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# Conservation status of *Sorex alpinus* within a community of small mammals in the Oberpfälzer Forest (Bavaria, Germany): results of a 16-year study (Eulipotyphla: Soricidae)

Richard KRAFT[1*] & Wilfried KLEMMER[2]

[1] Frühlingstr. 43, D–82223 Eichenau, Germany
[2] Wutzmühlstrasse 20, D–93437 Furth im Wald, Germany
[*] corresponding author: richard.kraft.dxa2v@slmails.com

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**Abstract**. We collected data on small mammals at the southeastern foothills of the Oberpfälzer Forest (Upper Palatinate Forest), a low mountain range along the border between Bavaria and the Czech Republic. Special attention was paid to the conservation status of the Alpine shrew, *Sorex alpinus*. Over a 16-year period, 2009–2024, live trapping was carried out each year from mid/end September to mid/end October. A total of 2,976 small mammals of 15 species (eight rodent species, six insectivore species, and one carnivore species) were captured, with the most abundant species being the bank vole (*Clethrionomys glareolus*), followed by the yellow-necked mouse (*Apodemus flavicollis*) and the wood mouse (*A. sylvaticus*). The bank vole and yellow-necked mouse populations showed remarkable fluctuations, with peaks and crashes in subsequent years. Shrews were represented by six species, including the bicoloured white-toothed shrew (*Crocidura leucodon*), whose presence in a closed woodland is rather unusual. The Alpine shrew was recorded with a total of 26 specimens (0–4 individuals caught per year). This makes it by far the rarest of all the Soricinae species that have been recorded. We consider the Alpine shrew to be endangered in the lower mountain ranges of Bavaria due to climate change and habitat shift.

**Key words**. *Sorex alpinus*, *Neomys milleri*, Oberpfälzer Wald, density fluctuations, Red List.

## INTRODUCTION

The Alpine shrew (*Sorex alpinus* Schinz, 1837) is endemic to Europe, its distribution range is fragmented and extends across the high altitudes of the Alps, Carpathians, the Balkan Mountains, and a number of isolated low mountain ranges in Germany, Austria, the Czech Republic, and Poland (Meinig 2004). Its current distribution is interpreted as a relict and is probably a result of range dynamics during the Pleistocene (Starcová et al. 2016).

*Sorex alpinus* has been recently listed as "Near Threatened" in the IUCN Red List of Threatened Species, with the current population trend assessed as declining (Meinig et al. 2020a). The German populations are considered to be threatened to an unknown extent (Meinig et al. 2020b).

In the Bavarian Alps, however, the Alpine shrew is relatively common and occupies a largely continuous area up to 1870 m a. s. l., its population status is considered stable there (Kraft 2008, Rudolph & Boye 2017). In the non-Alpine regions of Bavaria, *Sorex alpinus* also occurs (or occurred) in four low mountain ranges: the Bavarian Forest, the Oberpfälzer (Upper Pala-

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tinate) Forest, the Fichtel Mountains, and the Rhoen Mountains (Fig. 1). There are historical records from the foothills of the Bavarian Forest at low elevations between 335 and 380 m a. s. l., extending as far as the Danube near Vilshofen (Bothschafter 1957), although it is not known whether the species still occurs there. There are also isolated records from the foothills of the Bavarian Alps, up to 40 km from the northern edge of this mountain range (Fig. 1). The distribution area of the species in the low mountain ranges of Bavaria is fragmented, with the

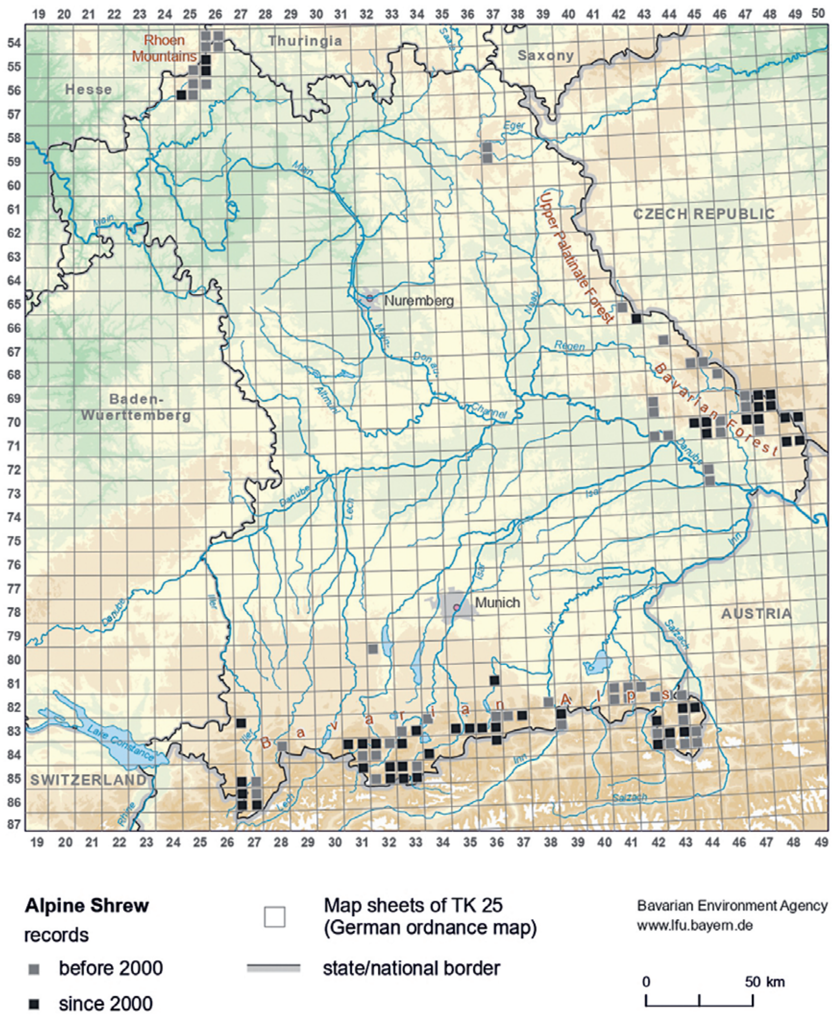


Fig. 1. Distribution of the Alpine shrew, *Sorex alpinus*, in Bavaria, as of 2024. Basis for the map: Bayerische Landesvermessungsverwaltung. Records in the Oberpfälzer Forest are in the grid mapping square 6642, 1st quadrant (historical records) and 3rd quadrant (present study).

