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# Mediterranean water shrew (*Neomys anomalus*): range expansion northward

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**Abstract:** We identified three individuals of the Mediterranean water shrew (*Neomys anomalus*) in Estonia, expanding the known distribution range of the species to the north by 500 km from the most northern location in Lithuania and over 700 km from Poland. The identification of the species in Estonia, the most northern known locality, was based on the position of mental foramen, height of coronoid process (>4.3 mm), and Libois index (<16.5). Individuals in the northern populations of *N. anomalus* were smaller than those from southern populations. The most reduced features (by about 10%) are the length of the maxillary and mandibular tooth rows, skull breadth, and height of mandibula. The range expansions require reconsidering known diagnostic characters of the species in comparison with the sympatric *N. fodiens* as well as the cut-offs for their measurements and, possibly, highlight the need to search for new diagnostic criteria.

**Key words**: *Neomys anomalus*, distribution range, diagnostic characters, Bergman's rule

## 1. Introduction

In the 20th century, the Mediterranean water shrew, *Neomys anomalus* Cabrera, 1907, was reported as inhabiting continental Europe between the latitudes of 37°N and 55°N and Asia Minor (Spitzenberger, 1999). On the southern edge of its limit, the species range was found to be about 1000 km greater than previously known in 2008 (Esmaeili et al., 2008), while the Gac peninsula in Poland was reported as the most northern part of the species distribution range in 1979 (Obertaniec, 1979). However, in 2012, evidence was published detailing a new locality of *N. anomalus* in Lithuania, i.e. expanding the known range by ca. 350 km to the northeast (Balčiauskas and Balčiauskienė, 2012).

When skulls of water shrews (*N. fodiens*) from Estonia were analyzed (Balčiauskas et al., 2014), three individuals not conforming to the diagnostic traits of the species were discovered and attributed to *N. anomalus*. With this discovery, the distribution range of *N. anomalus* was thus expanded even further to the north.

The aim of this paper is to present a new mammal species for Estonia, *N. anomalus*, and to discuss the spread of the species range northwards and to outline skull characters useful for species identification.

## 2. Materials and methods

A skull collection of 105 *Neomys* individuals trapped in Estonia (57.5°N to 59.5°N) between 1980 and 2002 was analyzed. Craniometric measurements were taken under a binocular microscope with a micrometric eyepiece or digital caliper, both graduated to 0.1 mm. In addition to the 18 skull characters measured (Figure 1) for each individual, we also had the animal's body weight (Q, g), body length (L, mm), tail length (C, mm), and hind foot length (P, mm) as registered at the time of trapping and written on the collection label. Ear length (A, mm) was not measured in all cases.

Several of these measurements (X7, X13, X2, and X4) are diagnostic, i.e. there is no overlap between *N. anomalus* and *N. fodiens* (Peman, 1983; Libois, 1986; Balčiauskas and Balčiauskienė, 2012). Along with foot length, the critical length being ca. 17 mm (B Kryštufek, personal communication), we used these characters to check if all the skulls had been correctly identified in the collection.

Based on nonoverlapping measurements between *N. anomalus* and *N. fodiens* in Lithuania, namely hind foot length, tail length, height of coronoid process, rostral length, condylobasal length, condyloincisive length, postglenoid width, and zygomatic width (Balčiauskas and Balčiauskienė, 2012), we checked the Estonian material creating scatterplots for the pairs of these characters.

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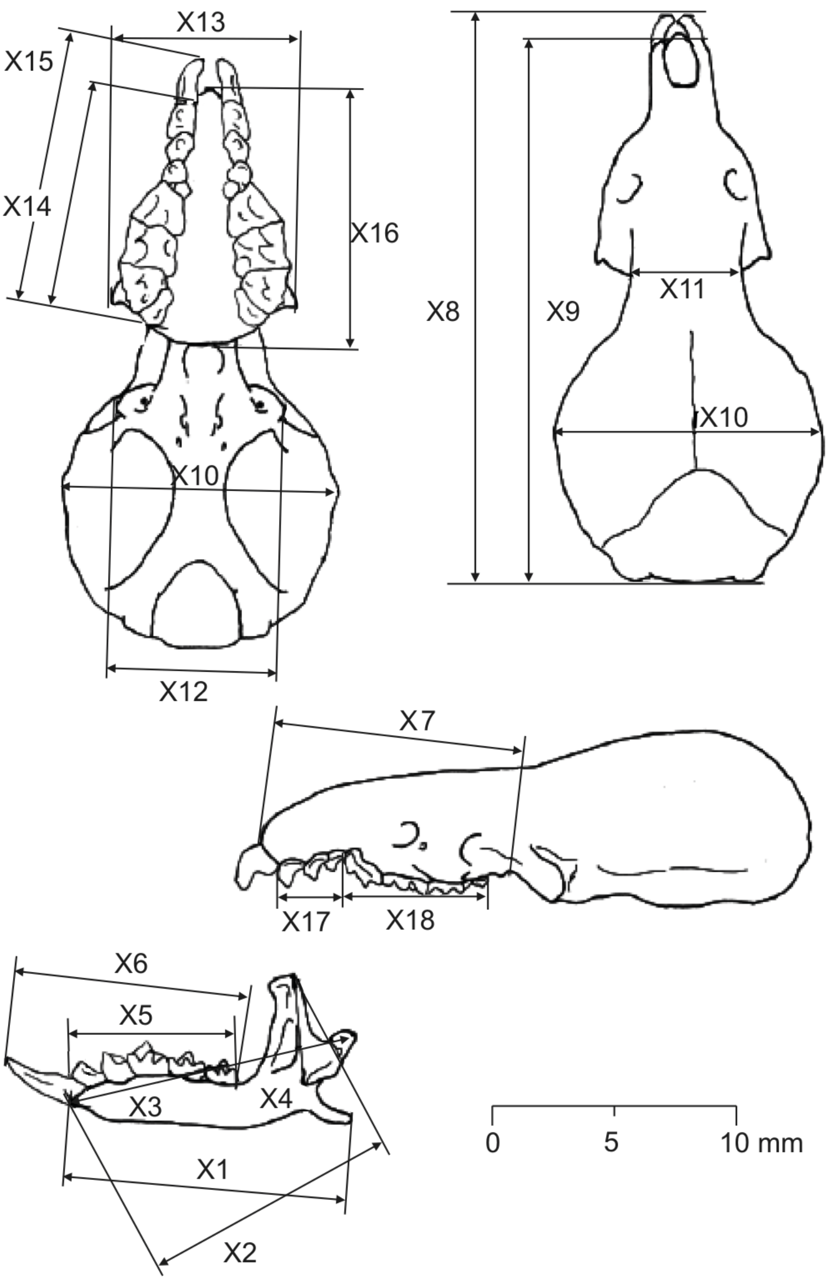


