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First results on the feeding ecology of the Transcaucasian water shrew *Neomys teres* (Soricomorpha: Soricidae) from Armenia

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Abstract: Microscopic examination of alimentary tracts of 14 *Neomys teres* Miller, 1908 from a mountainous region in northern Armenia produced the first data on the diet of this almost unknown species of conservation concern. Twenty-three different prey types were distinguished in summer-caught shrews, all of which were invertebrates (14 terrestrial and 9 aquatic in origin). The dominant dietary items were Coleoptera and Diptera adults, Araneae, Opiliones, and Lumbricidae, as well as freshwater crustaceans and Trichoptera larvae. Prey ranged from <3 to >16 mm in length, but those eaten most frequently were 6–10 mm in length. Although *N. teres* was captured beside streams and rivers, aquatic prey comprised only 27% of the dietary composition. Despite the morphological similarity of *N. teres* to *Neomys fodiens* (Pennant, 1771), its foraging niche more closely resembles that of upland populations of *Neomys anomalus* Cabrera, 1907 and its reliance on aquatic habitats remains equivocal.

Résumé : L'examen au microscope des tubes digestifs de 14 *Neomys teres* Miller, 1908 provenant d'une région montagneuse du nord de l'Arménie fournit les premières données sur le régime alimentaire de cette espèce presque inconnue dont la conservation est préoccupante. Vingt-trois types différents de proies, tous des invertébrés (14 d'origine terrestre et 9 d'origine aquatique), se reconnaissent chez les crossopes récoltées en été. Les proies dominantes sont des adultes de coléoptères et de diptères, des araignées, des opilions et des lumbricidés, de même que des crustacés d'eau douce et des larves de trichoptères. Les proies varient en longueur de <3 à >16 mm, mais celles qui sont le plus fréquemment ingérées ont 6–10 mm de longueur. Bien que les crossopes aient été capturées près de ruisseaux et de rivières, les proies aquatiques représentent seulement 27 % de la composition de leur régime alimentaire. Malgré une ressemblance morphologique à *Neomys fodiens* (Pennant, 1771), la niche alimentaire de *N. teres* se rapproche plus de celle des populations de *Neomys anomalus* Cabrera, 1907 des terres hautes et sa dépendance des habitats aquatiques reste ambiguë.

[Traduit par la Rédaction]

Introduction

Three species of water shrew belonging to the genus *Neomys* Kaup, 1829 are found in Eurasia. *Neomys fodiens* (Pennant, 1771) (the Eurasian water shrew) and *Neomys anomalus* Cabrera, 1907 (the Mediterranean or southern water shrew) are widely distributed in allopatry and sympatry in Europe (Spitzenberger 1990; Mitchell-Jones et al. 1999; Kryštufek et al. 2000), and their ecology has been subject of a number of studies (e.g., Rychlik 1997, 2000, 2005; Churchfield and Rychlik 2006 and papers cited therein). In contrast, the Transcaucasian water shrew, *Neomys teres* Miller, 1908 (previously known as *Neomys schelkovnikovi* Satunin, 1914: see Kryštufek et al. 1998 and Hutterer 2005) is almost unknown. Compared with the other two *Neomys* species, *N. teres* has a very limited distribution. It is found only in the Caucasian region, from southeastern Russia to northern Iran and from northeastern Turkey to Azerbaijan, with Armenia placed in the centre of its range (Kryštufek et al. 2000). It is included on the IUCN list of

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Fig. 1. Map showing the location of the study area (stippled) near the town of Dilijan, Armenia.

threatened species under the category of lower risk (least concern) (Stone 1995; IUCN 2006) because it is locally abundant. However, with its restricted range and close association with pristine freshwater streams and rivers, it is vulnerable to habitat loss and degradation. Apart from a few anecdotal observations, its mode of life and ecology have not been investigated thus far (Gureev 1979; Sokolov and Tembotov 1989; Stone 1995; Kryštufek and Vohralík 2001), and so its conservation needs cannot be properly addressed.