individual subpopulations being isolated from each other and from the main Alpine area (Kraft 2008, Rudolph & Boye 2017). The Alpine shrew is elusive and difficult to capture, data on its occurrence are thus very patchy, and only the Rhoen and the Bavarian Forest have sufficient evidence of reasonably continuous populations (Müller et al. 2012; additional data in the database of the Bavarian Environment Agency, Landesamt für Umwelt; Fig. 1). The Bavarian Forest records are part of a larger more or less continuous distribution area that also includes the wider Šumava region of the Czech Republic, from the southern edge of the Český les Mountains in the northwest to the foothills of the Novohradské hory Mountains in the southeast of the Bohemian Massif (Anděra & Hanzal 2022).

In the Fichtel Mountains, the species is considered extinct or lost; the only confirmed records for this low mountain range are two individuals captured in the 1950s (Kahmann 1952; see Fig. 1, map grid 5937). Follow-up projects, see Brünner (2017) and Kraft (2019) did not yield any new evidence of the species.

The situation was similar in the Oberpfälzer Forest, which is a part of the Bohemian Massif and, together with the Bavarian Forest and the Fichtel Mountains, forms the East Bavarian Border Mountains. Prior to the start of this study, the presence of *Sorex alpinus* in the area was only documented by two specimens, trapped by G. Heinrich in 1948 in or near Waldmünchen, a small town on the southern slope of the mountains (grid mapping square code 6642, exact trapping location not specified). These two captures are confirmed by preserved skulls and skins, one deposited in the Munich State Zoological Collection (ZSM 1977/969), and the other in the State Museum of Natural History Stuttgart (SMNS 3501; see Kraft et al. 2010 for details). They appear to have been the only records of the species for the Oberpfälzer Forest for decades.

First in 2009, W. Klemmer succeeded in catching three Alpine shrews again in this area, in the same mapping square as Waldmünchen (6642), from where Heinrich's specimens were reported (Kraft et al. 2010). This appears to be the only known population of the Alpine shrew in the entire Oberpfälzer Forest. Attempts by Malec & Kraft (unpubl.) in 2010 to record the species in the northern Oberpfälzer Forest (e.g. around Flossenbürg, 6240) were unsuccessful despite intensive survey efforts with several hundreds trap nights. This corresponds to the distribution pattern in the Český les (Bohemian Forest) Mountains, the Czech part of the Oberpfälzer Forest, where the occurrence of the Alpine shrew is also restricted to the south, with the northernmost record near the village of Závist (6542), 25 km NNW of our trapping site (Anděra & Hanzal 2022).

The occurrence of the Alpine shrew at lower elevations is locally limited to relic sites with rather cool and wet microclimatic conditions, such as densely overgrown banks or moss-covered basalt boulder fields (Görner 2005, Kraft 2008, Meinig et al. 2020a). As wet or swampy habitats have been lost on a large scale in many places due to drainage and afforestation, a decline in the non-Alpine populations of *Sorex alpinus* in Bavaria can be expected. In the Bavarian Forest, for example, until the 1960s, large parts of the fen areas were drained through ditches and then afforested with spruce trees (Demartin et al. 2021). In addition, the replacement of deciduous and mixed forests by coniferous plantations, and the associated change in local microclimate, has probably also led to the loss of the Alpine shrews' habitat in the low mountain ranges (Gahsche 1994). In the long term, climate change, which is leading to a deep restructuring of forests as the groundwater levels are falling, is likely to lead to shrinking of habitable areas.

Therefore, we decided to launch a multi-year monitoring project to document the abundance and conservation status of the Alpine shrew in the Bavarian mountain range, in order to provide benchmarks for possible future population declines.

## MATERIAL AND METHODS

### Study area

The Oberpfälzer Forest (Upper Palatinate Forest) is a low mountain range in Central Europe. It is a part of the larger Bohemian Massif and stretches about 100 km from south to north, halfway between the Bavarian Forest in the south and the Fichtel Mountains in the north. Along the main ridge runs the border between Bavaria (Germany) and Bohemia (Czech Republic). The highest peaks on the Bavarian side are between 800 and 900 m a. s. l. The climate in the Oberpfälzer Forest is subcontinental or humid continental, the average annual temperature in the study area is 8.2 °C, the annual rainfall is 875 mm (https://de.climate-data.org/europa/deutschland/bayern/waldmuenchen-14601).

The trapping sites are located in a montane mixed beech-fir-spruce forest at the southernmost slope of the mountain area, about 2 km northwest of Furth im Wald, at altitudes between 525 and 549 m a. s. l. (Fig. 2). The forest is made up of 50% beech and 10–15% fir, with the remainder being spruce, sycamore maple, Norway maple, ash, and wych elm. Tree cover is partly dense with a shady canopy, but some trapping sites are in more open canopy locations.

Because of the Alpine shrews' preference for stony, crevice-rich habitats near streams and other small watercourses, traps were set on the banks of two small, fast-flowing streams with densely overgrown banks lined with boulders of granite and gneiss. The depth of the water is from a few centimetres to about 20 cm, only at the scour points it is up to about 50 cm. The herbaceous vegetation on the banks is very dense and consists of the hairy goiter (*Chaerophyllum hirsutum*), bittercress (*Cardamine amara*), opposite-leaved spleenwort (*Chrysosplenium oppositifolium*), ferns, and various mosses and sphagnums (*Sphagnum* sp.).

