Novitates Theriologicae, **13** (2022): 71–79
doi: http://doi.org/10.53452/nt1332

Morphological features of *Pipistrellus nathusii* from the eastern part of its range (Middle Volga region)

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Artemieva, E., I. Zagorodniuk. **Morphological features of *Pipistrellus nathusii* from the eastern part of its range (Middle Volga region).** — A study was carried out on the morphometric parameters of regional samples of *Pipistrellus nathusii* populations from the Middle Volga region, which is the eastern part of the species' range. In general, metric characters are typical of those of the species; clear differences were found by the colouration of wing membranes. The right-bank sample corresponds to the typical (northern, forest) form of *P. nathusii*. The left-bank (eastern) sample corresponds to the more southern and steppe form, which is characterized by a light tone of coat and a well-defined narrow white stripe on the edge of the wing, which is designated as colour type *pargaré*. Obviously, this feature of colouration is a marker of the most south-eastern *P. nathusii*. Moreover, this feature characterizes the whole group of pipistrelles and is well known for the desert form of *P. pipistrellus bactrianus*, and is most pronounced in the eastern *P. kuhlii lepidus*. Original data on cases of detection *pangaré*-type depigmentation in other species of bats in the Volga region are noted (*Vespertilio murinus* and *Myotis daubentonii*). Thus, the *pangaré*-type colour of wing membranes in different bat species is a regional trait. In general, this is in line with Gloger's ecogeographic rule of ligher colouration in arid conditions.

Introduction

The eastern populations of many European bat species are of interest in connection with the clarification of the boundaries of their species ranges and their morphological features, which is associated with the pronounced geographical variability of many species having wide ranges. One of these regions is the Middle Volga region. The study of bats in this region and the morphological and ecological features of some species remains relevant, despite previous studies (Popov 1960; Strelkov & Ilyin 1990; Ilyin & Smirnov 2000; Bezrukov & Smirnov 2012). Of particular interest are the features of Nathusius's pipistrelle, *Pipistrellus nathusii*, in which there are individuals with a pronounced *pangaré*-type in wing colouration, that is, depigmentation of the free edge of the wing membrane.

The bat *Pipistrellus nathusii* Keiserling et Blasius, 1839 is a species that has a wide range extending from France to the Urals. It is migratory here, seasonally present, with a pronounced seasonality of reproduction. According to the directions

of its seasonal migrations (northeasterly vector) (Hutterer *et al*. 2005) and areas of permanent residence, this is a species whose range has recently unambiguously expanded in a northeasterly direction; it is also one of the few who inhabited the most north-eastern corners of Europe. All north-eastern populations belong to the south-western part of the range. Studies of the species in the eastern part of the range showed that, in the Volga region, it is the most common and numerous among local bats (Strelkov & Buntova 1982; Smirnov et al. 2012, 2017; Artemieva 2021). For this species, important material was accumulated by the authors, which makes it possible to give its morphological characteristics. The aim of the article is to identify the morphological features of *P. nathusii* in the Middle Volga region.

Materials and Methods

The species was recorded and collected in the following localities: Pervomaiske, Stara Maina, Krasna Poliana, Smorodino, Shylovka, Undory, and the city of Ulyanovsk. The morphological material was collected mainly during the field season of 2021 at the biological station 'Stara Maina.' Bats were caught near the shelters using a 'mobile trap' (two paired fishing rods, between which a 2x1.5 m net is stretched, with a net of fishing line with a mesh of 14 mm) (Borisenko 1999). Original photographs with detailed morphological features were also accumulated.

Two geographic samples of *P. nathusii* were studied: from the populations of the left bank and the right bank of the Middle Volga region. Individuals were measured alive (using a caliper) with the subsequent analysis of 7 morphometric characters: body length, forearm length, tail length, foot length, tibia length, ear length, and wingspan. The identification of the trapped individuals was carried out using the works by Dietz & Helversen (2004), Zagorodniuk *et al*. (2002), and Zagorodniuk (2003). For all individuals, sex and age were determined (Dietz & Helversen 2004). A total of 19 specimens of this species were studied and 50 pro-photographs with details of coat and wing colouration and ears and pawa morphology were processed.