**Figure 1.** Skull measurements of *Neomys*: X1 – angular length of mandibula, X2 – coronoid length of mandibula, X3 – length of mandibula, X4 – height of coronoid process, X5 – length of mandibular tooth row, X6 – length of mandibular tooth row with incisive, X7 – rostral length, X8 – condyloincisive length, X9 – condylobasal length, X10 – cranial width, X11 – interorbital breadth, X12 – postglenoid width, X13 – zygomatic width, X14 – length of maxillary tooth row, X15 – length of maxillary tooth row with incisive, X16 – palatal length, X17 – length of the unicuspid tooth row, and X18 – length of the molariform tooth row.

We also tested the applicability of the formula of Libois (1986): $X = 2.58 \times X4 + 2.78 \times X5 - X3$, where $X > 18.43$ is *N. fodiens* and $X < 18.43$ is *N. anomalus*. As there have only been a few *N. anomalus* individuals identified in Lithuania (Balčiauskas and Balčiauskienė, 2012), we had no possibility to carry out statistical analysis over the short geographic scale, as we did with *N. fodiens* (Balčiauskas et al., 2014).

For specimens in which the measurements and Libois index values were smaller than expected for *N. fodiens*, we checked the position of the lacrimal foramen in the maxilla and mental foramen in mandibula. For *N. anomalus*, the position of the mental foramen should be under the anterior edge of M1 (Barti, 2006), and the position of the lacrimal foramen should be between M1 and M2 (Barti, 2006; Rolland, 2008).

All statistics were done in Statistica ver. 6 (StatSoft, 2010).

## 3. Results

Diagnostic features of N. *anomalus* from Estonia are presented in Figures 2a–2f. According to the mental foramen in the mandible, three *N. anomalus* individuals were identified for the first time in Estonia (Table 1; Figures 2a, 2c, and 2e). The position of the lacrimal foramen (Figures 2b, 2d, and 2f) was not so characteristic, but nonetheless it was typically different than that of *N. fodiens*.

After analysis of measurements of cranial and mandibular characters, three individuals from Estonia in this study belonged undoubtedly to *N. anomalus*. In the scatterplots of character pairs, they were separated from *N. fodiens*, and the measurements were similar to those of the *N. anomalus* individuals from Lithuania. For