Neomys teres is the largest of the three *Neomys* species and it more closely resembles *N. fodiens* than *N. anomalus*, with well-developed stiff hairs on the large hind feet and the relatively longer tail (Kryštufek and Vohralík 2001). This suggests that it should resemble *N. fodiens* in swimming and diving ability, and it is predicted to have a semi-aquatic mode of life. Indeed, anecdotal accounts (Sokolov and Tembotov 1989 citing Satunin 1915) suggest that *N. teres* mainly hunts under water, also under ice in winter, and sometimes hunts insects or collects dead aquatic animals found on mud along stream banks. Sokolov and Tembotov (1989) concluded that *N. teres* has a broad diet, including many insects and their larvae, worms, snails, fish, spawn, frogs, and tadpoles. However, there have been no detailed studies of feeding habits and foraging mode of *N. teres* to support these observation and speculations, as well as no data to indicate the extent of aquatic foraging in this species.

The aim of this study was to investigate the feeding habits of *N. teres* and elucidate its foraging mode and trophic niche. We predicted that, given its size and morphological adaptations, it should demonstrate a high level of aquatic foraging. Since it is nowhere sympatric with *N. fodiens* (Sokolov and Tembotov 1989; Kryštufek et al. 2000), interspecific competition is absent and so it was predicted to have a mode of life and trophic niche that closely resembled that of its congenor and counterpart *N. fodiens*.

Material and methods

Alimentary tracts of *N. teres* were extracted from wet specimens kept in the collection of the Department of Biology, Yerevan (Erevan) State University (Armenia). These shrews were captured during investigations (conducted in July and August of 1987–1989 and of 1999) of the biodiversity of a little-studied mountainous region near the town of Dilijan (Dilizhan) (ca. 40°45′N, 44°53′E; north of Lake Sevan) (Fig. 1). All water shrews but one were captured along the river Aghstev (a tributary of the river Kur) on a 4–5 km stretch passing the village of Haghardzin (Agartsin) and along its tributary streams Haghardzin and Bldan-Chay. Aghstev is a mountain river, descending 200 m at the investigated section (from 1550 to 1350 m), and relatively short tributary streams flow to the river from hills reaching 1800–2200 m. The hills are covered with deciduous forests (mainly *Fagus* L. and *Quercus* L.) and with occasional clearings containing herbaceous plants. At the bottoms of the steep-sided valleys, the river and streams pass through a habitat rich in bushes, grasses, and herbaceous plants. One water shrew was captured near the town of Ijevan, about 35 km down the river Aghstev, where the landscape is more open.

Small mammals were captured in wooden box-traps and dry metal pitfall traps placed along the water courses. The traps were left open throughout the day and night and were inspected each morning. Small mammals (including shrews) found dead in the traps were first preserved in 10% formalin to serve as voucher collections for the Yerevan State University. However, before immersion in formalin, their bellies were cut open along the midline. After the initial preservation, the specimens were transferred to 70% alcohol.

Analysis of the diets of shrews was based on microscopic examination of prey remains in the alimentary tracts taken from the preserved specimens. The trapping method was not ideal for the investigation of shrew diets: kill-trapping is generally more effective because stomachs are likely to contain larger quantities of undigested food remains compared with live-trapped individuals. However, the stomachs of *N. teres* contained many prey fragments, and identifiable invertebrates were found in all the specimens examined. Since these shrews belong to a little-known and unusual species, any new information about their ecology was deemed useful. Identification of invertebrate prey remains was facilitated by use of a reference collection of potential prey items. Comparison of prey remains with a reference collection of invertebrates also permitted prey to be assigned to different body size classes. Individual arthropod prey were distinguished by their morphology and number of appendages or mouthparts, thus permitting the number of occurrences of each prey type eaten by each shrew to be scored. Multiple items of exactly the same prey type eaten per shrew were very rare. It was not always possible to count the number of molluscs (identified by fragments

Table 1. Diet of *Neomys teres* from Armenia (n = 14).

	Percent frequency of occurrence	Percent dietary composition
Terrestrial prey		
Coleoptera: Staphylinidae	14.3	2.4
Other Coleoptera adults indeterminant	35.7	6.0
Coleoptera larvae	21.4	2.9
Diptera adults: Culicidae	21.4	2.5
Diptera adults indeterminant	35.7	4.8
Diptera larvae: Tipulidae	14.3	2.4
Diptera larvae indeterminant	7.1	1.2
Lepidoptera larvae	14.3	15.7
Heteroptera	14.3	1.9
Chilopoda: Geophilomorpha	7.1	1.7
Araneae	71.4	9.9
Opiliones	42.9	5.0
Gastropoda: slugs	7.1	1.2
Lumbricidae	42.9	15.5
Aquatic prey		
Trichoptera larvae	42.9	8.4
Plecoptera nymphs	21.4	2.9
Ephemeroptera nymphs	14.3	1.9
Insect nymph indeterminant	14.3	1.9
Coleoptera adults	7.1	1.2
Coleoptera larvae	7.1	1.2
Diptera larvae: Chironomidae	7.1	0.8
Gammarus	21.4	3.2
Asellus	35.7	5.4

of shell and (or) radula) and earthworms (chaetae) eaten per shrew, and thus, their presence was scored as a single occurrence for the purpose of the analyses unless there was clear evidence that more than one individual had been consumed.