Metric data were analysed using standard tests in MS Excel. As a measure of difference, we used the coefficient of divergence (CD), or the Lyubishchev coefficient, an index of samples divergence (Lyubishchev 1959; Zagorodniuk 2004).

Results

In this work, two groups of characters are studied—metric and colouration.

Metric characters

Three of the seven morphometric characters studied were found to be the most significant: body length, forearm length, and wingspan. The samples were formed according to the criteria of sex and age (Table 1). After this, a pairwise comparison of the four groups was carried out.

Table 1. Comparison of sex and age groups of *Pipistrellus nathusii* in morphometric characters (combined samples from all studied localities)

Таблиця 1. Порівняння статевих груп *Pipistrellus nathusii* за морфометричними ознаками (об'єднані вибірки з усіх досліджених місцезнаходжень)

Characters, mm	Age	Males	N	Females	n	CD
Body length	adultus	47.3 ± 3.20	4	50.5 ± 0.71	2	-0.99
	juvenilis	45.9 ± 2.05	5	43.8 ± 2.31	5	0.67
Forearm length	adultus	33.1 ± 0.25	4	34.4 ± 0.21	2	-3.74
	juvenilis	33.0 ± 035	5	33.9 ± 0.89	5	-0.94
Wingspan	adultus	24.4 ± 0.95	4	24.3 ± 0.35	2	0.12
	juvenilis	23.8 ± 0.91	5	23.4 ± 0.79	5	0.37

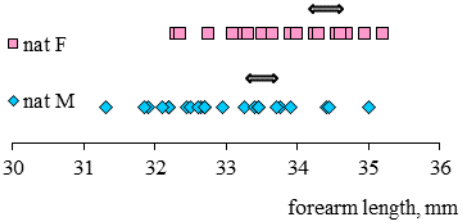

Fig. 1. Distribution of forearm length in males and females of *Pipistrellus nathusii* (adults) in the total sample of the studied specimens (ranges of variability are marked with a double-sided arrow ↔). For comparison, data for a sample from Ukraine are presented (after: Zagorodniuk 2018).

Рис. 1. Розподіл довжини передпліччя у самців і самок *Pipistrellus nathusii* (дорослі особини) у сукупній вибірці вивчених зразків (позначені двосторонньою стрілкою ↔). Для порівняння взято дані для вибірки з України (за: Загороднюк 2018).

The greatest differences in all pairs of comparisons were found between adult females and males by the length of the forearm (CD = 3.74): the value of this character is smaller in males. In fact, males and females from the studied sample do not overlap in this measurement, although in this species the overlap of data for males and females is generally significant (Fig. 1). In the group of adults, females are larger than males in almost all characters.

In young bats, when compared with adults, males are ahead of females in two out of three metric characters, which indicates their faster growth. It is important to note that the growth of juveniles continues until the onset of seasonal migration and during it, since the sample of juveniles includes specimens from August as well (in total, juveniles were studied on the following dates: 11.07, 12.07, 22.07, 8.08, 11.08, 13.08, 08, and 27.08).

Colouration features

Comparison of the left-bank and right-bank samples revealed differences in the colouration of the body and wing membranes.

The right-bank samples are characterized by a light, greyish-beige colour and a uniform colour of the membranes.

On the contrary, left-bank pipistrelles are characterized by a darker, brownish-red colour of the body and the presence of a pronounced depigmentation strip along the free edge of the wing membrane.

In the terminology of fur colours in mammals, this refers to the lightening of the colouration, known as dilution, and the appearance of depigmented areas along the margin of the membranes, which corresponds to the colouration type '*pangaré*.' In a broader sense, *pangaré* as a lightening of individual parts of the body also extends to the groin, armpits, and belly.

Photographic materials from the left bank and right bank samples of *P. nathusii* are presented below (Fig. 2). In particular, a specimen of the "northern" color type (light, without a white wing margin) was caught at the Pervomaiskoye locus (Fig. 2*a*–*b*). On the contrary, a specimen of the "southern" form was caught in a pine forest in the vicinity of Stara Maina: it is distinguished by the presence of a narrow white stripe along the wing margin (Fig. 2*c*–*f*).