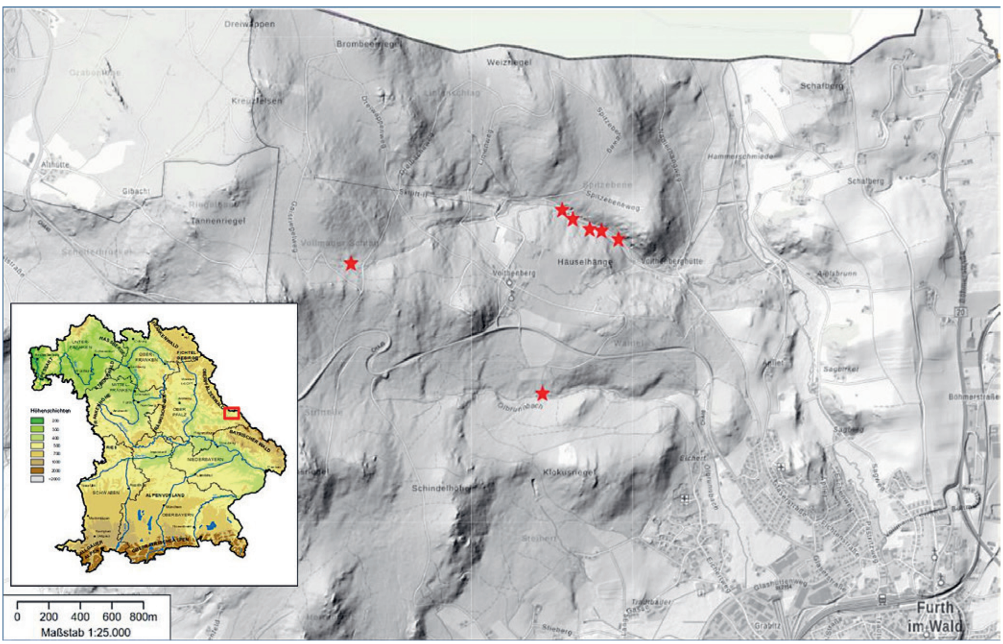


Fig. 2. Catch sites in the study area north-west of Furth im Wald and near the border with the Czech Republic, grid mapping square 6642, 3rd quadrant. Background map: Bayerische Landesvermessungsverwaltung.

Trapping method

The live capture was carried out with the permission of the district government of the Upper Palatinate, Regensburg, No. 55.1-8642.4-38.

Twenty-four live traps were used, consisting of two parts: an aluminium tunnel (diameter 4.5×4.5 cm) with a step ramp, and an attached wooden nest box, that can be filled with nesting material and food. To avoid underestimating lighter species such as the pygmy shrew, the trigger mechanism has been finely tuned. The bait consisted of a toast soaked in cod liver oil, live mealworms, and apple pieces. Trapping was carried out annually in autumn for three weeks (late September to early October, depending on the weather). A trapping period lasted on average 21 days, resulting in an average of 548 trap nights per year (8,769 nights in total, see Table 1).

Traps were set and checked by the second author (WK) with the help of Christina and Anna Klemmer. To prevent recapture, live animals were released at a distance from the trap site. The skins and skulls of animals that died accidentally in the traps have been deposited in the W. Klemmer's collection at Furth im Wald. The project was launched in 2009 and will continue. The results from 2009–2024 are reported here.

## RESULTS

A total of 2,976 small mammals were captured during 8,769 trapping nights in 16 trapping seasons (Table 1). These individuals represented 15 species, of them eight rodent species, six insectivore species, and one carnivore species (Fig. 3). By far the most common species was the bank vole (*Clethrionomys glareolus*), which accounted for 38.4% of all small mammals captured. It was followed by the yellow-necked mouse (*Apodemus flavicollis*) with a share of 20.9% and the wood mouse (*Apodemus sylvaticus*) with 16.1%. These three species, which together accounted for about three quarters of the total catch, showed pronounced 2- and 3-year density variations, with peaks and intervening years of lower densities (Fig. 4). In the bank vole and yellow-necked mouse, these fluctuations correlated positively with the abundance of

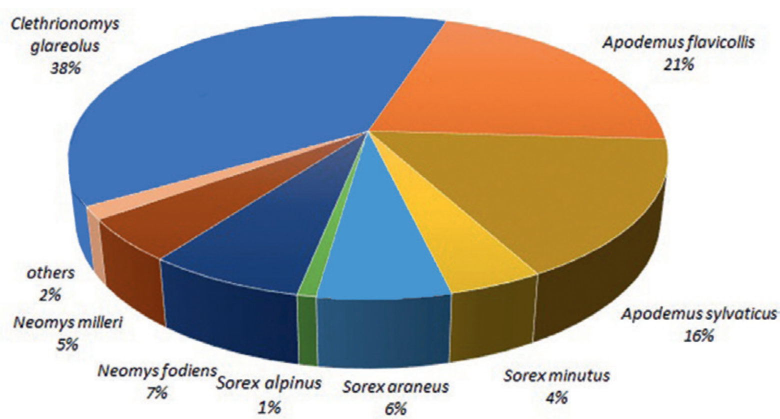


Fig. 3. Species composition and relative species density across all trapping sites and trapping periods 2009–2024 (n=2976). Species summarized under "others" are: *Crocidura leucodon* (8 specimens), *Microtus agrestis* (13), *Microtus subterraneus* (9), *Micromys minutus* (3), *Glis glis* (8), *Arvicola amphibius* (1), and *Mustela nivalis* (3).