The results were expressed as follows: percent frequency of occurrence of food items (i.e., the proportion of specimens containing a named food type), percent dietary occurrence of food items (i.e., the number of occurrences of a named food type as a proportion of the total occurrences of all food types), and percent volume composition of each food type (estimated by comparing the sizes of food remains with specimens in the reference collection). An index of the contribution of each food type was derived that incorporated the latter two measures: percent dietary composition = (percent dietary occurrence + percent volume composition)/2.

Results

Fourteen specimens of *N. teres* were available for the diet study, including 5 adults (2 males, 3 females) and 9 subadults (3 females, 5 males, 1 undetermined sex). Prey fragments were found in the alimentary tracts of all specimens. The mean number of prey items found per shrew was 6.2 (range 3–14). Twenty-three different prey types were distinguished (Table 1), all of them invertebrates. Figure 2 shows the cumulative percentages of different prey taxa found as increasing numbers of diet samples were examined. Since all prey taxa were discovered by the 11th sample, it was concluded that sufficient samples were examined to be representative of the diet of *N. teres* from the study area.

Fourteen of the 23 prey types were terrestrial in origin, but 9 prey types were aquatic invertebrates. There was no evidence of vertebrate prey, such as fish or amphibians, having been eaten. The terrestrial prey items eaten most frequently were Coleoptera and Diptera adults and Araneae, followed by Opiliones and Lumbricidae (Table 1). Among aquatic prey, freshwater crustaceans (*Asellus* Geoffroy, 1764 and *Gammarus* Fabricius, 1775) and Trichoptera larvae were the most important. In terms of the percent dietary composition (incorporating total occurrence and volume contributions), the most important prey was Lumbricidae. Although Lepidoptera larvae appeared to be a major prey item, only two shrews had eaten them, with one having devoured 12 caterpillars.

Eleven of the 14 shrews (79%) had eaten aquatic prey. Up to six different freshwater prey per shrew were consumed, of which Trichoptera larvae and crustaceans were predominant. Twenty-nine percent of prey occurrences were aquatic (33% if mass consumption of Lepidoptera larvae by just one shrew is excluded). In terms of dietary composition, 27% was aquatic in origin (Table 1).

The size of prey items ranged from tiny Araneae <3 mm in length to Myriapoda and Lumbricidae >15 mm in length. The size of Lumbricidae could not be determined accurately from their remains (mostly chaetae) and so were given conservative estimates based on the minimum size in the reference collections. Based on all occurrences, the prey eaten most frequently were small invertebrates of 6–10 or 3–5 mm in length (Fig. 3).

Discussion

One criticism of the study is that diet samples were taken

Fig. 2. Cumulative number of prey types found as successive samples of alimentary tracts of *N. teres* were examined.