Individuals with such phenotype have not been previously described by researchers of bats in the region. In particular, in the more northern regions (Volga-Kama Kray), this colouration variant was not noted (Popov 1960).

Discussion

The species *Pipistrellus nathusii* has a very wide geographic range (Fig. 3), within which a pronounced geographic variability has formed. In particular, such variability is manifested in the general lightening of the colouration that may be referred to a type 'dilution.' Two colour races exist in populations that are spatially separated and confined to different biotopes. The typical race (without a white marginal stripe) inhabits forest biotopes, while the race with a white stripe (*pangaré*) occurs in steppe localities.

As it can be seen, the dilution morph can be designated as a desert (southern) colouration type. The same form was recently described for the population of *P. nathusii* from the Black Sea region (Zagorodniuk 2020), and earlier a similar form was described for the Asian population of the common pipistrelle, *P. p. bactrianus* (Ognev 1928; Kuzyakin 1950). At the same time, investigators of this pipistrelle subspecies do not report anything about the same morphotype in eastern *Pipistrellus nathusii* (Ognev 1928: 486–490). A specimen of the 'steppe' morphotype *P. p. bactrianus* is shown in Fig. 4.

Such colouration from the dilution group (lightness) is referred by us to the type of undergrowth (Pangare or Mealy). It is not a diagnostic trait of species, but marks the desert and southern forms of almost all East European pipistrelles, which we noted earlier for the south Ukrainian *P. nathusii* (Zagorodniuk 2020: 188). At the same time, it is important to note that such morphotype has not been described in other, more northern, areas (see: Abelentsev & Popov 1956); therefore, such specimens may be migrants from the north-east, that is, from the Volga region.

Fig. 2. Features of colouration in Nathusius' pipistrelle *Pipistrellus nathusii*: *a–b*—northern forest form without a white stripe along the wing margin (ventral and front views, 08.08.2009, leg. E. Artemieva); *c–d*—southern steppe form, with narrow white stripe along the wing margin (ventral and dorsal views, 17.06.2009, leg. Kondratiev); *e–f*—southern steppe form, a narrow white stripe along the wing margin (ventral view); *f*—place of attachment of the hindfoot to the wing membrane (22.07.2021). Photo by E. Artemieva.

Рис. 2. Особливості забарвлення у нетопира лісового, *Pipistrellus nathusii*: *a–b* — північна лісова форма без білої смуги по краю крила (вид знизу та спереду, 08.08.2009, leg. Е. Артемьева); *c-d* — південна степова форма, з вузькою білою смугою по краю крила (вид знизу та зверху, 17.06.2009, leg. Kondratiev); *e–f* — південна степова форма з вузькою білою смугою по краю крила (вид знизу) та місце прикріплення лапки до болони (22.07.2021). Фото Є. Артем'євої.

Fig. 3. Geogrpahic range of Nathusius' pipistrelle, *Pipistrellus nathusii* (IUCN website). The white circle indicates the study area of the species in the eastern part of the range.

Рис. 3. Ареал нетопира лісового, *Pipistrellus nathusii* (з вебсайту МСОП). Білим колом позначено область дослідження виду у східній частині його ареалу.

Fig. 4. Specimen of *Pipistrellus bactrianus*, collected in Mary on 7 August 1938 and stored in the Museum of Nature of Kharkiv University (♀ No. 2544). The depigmentation of the posterior edge of the wing membrane is clearly visible. Photo by Yu. Iliukhin.

Рис. 4. Зразок *Pipistrellus bactrianus*, зібраний у Мари 07.08.1938, зберігається в Музеї природи Харківського університету (♀ № 2544). Добре видна депігментація заднього краю крилової мембрани. Автор фото: Ю. Іллюхін.