Table 1. Individual numbers of all species caught per year. Asterisks denote beech mast years.

| species \ year | 2009* | 2010 | 2011* | 2012 | 2013 | 2014* | 2015 | 2016* | 2017 | 2018* | 2019 | 2020* | 2021 | 2022* | 2023 | 2024 | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Clethrionomys glareolus* | 57 | 183 | 74 | 164 | 23 | 24 | 67 | 36 | 123 | 21 | 127 | 47 | 83 | 25 | 58 | 31 | 1143 |
| *Apodemus flavicollis* | 7 | 61 | 5 | 21 | 7 | 25 | 17 | 27 | 64 | 10 | 151 | 11 | 125 | 18 | 34 | 37 | 620 |
| *Apodemus sylvaticus* | 34 | 8 | 23 | 69 | 7 | 53 | 34 | 27 | 16 | 31 | 43 | 13 | 76 | 9 | 24 | 12 | 479 |
| *Sorex minutus* | 22 | 3 | 9 | 4 | 20 | 9 | 26 | 14 |  | 5 | 1 | 2 | 1 | 3 |  | 8 | 127 |
| *Sorex araneus* | 6 | 5 | 3 | 11 | 37 | 4 | 54 | 10 | 5 | 26 | 3 | 2 |  | 8 | 4 | 1 | 179 |
| *Sorex alpinus* | 3 |  |  | 3 | 4 |  | 7 | 1 | 1 | 3 |  |  |  | 3 | 1 |  | 26 |
| *Neomys fodiens* | 9 |  | 19 | 12 | 12 | 3 | 2 | 26 | 17 | 4 | 11 | 17 | 15 | 23 | 27 | 14 | 211 |
| *Neomys milleri* | 2 |  | 9 | 2 | 8 | 1 | 13 | 12 | 12 |  | 15 | 8 |  | 28 | 13 | 23 | 146 |
| *Crocidura leucodon* |  |  | 1 |  |  | 2 | 1 |  |  |  | 1 | 3 |  |  |  |  | 8 |
| *Microtus agrestis* | 1 |  |  | 1 |  | 9 | 2 |  |  |  |  |  |  |  |  |  | 13 |
| *Microtus subterraneus* | 2 |  |  |  | 2 | 1 |  |  |  | 1 |  |  |  | 1 | 1 | 1 | 9 |
| *Micromys minutus* |  |  | 1 |  |  | 2 |  |  |  |  |  |  |  |  |  |  | 3 |
| *Glis glis* | 1 |  |  |  |  |  |  |  |  |  |  | 2 |  | 1 | 3 | 1 | 8 |
| *Arvicola amphibius* |  |  |  |  |  |  | 1 |  |  |  |  |  |  |  |  |  | 1 |
| *Mustela nivalis* |  |  |  |  |  | 1 |  | 1 |  |  |  |  | 1 |  |  |  | 3 |
| sum per year | 144 | 260 | 144 | 287 | 120 | 134 | 224 | 154 | 238 | 101 | 352 | 105 | 301 | 119 | 165 | 128 | 2976 |
| trap nights | 552 | 414 | 460 | 506 | 506 | 600 | 575 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 356 | 600 | 8769 |

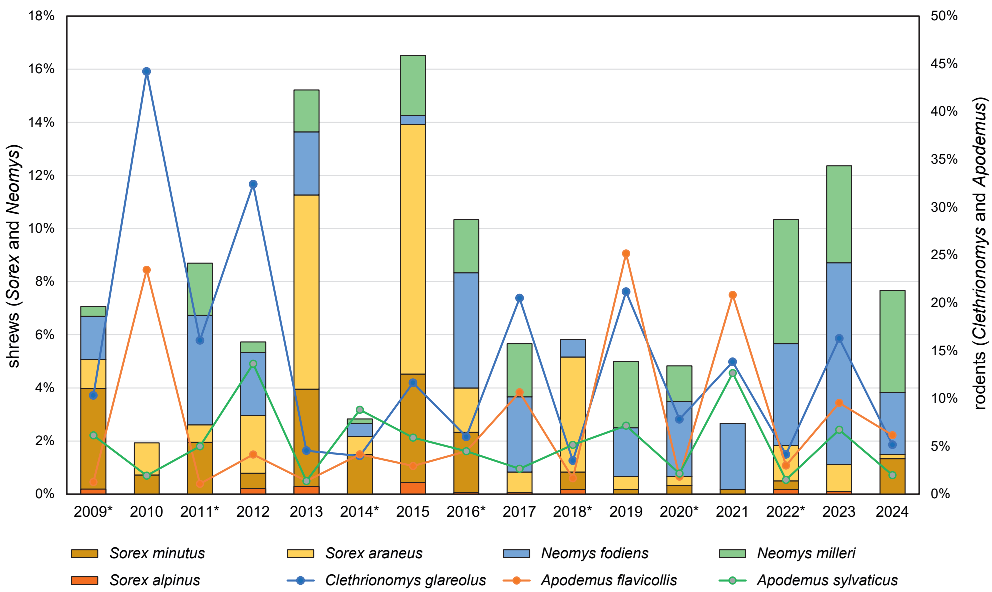


Fig. 4. Relative abundance (individuals per 100 trap nights) of small mammal species captured. Asterisks denote beech mast years; species with a percentage less than 1% are not included.

beech mast, i.e. their numbers were highest in the year following each beech mast peak. (See asterisks on the corresponding year in Fig. 4; BMEL 2024). An exception is the year 2015, when an earlier beech mast peak did not lead to a significant increase in these rodent species.

The red-toothed shrews (Soricinae) accounted for 23% of the total mammal yield; they are represented by five species, i.e. with the exception of the crowned shrew (*Sorex coronatus*), whose eastern distribution limit is found in western Bavaria, all Central European Soricinae species occur here.

The Alpine shrew was recorded with a total of 26 specimens (9 ♂♂, 8 ♀♀, 9 undetermined), representing 0.9% of the total catch. Its presence at the trapping sites was irregular, with the number of specimens caught varying between zero and four per year.

The only representative of the white-toothed shrews (Crocidurinae) was the bicoloured white-toothed shrew (*Crocidura leucodon*) with only one to three individuals captured in five of the 16 study periods (eight individuals in total). It occurred in the study area only as a transient resident or migrant. As a thermophilic species, it prefers open, dry habitats, whereas submontane humid forests, such as those found in the study area, are not a typical habitat.