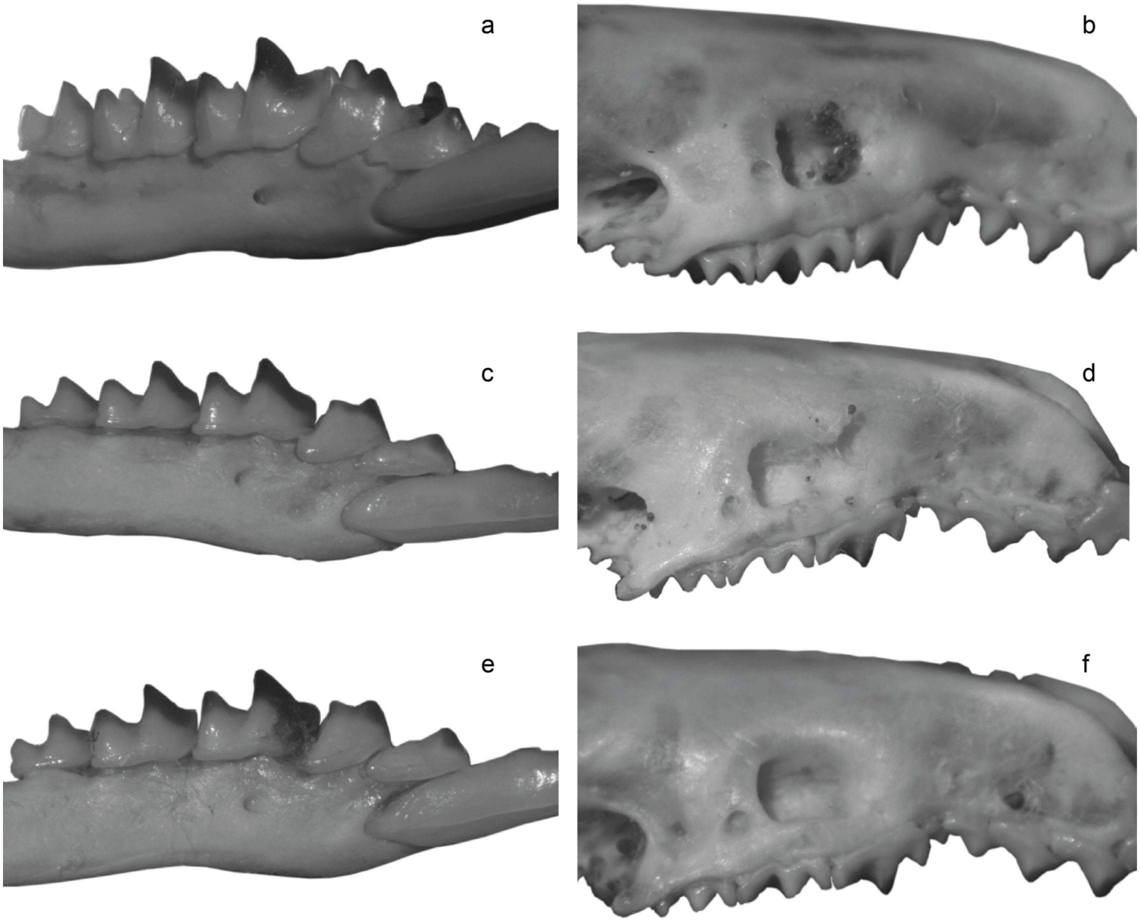


**Figure 2.** Position of the mental foramen (a, c, e) and lacrimal foramen (b, d, f) in *Neomys anomalus* from Estonia (not to scale).

**Table 1.** Collection data on *Neomys anomalus* from Estonia.

| Label | Sex | Age | Q, g | L, mm | C, mm | P, mm | A, mm |
|---|---|---|---|---|---|---|---|
| UTM – EK78, Võhma, 1981.08.06, leg. A. Kirk, U. Timm | ♂ | Ad. | 15.1 | 80 | 51 | 16.5 | 6 |
| UTM – MG40, Altja, 1989.07.24, leg. T. Maran, U. Timm | ♂ | Juv. | 6.6 | 70 | 58 | 17.0 | |
| UTM – LF59, Sõrve, 1999.09.10, leg. U. Timm | ♂ | Ad. | 18.0 | 84 | 55 | 17.0 | |

the scatterplots, the height of coronoid process (X4) in combination with two other characters from both the skull and mandible was used (Figure 3).

The Libois (1986) formula showed a clear separation of *N. fodiens* and *N. anomalus* in Estonia ($F_{1,50}$ = 13.3, P = 0.0006) and Lithuania ($F_{1,105}$ = 29.3, P < 0.0001) and in a general sample from both countries ($F_{1,157}$ = 48.1, P < 0.0001). The values of Libois X did not overlap between the species (Table 2). The cut-off value separating *N. fodiens* and *N. anomalus* was smaller than the value of 18.43 given for Belgium and Luxemburg by Libois (1986).

Comparison of cranial measurements showed that the northern *N. anomalus* specimens are characterized by smaller skull measurements when compared to the

