic niche in the contact zone.

S. araneus diet is based mainly on animals that live in the humus layer. This could be related to a subterranean way of life (Pernetta 1976, Butterfield *et al.* 1981), as revealed under laboratory conditions (Ellenbroek 1990).

Diet similarities for *S. coronatus* and *S. araneus* also suggested a similar way of life. *S. coronatus* feeds on almost all available resources (Table 2) which shows a clear tendency towards a trophic oportunism. Differences between the diet and the invertebrates from different sampling areas indicate a high level of correlation between feedings habits and humus faunistic composition, while the correlation between the diet and the ground's surface fauna is very low. The former corroborates the opinion that this species uses subterranean galeries for the majority of its feeding activity.

Comparison between H_p and H_z for the whole sampling indicated a similarity in both values. This verified the absence of intra-populational diet patterns. The high value of H_z implied a diversified diet. Meanwhile, the high equitability value showed an equal feeding distribution between used resources.

Concerning the seasonal diversity values, H_p was higher than H_z in winter and spring. It was related to certain intra-populational trophic segregation within the sample in this period. In summer and autumn the food sources diversified and the values of H_p and H_z were closer. This suggested the lack of different trophic patterns in the population during these periods.

Males ingested more types of food, but the females diet had a higher equitability ratio. The diversity value was not different between sexes. Consequently, a trophic differentiation between sexes could not be concluded.

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