Rare species that were caught only once or at longer annual intervals from year to year include the harvest mouse (*Micromys minutus*), the field vole (*Microtus agrestis*), the common pine vole (*Microtus subterraneus*), the northern water vole (*Arvicola amphibius*), the European edible dormouse (*Glis glis*), and the least weasel (*Mustela nivalis*).

## DISCUSSION

### Small mammal community composition and dynamics

As is typical of old mixed forests in the temperate zone of Central Europe, bank voles, yellow-necked mice, and wood mice form the numerically dominant group within the small mammal community. The former two have in common that tree seeds and fruits, especially beechnuts, acorns, spruce and fir seeds, make up a high proportion of their diet, depending on seasonal availability (Zemanek 1972, Canova 1993). Consequently, their catch rates and abundance vary greatly from year to year, depending on the degree of fructification of the forest trees. In the mast years, when seed production is high, survival of these small mammals is high, and the reproductive period can begin up to a month earlier than in years without mast, and even winter reproduction can occur, so there is a significant increase in the populations of the bank vole and yellow-necked mouse in the following year (Jensen 1982, Eriksson 2006, Eccard & Ylönen 2011, Imholt et al. 2014, Wereszczyńska et al. 2007, Zárybnická et al. 2017). The Pearson correlation coefficient of the relative catch rates (n individuals/100 trap nights) of the bank vole and yellow-necked mouse is r=0.61, indicating a moderately strong positive correlation between them (see heatmap Fig. 5). In contrast, the catch data on the wood mouse are only weakly positively correlated with those of the bank vole and yellow-necked mouse. However, this only explains the fact that beech mast does not induce pronounced density peaks in *Apodemus sylvaticus* as it does in the other two rodent species, otherwise the food niches of these species overlap strongly (Canova 1993).

Catch rates of the red-toothed shrews also varied greatly from year to year, with some trapping periods showing clear abundance maxima, contrasting with years of extremely low catch rates. No positive correlation was found between the density indices of the shrews and those of the bank voles and *Apodemus* species, the correlation coefficients between the respective species pairs are well below 0.5 or –0.5, only *Sorex minutus* and *Apodemus flavicollis* show a weak negative correlation with a value of –0.5 (Fig. 7). This is consistent with the results of a seven-year population study of the common and pygmy shrews in a mixed forest in Lithuania (Mažeikytė 2009), where no correlation was found between these three dominant rodent species and the shrews. However, in a long-term study in Lapland, Henttonen et al. (1989) found that the summer declines in shrew density tended to coincide with declines of the microtine rodents, and identified specialist weasel predation as a common factor affecting both shrew and microtine dynamics.

| | *Cl.. glareolus* | *A. flavicollis* | *A. sylvaticus* | *S. minutus* | *S. araneus* | *S. alpinus* | *N. fodiens* | *N. milleri* |
|---|---|---|---|---|---|---|---|---|
| *Clethrionomys glareolus* | 1,00 | | | | | | | |
| *Apodemus flavicollis* | 0,61 | 1,00 | | | | | | |
| *Apodemus sylvaticus* | 0,22 | 0,20 | 1,00 | | | | | |
| *Sorex minutus* | -0,31 | -0,50 | -0,14 | 1,00 | | | | |
| *Sorex araneus* | -0,18 | -0,35 | -0,13 | 0,69 | 1,00 | | | |
| *Sorex alpinus* | -0,17 | -0,47 | 0,01 | 0,66 | 0,88 | 1,00 | | |
| *Neomys fodiens* | -0,14 | -0,13 | -0,03 | -0,29 | -0,31 | -0,17 | 1,00 | |
| *Neomys milleri* | -0,29 | -0,12 | -0,44 | -0,10 | -0,03 | 0,06 | 0,58 | 1,00 |

Fig. 5. Heatmap of Pearsons correlation coefficient of species trapped, showing positive (green) or negative (red) correlation between their catch rates. Calculated with the CORREL function in Excel.

Whether autumnal density fluctuations in shrews are controlled by climatic factors has been the subject of contradictory research results. Studies of long-term dynamics of the common shrew in Finland (Henttonen et al. 1989) and England (Churchfield 1990), and of the common and pygmy shrews in Lithuania (Mažeikytė 2009), have shown that population densities of these species fluctuate both seasonally and annually, but with no consistent correlation with the relative severity of the winter weather. However, Dokulilová et al. (2023), in a long-term study of shrews in mountain ranges in the Czech Republic, provided evidence that autumn abundance of shrews was significantly dependent on a subset of climate variables: longer duration of snow cover in the winter prior to capture, higher mean North Atlantic Oscillation (NAO) in the months prior to capture, and NAO in September negatively affected autumn abundance of shrews, whereas higher NAO in May and October increased their abundance. However, Anděra & Hanzal (2022) questioned how extremely cold-loving species such as the Alpine shrew will respond to the current climate warming. In particular, the extent to which the macroclimatic changes are reflected in the microclimatic conditions of the favoured habitats or in their conversion or decline will be crucial.

Despite marked year-to-year fluctuations in density, the two terrestrial shrew species (*Sorex araneus* and *S. minutus*) and the two semi-aquatic *Neomys* species were found at approximately the same relative abundance throughout the 16-year study period (Fig. 3). In a field study in the Białowieża National Park in eastern Poland, Churchfield & Rychlik (2006) investigated a syntopic occurrence of these four species and found evidence of niche differentiation between them in terms of foraging and prey composition, conditions required for coexistence in freshwater habitats such as marshes, bogs, and riparian zones.