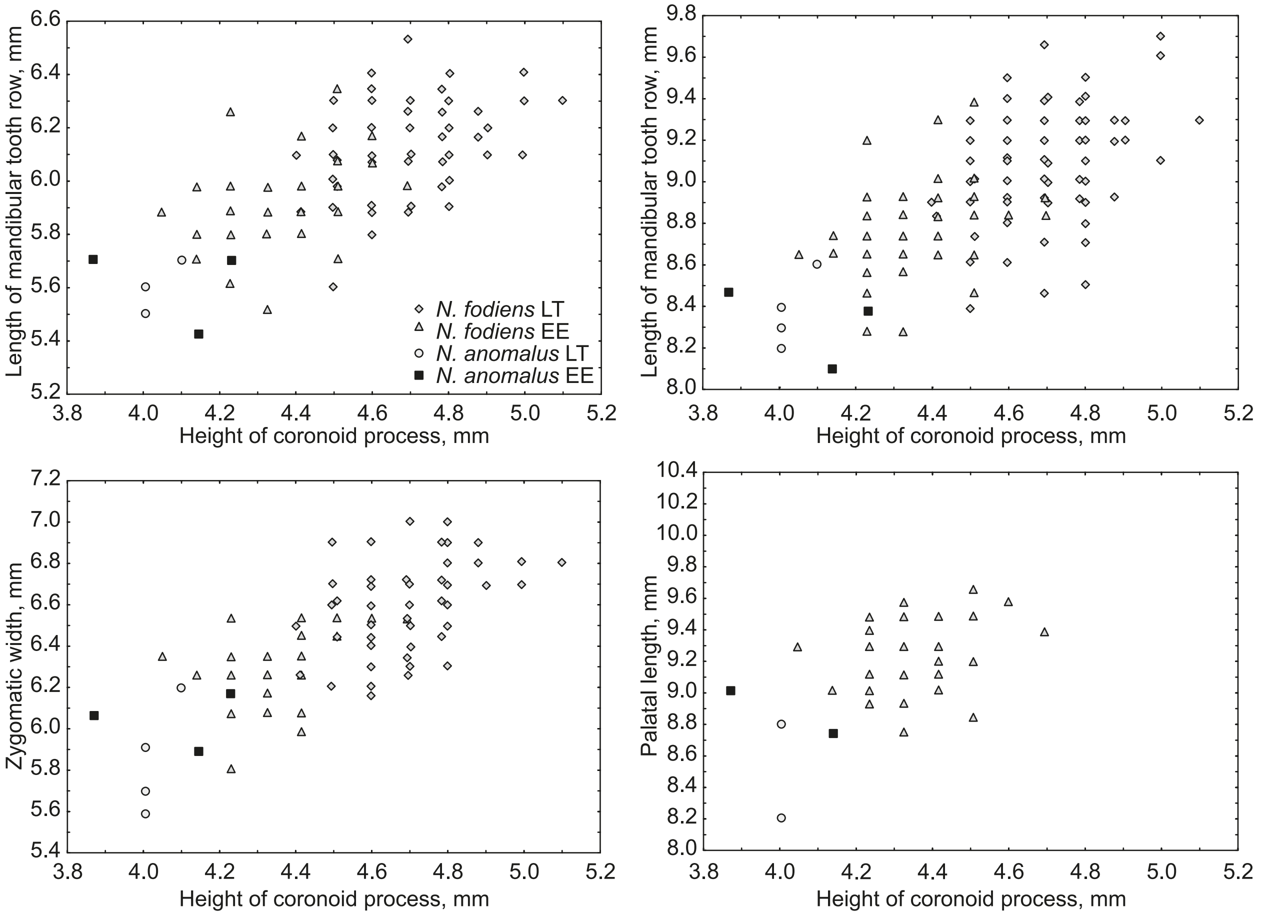


**Figure 3.** Scatterplots of character pairs for *Neomys fodiens* and *N. anomalus* in Lithuania and Estonia.

**Table 2.** Distinguishing between *Neomys fodiens* and *N. anomalus* in Lithuania and Estonia according to the formula X = 2.58 × X4 + 2.78 × X5 – X3 by Libois (1986). Data for *N. fodiens* from Balčiauskas et al. (2014).

| Species | Country | n | Avg ± SE | Min–max |
|---|---|---|---|---|
| *N. fodiens* | Estonia | 49 | 17.35 ± 0.07 | 16.58–18.51 |
| *N. anomalus* | Estonia | 3 | 16.25 ± 0.11 | 16.07–16.47 |
| *N. fodiens* | Lithuania | 103 | 18.59 ± 0.06 | 17.12–20.12 |
| *N. anomalus* | Lithuania | 4 | 15.96 ± 0.19 | 15.61–16.42 |
| *N. fodiens* | Both countries | 152 | 18.19 ± 0.06 | 16.58–20.12 |
| *N. anomalus* | Both countries | 7 | 16.08 ± 0.13 | 15.61–16.47 |

X3 – length of mandibula, X4 – height of coronoid process, X5– length of mandibular tooth row.

southern populations. For example, when compared to Spain, the skull measurements of *N. anomalus* in Lithuania were on average 8.2% smaller, and those in Estonia by 7.0% (Table 3). The most reduced characters were related to the length of maxillary (X14, 12,7%) and mandibular (X5, 9.8%) tooth rows, skull breadth (X11, 10.2%), and height of mandibula (X4, 9.2%). Furthermore, the decrease of skull measurements between Lithuania and Estonia was expressed only by shorter mandible and mandibular tooth rows (X1 – 2.1%, X2 – 1.2%, X3 – 0.5%, X6 – 0.8%). These differences were not significant. The other skull measurements for *N. anomalus* from Estonia were found to be bigger than those of Lithuania (Table 3), but the sample sizes in both countries were very small.

The new *N. anomalus* localities extended the known northern range of the species to the Estonian coast of the Baltic Sea, a distance of over 700 km from the most northern location in Poland and about 500 km from Lithuania (Figure 4).

## 4. Discussion

Range shift, mainly to the north (Hickling et al., 2006; Parmesan, 2006; La Sorte and Thompson, 2007; Chen et al., 2011;, Thomas et al., 2012) or up slopes (Wilson et al., 2005; Moritz et al., 2008; Rowe et al., 2010), is currently known for many terrestrial species. Various reasons for range shifts have been mentioned, such as climate change, mainly global warming (Walther et al., 2002; Parmesan and Yohe, 2003; Chen et al., 2011); the influence of protected areas (Thomas et al., 2012); changes of habitats (Balčiauskas et al., 2010; Mori et al., 2013); and the complex interaction of several factors (Carroll, 2007).

However, so far mainly birds and butterflies have been used as examples of such spread (Franco et al., 2006; Hickling et al., 2006; La Sorte and Thompson, 2007; Drees et al., 2011). Sometimes, along with the spread north, a simultaneous contraction of the range in the south has occurred (Wilson et al., 2005; Levinsky et al., 2007; Drees et al., 2011).