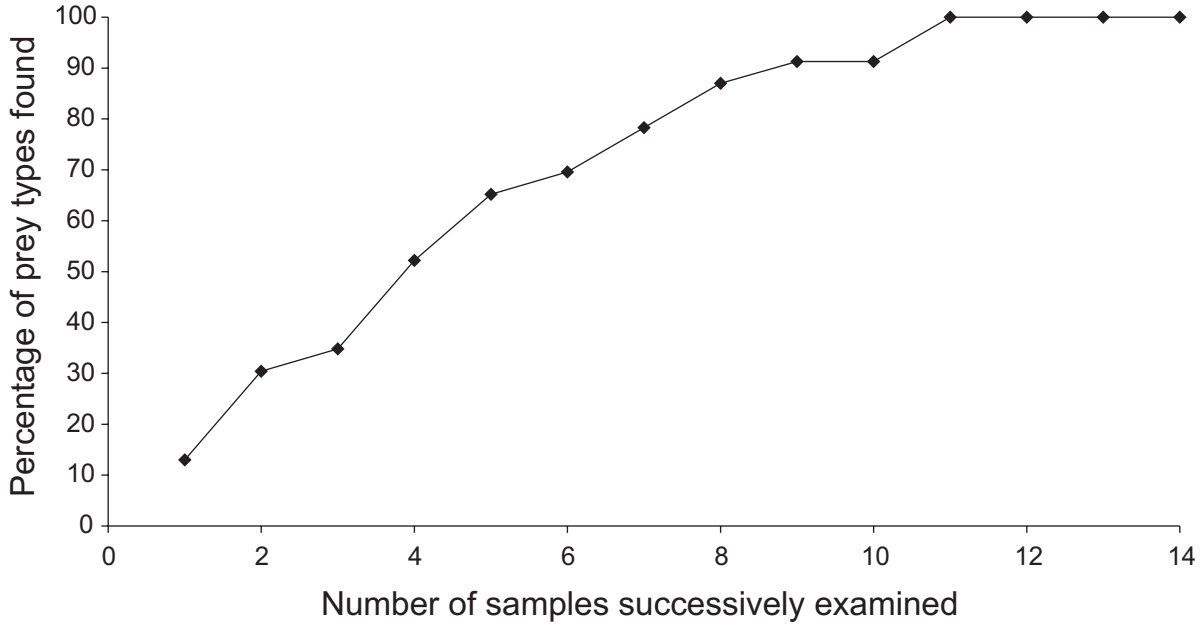
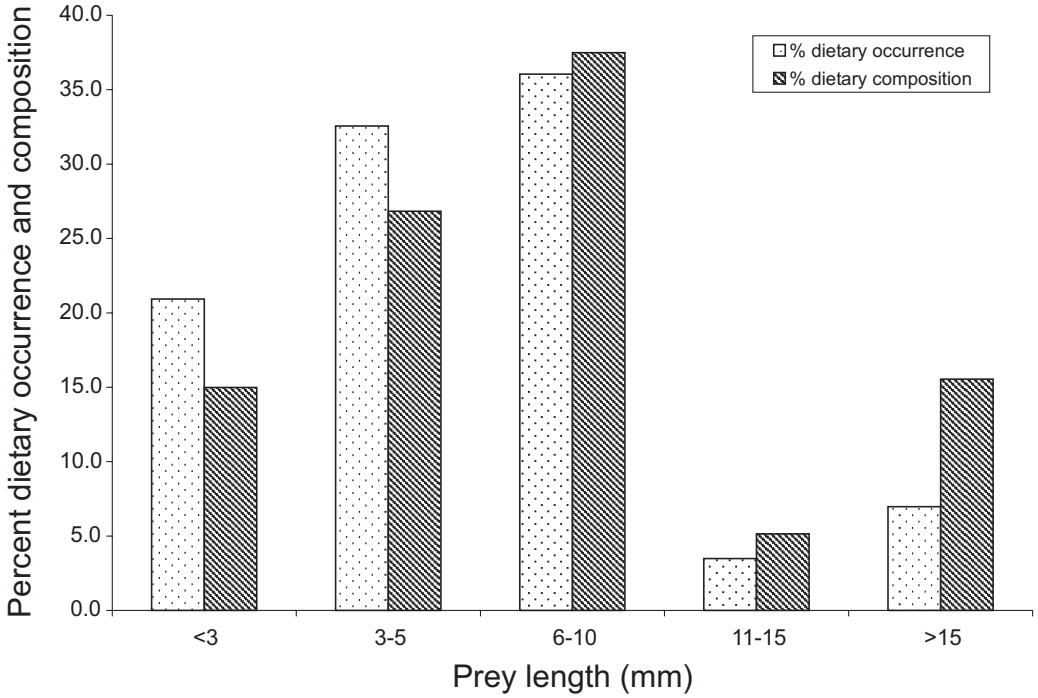


Fig. 3. Prey sizes eaten by *N. teres* from the Dilijan region, northern Armenia.



mainly from specimens that had died in traps and so were unlikely to have full stomachs by the time of collection. However, all specimens contained recognisable prey remains and the total number of prey types found (23) was similar to that found in scats collected from live-trapped *N. fodiens* and *N. anomalus* (Churchfield and Rychlik 2006). Moreover, the mean number of prey items per shrew exceeded that found in *Neomys* scats by Churchfield and Rychlik (2006). Thus, we concluded that the data presented here are representative of the diet of *N. teres* living in northern Armenia around Dilijan.