The question is whether the fluctuations in abundance within the Soricinae group are synchronous or not. In fact, the three *Sorex* species show similar population trends, with correlation coefficients of relative catch rates (n individuals/100 trap nights) between 0.66 and 0.88, indicating strong to moderately positive correlations (Fig. 5). However, the comparison with the two *Neomys* species gives a different picture: Fig. 4 shows that in some years high catches of the common and pygmy shrews coincide with low catches of both *Neomys* species and vice versa.

Capture rate of *Neomys fodiens* exceeds that of *Neomys milleri* by a ratio of 1.5:1 (211 vs. 146 individuals, Table 1). This may be due to the trap position right at the edge of the streams: Keckel et al. (2014) showed how, in a syntopic occurrence, the two species avoid interspecific competition through differential microhabitat selection: *N. anomalus* was captured more often at sites further from the water edge, while *Neomys fodiens* was recorded more often at the water edge than in the surrounding area. In our study, placing the traps directly at the water edge may have simulated a numerical dominance of the water shrew. In Bavaria as a whole, however, both species occur with about the same frequency: in an analysis of approximately 10,000 barn owl pellets with a total of more than 34,000 prey items, collected between 1990 and 2004 throughout Bavaria (excluding the Alps and other mountainous areas), 285 skulls of *Neomys milleri* were found compared to 244 of *N. fodiens*, resulting in abundance values of 0.83 and 0.71, respectively (Kraft 2008). But the distribution of *N. milleri* across Bavaria is not uniform and shows regional differences: it is relatively common in the northeast, especially in the lower hilly ranges with high rainfall, but also in the foothills of the Alps. Otherwise, there are gaps in the dry and warm areas of Lower and Middle Franconia, where it is restricted to the rainy low mountain ranges (Kraft 2008).

In the Bavarian red list, *Neomys milleri* (listed as *Neomys anomalus*) is categorised as near-threatened (V = Vornwarnliste, Rudolph & Boye 2017), a category used for species that

Fig. 6. *Sorex alpinus*, a specimen trapped in the study area in September 2022. Photo by Richard Kraft.

have declined noticeably but are not currently endangered. However, assessments of the species conservation status and threat level vary regionally: in four of 16 federal states of Germany, it is classified as either endangered (Baden-Württemberg, Nagel 2005; Thuringia, Görner 2009; and Saxony, Kapischke 2009), or critically endangered (North Rhine-Westphalia, Vierhaus & Meinig 2009, Meinig et al. 2020b). It is not included in the Red Lists of the other federal states, either because it is not considered endangered or because the species is absent (see Table 4 in Meinig et al. 2020b).

For North Rhine-Westphalia in particular, Vierhaus & Meinig (2009) see a high risk of its extinction due to rainfall deficits and resulting low groundwater levels. Stefen (2024) also sees global warming as a threat, as small water bodies and fen meadows dry up due to increasing drought. The national Red List of Germany therefore indicates a high level of responsibility for the conservation of the species (Meinig 2004).

The different conservation statuses reflect the overall geographical situation of the Miller's water shrew: its post-glacial range, which extended as far north as Schleswig-Holstein and Mecklenburg-Western Pomerania, has been shrinking for about 1,000 years and is highly fragmented and patchy at the edges of its distribution, especially at its northern limits, which run through Germany (Hutterer 1982b, Heinrich 1989).

In the Czech Republic, however, the availability of new data for *Neomys milleri* has led to a significant change in the assessment of the status of the population: although it was previously classified as critically endangered, recent mapping by Anděra & Hanzal (2022) shows no evidence of endangerment, but rather an increasing population trend and colonisation of regions where it was previously absent. However, it is not clear whether this is due to population growth, more intensive trapping, or because it was previously overlooked and confused with *Neomys fodiens* (M. Anděra, in litt.).

### Population status and risks of *Sorex alpinus*

With a catch rate of less than 1% over the entire study period, the Alpine shrew stands out clearly from the other species of red-toothed shrews in the study area. Although the habitat structure at the trapping sites provides favourable living conditions for this cold-adapted species, its numbers are much lower than those of the other red-toothed shrew species, and in some years (e.g. 2019–2021) not a single specimen was caught despite the same trapping intensity.

One might assume that the Alpine shrew rarity is due to a lower reproductive rate compared to other shrews. However, data on thousands of Soricinae shrews collected over decades in Slovakia and analysed by Baláž & Ambros (2006) do not support this assumption: the reproductive cycle of *S. alpinus* lasts as long as the reproductive period of *S. araneus* and *S. minutus*, with pregnant females being found from the 2nd week of April to the 3rd week of September, and with two to three litters per season (see Spitzenberger 1990). Although the average number of embryos in *Sorex alpinus* is slightly lower than in *S. araneus* and *S. minutus* (5.72 vs. 6.12. and 6.97, respectively), this does not indicate how many young are actually born and successfully reared.

However, when comparing capture rates, it should be borne in mind that the Alpine shrew occupies the ecological niche of a crevice dweller, spending much time in underground structures or cavities and less time above ground (Hutterer 1982a). In this way, it avoids direct competition for food with the syntopic common and pygmy shrews (Kuviková 1986, Klenovšek et

Fig. 7. *Neomys milleri,* a specimen trapped in the study area in September 2022. Photo by Richard Kraft.

al. 2013). The resulting low capture success and occasional negative capture results may lead to erroneous conclusions about the presence or absence of the Alpine shrew in a study area.

However, because the Alpine shrew population in the southern Oberpfälzer Forest is isolated from the Bavarian Forest and other subpopulations, it may be at risk of local extinction. Due to its altitude, the Oberpfälzer Forest has a cool and rainy climate, providing favourable living conditions for cold-adapted organisms such as the Alpine shrew and other Soricinae species. However, since the middle of the 20th century, the average annual temperature in the East Bavarian hills and mountains has already risen by 1.9 °C (BLfU 2021) and the region has experienced several dry summers in recent years. In particular, the years of extreme heat and drought since 2015 have weakened the forests and at the same time greatly promoted the spread of forest-damaging insects (Bayerisches Staatsministerium für Ernährung, Landwirtschaft und Forsten 2023). The local forest administration expects further damage due to rainfall deficits and massive bark beetle infestation, and predicts a drastic change in the forest. Small surface water bodies, which are important habitats for the Alpine shrew (as well as for the two semi-aquatic *Neomys* species), are expected to dry up.