**Table 3.** Cranial measurements (in mm) of *Neomys anomalus* in Spain (n = 10, according to Peman, 1983), Lithuania (n = 4), and Estonia (n = 3). In Lithuania and Estonia, the localities are the most northerly situated for the whole species range.

| | Spain | | Lithuania | | Estonia | |
|---|---|---|---|---|---|---|
| | Avg ± SE | Min–max | Avg ± SE | Min–max | Avg ± SE | Min–max |
| X1 | 10.15 ± 0.07 | 9.8–10.8 | 9.7 ± 0.12 | 9.3–9.8 | 9.4 ± 0.25 | 9.2–9.9 |
| X2 | 8.89 ± 0.10 | 8.48–9.45 | 8.5 ± 0.25 | 7.9–9.1 | 8.4 ± 0.37 | 7.9–9.1 |
| X3 | 10.45 ± 0.09 | 10.0–10.76 | 9.9 ± 0.15 | 9.5–10.2 | 9.9 ± 0.22 | 9.6–10.3 |
| X4 | 4.49 ± 0.02 | 4.35–4.6 | 4.0 ± 0.03 | 4.0–4.1 | 4.1 ± 0.11 | 3.9–4.2 |
| X5 | 6.22 ± 0.06 | 5.83–6.4 | 5.6 ± 0.05 | 5.5–5.7 | 5.6 ± 0.09 | 5.4–5.7 |
| X6 | 8.9 ± 0.09 | 8.45–9.3 | 8.4 ± 0.09 | 8.2–8.6 | 8.3 ± 0.11 | 8.1–8.5 |
| X7 | 9.09 ± 0.11 | 8.64–9.45 | 8.7 ± 0.12 | 8.4–9.0 | 8.9 ± 0.18 | 8.7–9.3 |
| X8 | | | 19.1 ± 0.28 | 18.8–19.7 | 19.6 ± 0.33 | 19.1–20.2 |
| X9 | | | 18.1 ± 0.47 | 17.4–19.0 | 18.8 ± 0.33 | 18.3–19.4 |
| X10 | | | 9.7 ± 0.26 | 9.3–10.2 | 9.9 ± 0.25 | 9.6–10.4 |
| X11 | 4.44 ± 0.04 | 4.35–4.7 | 3.9 ± 0.13 | 3.6–4.0 | 4.0 ± 0.06 | 3.9–4.0 |
| X12 | 6.18 ± 0.05 | 5.95–6.7 | 5.6 ± 0.11 | 5.4–5.9 | 5.7 ± 0.08 | 5.6–5.9 |
| X13 | 6.42 ± 0.04 | 6.25–6.7 | 5.9 ± 0.13 | 5.6–6.2 | 6.0 ± 0.08 | 5.9–6.2 |
| X14 | 8.78 ± 0.09 | 8.3–9.0 | 7.6 ± 0.05 | 7.4–7.6 | 7.7 ± 0.03 | 7.6–7.7 |
| X15 | 9.5 ± 0.17 | 9.15–9.7 | 8.8 ± 0.06 | 8.6–8.9 | 9.0 ± 0.13 | 8.8–9.3 |
| X16 | 9.24 ± 0.09 | 8.79–9.6 | 8.5 ± 0.30 | 8.2–8.8 | 8.9 ± 0.14 | 8.7–9.0 |
| X17 | | | 2.9 ± 0.05 | 2.7–2.9 | 2.9 ± 0.03 | 2.9–2.9 |
| X18 | | | 4.6 ± 0.10 | 4.3–4.8 | 4.6 ± 0.05 | 4.5–4.7 |