Our data reveal that *N. teres* is a broad-spectrum feeder of aquatic and terrestrial invertebrates. Despite its relatively large size, *N. teres* resembles other shrew species (genera *Sorex* L., 1758 and *Neomys*) in consuming predominantly small prey of 3–10 mm in length, suggesting that it too is opportunistic with respect to prey size and eats common and abundant items (Churchfield and Sheftel 1994; Churchfield et al. 1997; Castién and Gosálbez 1999; Churchfield and Rychlik 2006).

Our results do not support Satunin's (1914) statement (cited in Sokolov and Tembotov 1989) that *N. teres* (= *N. schelkovnikovi*) mainly hunts underwater, since most prey occurrences (71%) were terrestrial in origin. Our results also do

not provide evidence to support the suggestion by Sokolov and Tembotov (1989) that *N. teres* catches amphibians and fish, although our sample size was small.

Neomys teres combined aquatic foraging with terrestrial hunting, suggesting a foraging mode similar to that of other *Neomys* species. Studies of *N. fodiens* and *N. anomalus* have demonstrated that, although both species will hunt for aquatic prey, the former is better adapted for swimming and diving, which is reflected in its choice of microhabitat and foraging mode. Compared with *N. anomalus*, *N. fodiens* is more inclined to swim and dive, it occupies microhabitats closer to deep water, and a larger proportion of its prey are captured underwater (Kuvikova 1985*a*; Rychlik 1997, 2000; Soares and Rychlik 2004; Churchfield and Rychlik 2006). Accordingly, 20% of prey of summer-caught *N. fodiens* was aquatic compared with only 11% for *N. anomalus* (Churchfield and Rychlik 2006). Although *N. teres* externally resembles *N. anomalus* (Kryštufek and Vohralík 2001), its adaptations to semi-aquatic life are better developed (longer tail, larger hind feet, more pronounced fringes on hind feet, and eyes hidden in the fur). These features more closely resemble *N. fodiens* (Gureev 1979; Kryštufek et al. 1998, 2000; Kryštufek and Vohralík 2001), suggesting that it is similarly a good swimmer and diver. Aquatic prey comprised 27% of the diet of summer-caught *N. teres*, which more closely resembles the diet of *N. fodiens* than that of *N. anomalus*, as predicted. Also, its close association with streams or small rivers and apparent rarity in other habitats (Sokolov and Tembotov 1989; Kryštufek et al. 1998; 2000; Kryštufek and Vohralík 2001) show closer overlap with the habitat preferences of *N. fodiens* than that of *N. anomalus*.

The amount of aquatic foraging by *N. fodiens* and *N. anomalus* is very variable, which reflects the habitat type. In lowland habitats (e.g., alder forest, sedge swamp), where availability of terrestrial prey is high, aquatic prey comprise only 11%–20% of the diet of *N. fodiens* and 0%–11% of *N. anomalus* (Kuvikova 1985*a*; Churchfield and Rychlik 2006). However, aquatic prey of *N. fodiens* may exceed 50% in some lowland habitats (such as watercress (*Rorippa nasturtium-aquaticum* (L.) Hayek) beds; Churchfield 1984). In upland habitats (such as mountain streams), the proportion of aquatic prey in the diets of water shrews is usually much higher: 83%–95% in *N. fodiens* (Niethammer 1978; Kuvikova 1985*b*; DuPasquier and Cantoni 1992; Castién 1995) and 17%–61% of *N. anomalus* (Niethammer 1978; Kuvikova 1987). Therefore, we expected a high proportion of aquatic prey in the diet of *N. teres* living along mountain streams and small rivers. Contrary to this prediction, only 27% of its diet consisted of aquatic prey. This more closely resembles the diet of *N. anomalus* from upland populations rather than that of *N. fodiens*. Also a high consumption of Lepidoptera, Araneae, and Lumbricidae, noted in the present study, resembles feeding habits of *N. anomalus* (Kuvikova 1985*a*; Churchfield and Rychlik 2006). As to Lepidoptera, the result is perhaps incidental, since only two shrews ate them, but eating Araneae and Lumbricidae appear to be the norm.

For conservation and management purposes, it is important to understand the food and habitat requirements of a species. Our study has provided the first data on the feeding habits of *N. teres* in an attempt to elucidate its foraging requirements but, with its relatively low consumption of freshwater invertebrates, its reliance on aquatic habitats remains equivocal. Further investigation of this elusive and unusual species is needed in different parts of its range and in different seasons to fully reveal its feeding ecology and mode of life.

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