Although *Sorex alpinus* is not tied to specific forest types and can also colonise non-forest areas (Görner 2005), it is currently not possible to estimate how the expected conversion of forests, with the loss of shady and moist habitats, will affect the microclimate on the ground and the living conditions of the Alpine shrew. As even small changes in microclimate are sufficient to threaten populations of *Sorex alpinus* (Görner 2005), we consider climate change and the resulting changes in forest composition and soil moisture to be a potential threat to the Alpine shrew, especially outside of its main Alpine range.

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## REFERENCES

Anděra M. & Hanzal V., 2022: *Atlas rozšíření hmyzožravců České republiky* [*The Atlas of Distribution of Insectivores in the Czech Republic*]. Agentura ochrany přírody a krajiny České republiky, Praha, 123 pp (in Czech).

Baláž I. & Ambros M., 2006: Shrews (*Sorex* spp.) somatometry and reproduction in Slovakia. *Biologia, Bratislava*, **61**: 611—620.

BLfU [Bayerisches Landesamt für Umwelt], 2021: *Bayerns Klima im Wandel*, *Klimaregion Ostbayerisches Hügel- und Bergland*. Bayerisches Landesamt für Umwelt, Augsburg, 18 pp.

Bothschafter E., 1957: Die Alpenspitzmaus (*Sorex alpinus* Schinz, 1837) aus niedriger Höhenlage im Randgebiet des Bayerischen Waldes. *Säugetierkundliche Mitteilungen*, **5**: 28–30.

Brünner H., 2017: *Erfassung möglicher Vorkommen der Alpenspitzmaus* (*Sorex alpinus*) *im Fichtelgebirge*. Unpubl. final report. Regierung von Oberfranken, Regensburg, 30 pp.

BMEL [Bundesministerium für Ernährung und Landwirtschaft], 2024: *Ergebnisse der Waldzustandserhebung 2023*. Bundesministerium für Ernährung und Landwirtschaft, Bonn, 80 pp.

Canova L., 1993: Resource partitioning between the bank vole *Clethrionomys glareolus* and the wood mouse *Apodemus sylvaticus* in woodland habitats. *Italian Journal of Zoology*, **60**: 193–198.

Churchfield S., 1990: *The Natural History of Shrews*. C. Helm / A. and C. Black, London, 178 pp.
Churchfield S. & Rychlik L., 2006: Diets and coexistence in *Neomys* and *Sorex* shrews in Białowieża forest, eastern Poland. *Journal of Zoology*, *London*, **269**: 381–390.
Demartin G., Schöttner R., Siuda C., Feichtinger V., Hofmann R. & Scheidler M., 2020: Moorrenaturierungen im Klimaschutzprogramm Bayern 2050 – Handwerkszeug, Beispiele und Herausforderungen. *ANLiegen Natur*, **42**(1): 19–30.
Dokulilová M., Krojerová-Prokešová J., Heroldová M., Čepelka L. & Suchomel J., 2023: Population dynamics of the common shrew (*Sorex araneus*) in Central European forest clearings. *European Journal of Wildlife Research*, **69**: 54.
Eccard J. & Ylönen H., 2011: Initiation of breeding after winter in bank voles: Effects of food and population density. *Canadian Journal of Zoology*, **79**: 1743–1753.
Eriksson M., 2006: Winter breeding in three rodent species, the bank vole *Clethrionomys glareolus*, the yellow-necked mouse *Apodemus flavicollis* and the wood mouse *Apodemus sylvaticus* in southern Sweden. *Ecography*, 7: 428–429.
Gahsche J., 1994: Die Alpenspitzmaus (*Sorex alpinus*) im Harz. *Säugetierkundliche Informationen*, **3**(18): 601–609.
Görner M., 2005: Zum Vorkommen der Alpenspitzmaus (*Sorex alpinus*) in Deutschland und Hinweise zum Schutz. *Säugetierkundliche Informationen*, **5**(31): 575--586.
Görner M., 2009: Sumpfspitzmaus *Neomys anomalus*. Pp. 94–95. In: Görner M. (ed.): *Atlas der Säugetiere Thüringens*. *Biologie – Lebensräume – Verbreitung – Gefährdung – Schutz*. Arbeitsgruppe Artenschutz Thüringen e.V. & Landesjagdsverband Thüringen, Jena, 279 pp.
Heinrich D., 1989: Ein weiterer subfossiler Fund der Sumpfspitzmaus (*Neomys anomalus* Cabrera, 1907) in Norddeutschland. *Zeitschrift für Säugetierkunde*, **54**: 261–264.
Henttonen H., Haukisalmi V., Kaikusalo A., Korppimäki E., Norddahl K. & Skarén U. A., 1989: Long-term population dynamics of the common shrew *Sorex araneus* in Finland. *Annales Zoologici Fennici*, **26**: 349–355.
Hutterer R., 1982a: Biologische und morphologische Beobachtungen an Alpenspitzmäusen (*Sorex alpinus*). *Bonner Zoologische Beiträge*, **33**: 3–18.
Hutterer R., 1982b: Die Sumpfspitzmaus in Nordrhein-Westfalen. *Natur und Heimat*, **42**: 51–54.
Imholt C., Reil D., Eccard J. A., Jacob D., Hempelmann N. & Jacob J., 2014: Quantifying the past and future impact of climate on outbreak patterns of bank voles (*Clethrionomys glareolus*). *Pest Management Science*, **71**: 166–172.
Jensen T., 1982: Seed production and outbreaks of non-cyclic rodent populations in deciduous forests. *Oecologia*, **54**: 184–192.
Kahmann H., 1952: Beiträge zur Kenntnis der Säugetierfauna in Bayern. *Bericht der Naturforschenden Gesellschaft Augsburg*, **5**: 147–170.
Kapischke H.-J., 2009: Sumpfspitzmaus *Neomys anomalus* Cabrera, 1907. Pp. 100–101. In: Hauer S., Ansorge H. & Zöphel U. (eds.): *Atlas der Säugetiere Sachsens*. Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, Dresden, 416 pp.
Keckel M. R., Ansorge H. & Stefen C., 2014: Differences in the microhabitat preferences of *Neomys fodiens* (Pennant 1771) and *Neomys anomalus* Cabrera, 1907 in Saxony, Germany. *Acta Theriologica*, **59**: 485–494.
Klenovšek T., Novak T., Čas M., Trilar T. & Janžekovič F., 2013: Feeding ecology of three sympatric *Sorex* shrew species in montane forests of Slovenia. *Folia Zoologica*, **62**: 193–199.
Kraft R., 2008: *Mäuse und Spitzmäuse in Bayern*. Ulmer, Stuttgart, 111 pp.
Kraft R., 2019: *Suche nach Vorkommen der Alpenspitzmaus* (*Sorex alpinus*) *im Fichtelgebirge im Jahr 2019*. Unpubl. final report. Regierung von Oberfranken, Regensburg, 28 pp.
Kraft R., Klemmer W. & Malec F., 2010: Neue Nachweise der Alpenspitzmaus (*Sorex alpinus*) im Oberpfälzer Wald (Ostbayern). *Säugetierkundliche Informationen*, **7**(40): 335–340.
Kuviková A., 1986: Nahrung und Nahrungsansprüche der Alpenspitzmaus (*Sorex alpinus*, Mammalia, Soricidae), unter den Bedingungen der tschechoslowakischen Karpaten. *Folia Zoologica*, **35**: 117–125.