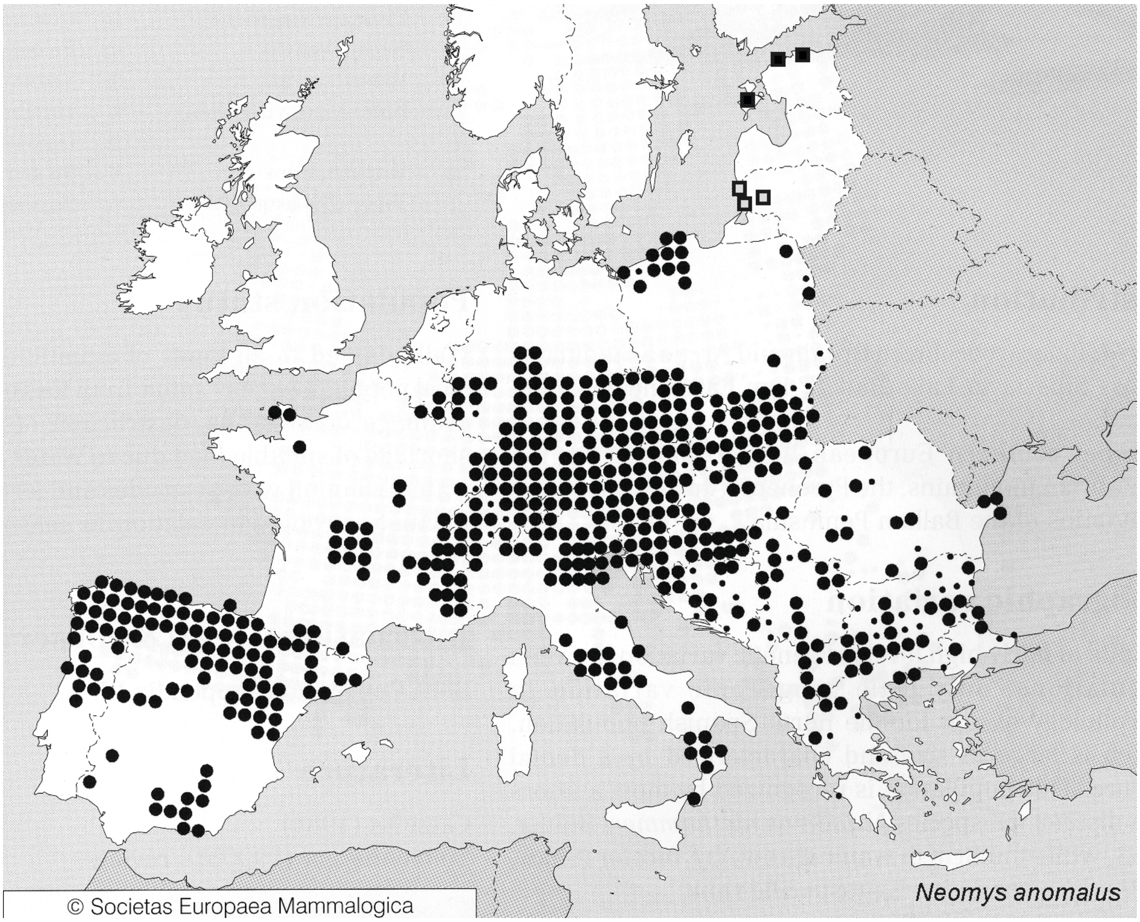


**Figure 4.** The former range of *Neomys anomalus* in Europe (dots) with new localities from Lithuania (empty squares) and Estonia (full squares) (map from Spitzenberger, 1999).

Few examples are known of the northward shift of ranges of other organism groups, such as mammals (Hickling et al., 2006; Levinsky et al., 2007; Moritz et al., 2008; Balčiauskas et al., 2010; Mori et al., 2013). Although the evidence is scanty, the available data for the range of several shrew species point to both a northward shift in their ranges and an upward shift in altitude terms (Moritz et al., 2008; Rowe et al., 2010). The arrival of several shrew species spreading northwards is foreseen in some national parks in the United States (Burns et al., 2003). Theoretically, a northward shift of invertebrates may also influence insectivorous shrew species whose diets will be affected (Levinsky, 2007).

Many shrew species do not conform to Bergmann's rule, i.e. individuals of the same species are smaller in the northern parts of their range (Ochocińska and Taylor, 2003; Yom-Tov and Yom-Tov, 2005). However, it was shown that both *N. fodiens* (Balčiauskas et al., 2014) and *N. anomalus* (Kryštufek and Quadracci, 2008) are larger in the southern parts of the range. The same is true even over short latitudinal distances for *N. anomalus* (Kryštufek and Vohralík, 2001). For *N. fodiens*, a diminishing of body and cranial measurements to the north was found in the middle of the distribution range (Balčiauskas et al., 2014), but only some (López-Fuster, 1990) or none (Kryštufek and Quadracci, 2008) of the measurements responded to negative latitudinal patterns in the southern part of the range.

In the situation where the body sizes of the two are expected to be similar, i.e. in the south of the range, what diagnostic characters could be used to separate the two sympatric species, *N. anomalus* and *N. fodiens?* What would the critical separation values be? Peman (1983) showed that the position of the lacrimal foramen provided a valid diagnosis in 94.4% of cases in the studied sample. In the situation where the position was unclear, the usage of other characters was advised.

A scatterplot of the tail length against hind foot length of a sample from Bulgaria (both *N. anomalus* and *N. fodiens*) showed some overlap in the range of 16–18 mm for hind foot and 52–60 mm for tail lengths (Popov and Zidarova, 2008). In our sample, such a scatterplot also had an overlap. As we only had a skull collection in Estonia, it was not possible to look at the appearance of the tail – the presence of the keel covering only part of the tail assisted in identifying *N. anomalus* in Lithuania (Balčiauskas and Balčiauskienė, 2012). However, in the Baltic (Lithuania plus Estonia) sample of *N. anomalus*, both tail and hind foot were significantly shorter compared to those in *N. fodiens* (tail 50.7 ± 2.4 vs. 61.2 ± 0.4 mm, $F_{2,129}$ = 17.07, P < 0.00001; hind foot 15.9 ± 0.5 vs. 17.9 ± 0.7 mm, $F_{2,129}$ = 20.28, P < 0.00001).

The height of the coronoid process (X4) is characterized as a diagnostic trait by all authors (Peman, 1983; Libois, 1986; Niethammer and Krapp, 1990), being less than 4.5 mm for *N. anomalus* in Belgium (Libois, 1986), less or equal to 4.6 mm in France, and 4.7 mm in Spain (Peman, 1983). In the individuals from Lithuania, this feature was also diagnostic: 4.0 mm in *N. anomalus* versus 4.4–5.1 mm in *N. fodiens* (Balčiauskas and Balčiauskienė, 2012). We tabulated the height of the coronoid process and hind foot length and found that measurements of *N. anomalus* from Estonia fall into the range of these measurements observed in other countries (Table 4).

Individuals of *N. anomalus* from Estonia with hind foot length of 16.5–17.0 mm and height of coronoid process of 3.9–4.2 mm fit into the scheme of the latitudinal size pattern (Kryštufek and Quadracci, 2008); i.e. the size of *N. anomalus* converges with the size of *N. fodiens* in the southern part of the distribution range. According to these two measurements (hind foot length and height of coronoid process), the Baltic (Lithuanian and Estonian) populations of *N. anomalus* are closest in size to those in Poland, the Czech Republic, and Germany.