Mažeikytė J. R., 2009: Population dynamics of the common shrew and pygmy shrew (Soricomorpha: Soricidae) in a clear-cut of a mixed forest in eastern Lithuania. *Estonian Journal of Ecology*, **58**: 205–215.

Meinig H., 2004: Einschätzung der weltweiten Verantwortlichkeit Deutschlands für die Erhaltung von Säugetierarten. *Naturschutz und Biologische Vielfalt*, **8**: 117–131.

Meinig H., Bertolino S. & Zima J., 2020a: *Sorex alpinus*. *The IUCN Red List of Threatened Species*: e.T29660A114024313. URL: dx.doi.org/10.2305/IUCN.UK.2020-2.RLTS.T29660A114024313.en.

Meinig H., Boye P. & Dähne M., 2020b: Rote Liste und Gesamtartenliste der Säugetiere (Mammalia) Deutschlands. *Naturschutz und Biologische Vielfalt*, **170**: 1–73.

Müller F., Lütt O. & Heddergott M., 2012: Die Alpenspitzmaus (*Sorex alpinus* Schinz 1837, Soricidae) – ein kaum bekanntes, vom Aussterben bedrohtes Kleinod der Säugetierfauna in der Rhön. *Beiträge zur Naturkunde in Osthessen*, *Fulda*, **49**: 3–7.

Nagel A., 2005: Sumpfspitzmaus *Neomys anomalus* Cabrera, 1907. Pp. 78–81. In: Braun M. & Dieterlen F. (eds.): *Die Säugetiere Baden-Württembergs*. *Band 2*. Eugen Ulmer GmbH & Co., Stuttgart, 704 pp.

Rudolph B.-U. & Boye P., 2017: *Rote Liste und kommentierte Gesamtartenliste der Säugetiere* (*Mammalia*) *Bayerns*. Bayerisches Landesamt für Umwelt, Augsburg, 83 pp.

Spitzenberger F., 1990: *Sorex alpinus* Schinz, 1837 – Alpenspitzmaus. Pp. 295–312. In: Niethammer J. & Krapp F. (eds.): *Handbuch der Säugetiere Europas*. *Band 3/1*. *Insektenfresser – Insectivora*, *Herrentiere – Primates.* Aula Verlag, Wiesbaden, 523 pp.

Starcová M., Vohralík V., Kryštufek B., Černá Bolfíková B. & Hulva P., 2016: Phylogeography of the Alpine shrew, *Sorex alpinus* (Soricidae, Mammalia). *Folia Zoologica*, **65**: 107–116.

Stefen C., 2024: Schwer fassbar, versteckt und rar? Zur Verbreitung der Sumpfspitzmaus (*Neomys anomalus milleri*) in Deutschland. *Säugetierkundliche Informationen*, **12**(61): 307–320.

Vierhaus H. & Meinig H., 2009: Säugetiere. Pp. 202–225. In: Behrens M., Fartmann T. & Hölkzel N. (eds.): *Auswirkungen von Klimaänderungen auf die Biologische Vielfalt*: *Pilotstudie zu den voraussichtlichen Auswirkungen des Klimawandels auf ausgewählte Tier- und Pflanzenarten in Nordrhein-Westfalen*. *Teil 2*: *zweiter Schritt der Empfindlichkeitsannayse – Wirkprognose*. Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz des Landes Nordrhein-Westfalen, Meinz, 364 pp.

Wereszczyńska A. M., Nowakowski W. K., Nowakowski J. K. & Jędrzejewska B., 2007: Is food quality responsible for the cold-season decline in bank vole density? Laboratory experiment with herb and acorn diets. *Folia Zoologica*, **56**: 23–32.

Zárybnická M., Riegert J., Bejček V., Sedláček F., Šťastný K., Šindelář J., Heroldová M., Vilímová J. & Zima J., 2017: Long-term changes of small mammal communities in heterogenous landscapes of Central Europe. *European Journal of Wildlife Research*, **63**(89): 1–12.

Zemanek M., 1972: Food and feeding habits of rodents in a deciduous forest. *Acta Theriologica*, **17**: 315–325.