As for the distribution range, *N. anomalus* is a species of shrew whose known distribution range has expanded nearly 1000 km in the south (Esmaeili et al., 2008) and over 700 km in the north in the last decade. Formerly, the northern edge of the range of the species in Belarus was considered to follow the basin of the Pripyat River (Kashtalian, 2005), before expanding over 250 km north to the Belarussian side of the Bialowiezha Forest. In neighboring Poland, the Bialowiezha Forest had been known to host *N. anomalus* for a long time (Pucek, 1984), and the most northern locality for this species was situated in Słowiński National Park near the Baltic coast

**Table 4.** Hind foot length (P) and height of coronoid process (HC) of *Neomys fodiens* and *N. anomalus* in various countries, presented as minimum–maximum or average (in parentheses) (from Niethammer and Krapp, 1990).

| Location | *N. anomalus* | | | *N. fodiens* | | |
|---|---|---|---|---|---|---|
| | n | P, mm | HC, mm | n | P, mm | HC, mm |
| Iberian Peninsula | 45 | 15.4–18 | 4.25–5.65 | 14 | – | 5.5–6.1 |
| Italy | 8 | 15.5–16.5 | 4.3–4.8 | 32 | 16–20 | 4.4–5.0 |
| Slovenia and Croatia | 37 | 14–17 (16.3) | 4.15–4.9 (4.5) | 14 | 17–20 (18.6) | 4.9–5.5 (5.2) |
| Serbia, Bosnia and Herzegovina | 6 | 15.4–18.2 | 4.65–4.8 | 14 | 18–19 (18.6) | 4.8–5.3 (5.0) |
| Macedonia | 13 | 15.5–17.1 (16.4) | 4.3–4.9 (4.61) | 16 | 17–20 (18.5) | 4.6–5.0 (4.8) |
| Bulgaria | 3 | 15–16 | – | 14 | 17–20 (18.3) | – |
| Greece | 11 | 15–16.6 (16) | 4.35–4.8 (4.5) | 3 | 18–19 (18.3) | 4.5–4.9 (4.7) |
| France | 5 | 15–16.4 | 4.1 | 137 | 16–21 (17.6) | 4.4–4.7 (4.5) |
| Switzerland | 32 | 14–17 | (4.41) | 16 | 18–19 | 4.4–5.0 |
| Liechtenstein | 7 | 14–17 (15.1) | 3.9–4.2 (4. 14) | 10 | 18–19 (18.1) | 4.5–4.9 (4.7) |
| Austria | 9 | 15.2–16.2 (15.7) | 4.0–4.4 (4.2) | 14 | 17.7–18.9 (18.5) | 4.5–4.9 (4.7) |
| Hungary | 9 | – | 4.25–4.47 | – | – | – |
| Moldova | – | 14.8–16.2 | – | – | – | – |
| Germany | 22 | 15–16.4 | 4.0–4.5 | 181 | 16–20 | 4.5–5.4 |
| Czech Republic | 23 | 14.5–16.0 | 4.1–4.4 (4.2) | 103 | 18–20 | 4.6–5.3 (5.0) |
| Ukraine | 7 | 13.8–18.0 | – | – | 16–21 | – |
| Poland (Białowieża) | 31 | 13–15.3 (14.5) | 3.8–4.3 (4.03) | – | 18–20 (18.2) | 4.8–5.5 (5.1) |

(Obertaniec, 1979). As identification of this species has been problematic, it is an open question, however, as to whether the range of *N. anomalus* has actually shifted north in the last decades – though only reidentified 2 years ago, the Estonian specimens actually date from the early 1980s. These range expansions therefore require reconsidering the known diagnostic characters of the species in comparison with the sympatric *N. fodiens* as well as the cut-offs for their measurements and, possibly, highlight the need to search for new diagnostic criteria.

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## References

Balčiauskas L, Balčiauskienė L (2012). Mediterranean water shrew, *Neomys anomalus* Cabrera, 1907 – a new mammal species for Lithuania. North-West J Zool 8: 367–369.

Balčiauskas L, Balčiauskienė L, Baltrūnaitė L (2010). Root vole, *Microtus oeconomus*, in Lithuania: changes in distribution range. Folia Zool 59: 267–277.

Balčiauskas L, Balčiauskienė L, Timm U (2014). Bergmann's rule for *Neomys fodiens* in the middle of the distribution range. Cent Eur J Biol 9: 1147–1154.

Barti L (2006). Az állkapcsi lyuk (Foramen mentale) helyzete, mint kiegészítõ határozóbélyeg a *Neomys* fajok (Mammalia, Insectivora Soricidae) biztosabb elkülönítésére. Acta Siculica 1: 191–199 (in Hungarian).

Burns CE, Johnston KM, Schmitz OJ (2003). Global climate change and mammalian species diversity in U.S. national parks. P Natl Acad Sci USA 100: 11474–11477.

Carroll C (2007). Interacting effects of climate change, landscape conversion, and harvest on carnivore populations at the range margin: marten and lynx in the northern Appalachians. Conserv Biol 21: 1092–1104.

Chen CI, Hill JK, Ohlemüller R, Roy DB, Thomas CD (2011). Rapid range shifts of species associated with high levels of climate warming. Science 333: 1024–1026.

Drees C, Brandmayr P, Buse J, Dieker P, Gürlich S, Habel J, Harry I, Härdtle W, Matern A, Meyer H et al. (2011). Poleward range expansion without a southern contraction in the ground beetle *Agonum viridicupreum* (Coleoptera, Carabidae). ZooKeys 100: 333–352.

Esmaeili HR, Gholamhosseini G, Teimory A, Kryštufek B (2008). Noteworthy record of the Mediterranean water shrew (*Neomys anomalus*) from South-Western Iran (Mammalia: Soricomorpha). Turk J Zool 32: 163–166.

Franco AMA, Hill JK, Kitschke K, Collingham YC, Roy DB, Fox R, Huntley B, Thomas CD (2006). Impacts of climate warming and habitat loss on extinctions at species' low-latitude range boundaries. Glob Change Biol 12: 1545–1553.

Hickling R, Roy DB, Hill JK, Fox R, Thomas CD (2006). The distribution of a wide range of taxonomic groups are spreading polewards. Glob Change Biol 12: 450–455.

Kashtalian AP (2005). Soricidae of Belarus – modern status and geographical distribution. In: Merritt JF, Churchfield S, Hutterer R, Sheftel BI, editors. Advances in the Biology of Shrews II. New York, NY, USA: International Society of Shrew Biologists.

Kryštufek B, Quadracci A (2008). Effects of latitude and allopatry on body size variation in European water shrews. Acta Theriol 53: 39–46.

Kryštufek B, Vohralík V (2001). Mammals of Turkey and Cyprus: Introduction, Checklist, Insectivora. Koper, Slovenia: Knijžnica Annales Majora.

La Sorte FA, Thompson FR (2007). Poleward shifts in winter ranges of North American birds. Ecology 88: 1803–1812.

Levinsky I, Skov F, Svenning JC, Rahbek C (2007). Potential impacts of climate change on the distributions and diversity patterns of European mammals. Biodivers Conserv 16: 3803–3816.

Libois RM (1986). Biogeography and ecology of the water shrews (genus *Neomys*) in Belgium and Luxemburg. Cahiers d'Ethologie Appliquee 6: 101–120.

López-Fuster MJ, Ventura J, Miralles M, Castién E (1990). Craniometrical characteristics of *Neomys fodiens* (Pennant, 1771) (Mammalia, Insectivora) from the northeastern Iberian Peninsula. Acta Theriol 35: 269–276.

Mori E, Sforzi A, Di Febbraro M (2013). From the Apennines to the Alps: recent range expansion of the crested porcupine *Hystrix cristata* L., 1758 (Mammalia: Rodentia: Hystricidae) in Italy. Ital J Zool 80: 469–480.

Moritz C, Patton JL, Conroy CJ, Parra JL, White GC, Beissinger SR (2008). Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. Science 322: 261–264.

Niethammer J, Krapp F (1990). Handbuch der Saugetiere Europas. Band 3 (Insektenfresser, Herrentiere). Wiesbaden, Germany: Aula-Verlag (in German).

Obertaniec J (1979). Występowanie rzęsorka mniejszego, *Neomys anomalus* Cabrera, 1907 (Insectivora) na Pomorzu. Przeg Zool 23: 172–173 (in Polish).

Ochocińska D, Taylor JRE (2003). Bergmann's rule in shrews: geographical variation of body size in Palearctic *Sorex* species, Biol J Linn Soc 78: 365–381.

Parmesan C (2006). Ecological and evolutionary responses to recent climate change. Annu Rev Ecol Evol S 37: 637–669.

Parmesan C, Yohe G (2003). A globally coherent fingerprint of climate change impacts across natural systems. Nature 421: 37–42.

Peman E (1983). Biometría y sistemática del género *Neomys*, Kaup 1771 (Mammalia, Insectivora), en el País Vasco. Munibe 35: 115–148. (in Spanish)

Popov VV, Zidarova SA (2008). Patterns of craniometric variability of *Neomys fodiens* and *Neomys anomalus* (Mammalia, Insectivora) in Bulgaria – role of abiotic and biotic factors. Acta Zool Bulgar 60: 171–185.

Pucek Z, editor (1984). Identification Keys on Polish mammals. Warsaw, Poland: PAN.

Rolland C (2008). Clé d'identification des micro-mammifères de Rhône-Alpes. Lyon, France: CORA Faune Sauvage.

Rowe RJ, Finarelli JA, Rickart E (2010). Range dynamics of small mammals along an elevational gradient over an 80-year interval. Glob Change Biol 16: 2930–2943.

Spitzenberger F (1999). *Neomys anomalus* Cabrera, 1907. In: Mitchell-Jones AJ, Amori G, Bogdanowicz W, Kryštufek B, Reijnders PJH, Spitzenberger F, Stubbe M, Thissen JBM, Vohralík V, Zima J, editors. The Atlas of European Mammals. London, UK: Academic Press, pp. 58–59.

StatSoft, Inc. (2010). Electronic Statistics Textbook. Tulsa, OK, USA: StatSoft.

Thomas CD, Gillingham PK, Bradbury RB, Roy DB, Anderson BJ, Baxter JM, Bourn NAD, Crick HQP, Findon RA, Fox R et al. (2012). Protected areas facilitate species' range expansions. P Natl Acad Sci USA 109: 14063–14068.

Walther GR, Post E, Convey P, Menzel A, Parmesan C, Beebee TJC, Fromentin JM, Hoegh-Guldberg O, Bairlein F (2002). Ecological responses to recent climate change. Nature 416: 389–395.

Wilson RJ, Gutiérrez D, Gutiérrez J, Martínez D, Agudo R, Monserrat VJ (2005). Changes to the elevational limits and extent of species ranges associated with climate change. Ecol Lett 8: 1138–1146.

Yom-Tov Y, Yom-Tov J (2005). Global warming, Bergmann's rule and body size in the masked shrew *Sorex cinereus* Kerr in Alaska. J Anim Ecol 74: 803–808.