This specimen of Nathusius' pipistrelle is neither unique nor isolated. A similar trend is typical for other forms of this genus and other species of bats. An expressive example is demonstrated by *P. kuhlii*, in which the eastern populations are characterized not only by a narrow white stripe on the wing, but also by a very wide zone of depigmentation on the plagiopathagium. This feature distinguishes the eastern populations of *P. kuhlii* from the western ones. This character allows for dividing this taxon into two allospecies: western *P. kuhlii* (s. str.) with a narrow band on the wing membrane and eastern *P. lepidus* with a wide band, up to 10 mm (e.g. see: Postawa & Marchewka 2021).

It is inportant that there are records of some other (not pipistrelle) bat species with a pronounced dilution morph along the wing edge also occuring in the Volga region. Similar specimens were trapped by the authors at the same localities: Daubenton's bat *Myotis daubentonii* and parti-coloured bat *Vespertilio murinus* (Table 2).

A large set of similar cases can be the key to understand the patterns of geographic variability in bats of the region (as well as across Euroope on the whole) and of the role of the regional component in it. The authors attribute this colouration form to Gloger's ecogeographical rule (1883). According to this rule, subspecies of the same species or closely related species of the same genus living in areas with different climates have also different colouration.

Table 2. Bat species with phenotypes with different variants of colour lightening in the eastern and southern areas of the range

Таблиця 2. Види рукокрилих, що мають фенотипи з різними варіантами освітлення забарвлення у східних і південних областях ареалу

Species	Colour lightening variants	References
Myotis daubentonii	dilution (Pangare)	data of E. Artemieva (unpublished)
Pipistrellus nathusii	dilution (Pangare), partial albinism	data of authors, Smirnov *et al*. 2012
Pipistrellus kuhlii	dilution (Pangare)	data of E. Artemieva (unpublished)
Eptesicus serotinus	partial albinism	Smirnov *et al*. 2012
Vespertilio murinus	dilution (Pangare)	data of E. Artemieva (unpublished)

Subspecies in warm and humid regions have darker and more saturated colouration that appear due to accumulation of *eumelanin* in the organism. And, conversely, subspecies from dry and hot regions commonly have light (red, yellow-brown) colouration, because under such climatic conditions *pheomelanin* are concentrated in the integument. Therefore, desert populations have so-called 'desert' colouration (Lopatin & Meleshko 2016). So, colour lightening is an adaptive feature of populations to exist in arid and semi-arid areas of the geographic range, and it is a climatic adaptation of species (Smirnov *et al.* 2012).

All these facts indicate the presence of homologous series in the colouration of species within the same family (Vespertilionidae). Possibly, that there is a common pattern of colouration and the presence of certain ecogeographical trends in variability in the space of the ranges of these species.

Moreover, the lightening of the pigmentation in the southern and south-eastern regions is a general ecogeographical phenomenon in different systematic groups. Thus, in the butterflies of family Lycaenidae, the form 'persica' is known from and widely distributed in arid regions. It appears in the expressed lightening of the background of the underside of the wings, as well as in fading and reduction of the wing pattern (Artemieva 1992, 2020).

As a result of the study of morphoecological features of Nathusius' pipistrelle populations from the studied eastern segment of its range (Middle Volga region), the following conclusion has been drawn.

1. The analysis of morphometric characters demonstrates a clear sexual dimorphism. The most significant character is the length of the forearm: in females it is longer (34.4 ± 0.21) than in males (33.1 ± 0.25). Juveniles do not reach the size of adults even in late August and at the beginning of the migration season. Metric characters are similar to data from other regions.

2. *Pipistrellus nathusii* from the Volga region show differences in colouration that correspond to the northern forest and the southern steppe forms. This phenomenon can be explained by Gloger's ecogeographical rule.

3. Dilution morph of the eastern (steppe) *P. nathusii* mark the south-eastern populations of this species, but also it appears entirely in all other species of the genus *Pipistrellus* on the whole (on the scale of regional fauna). Dilution morphotypes can also be found in some other bat species in this region.

Acknowledgments

The authors are grateful to Vadim Bezrukov for the provided materials and photos of bats, to Olga Saltykova for photos and consultations on the collection of bats and assistance in the collecting of the material. The authors are especially grateful to Dmitry Smirnov and Mikhail Drebet for consultations on the identification of bat species, and to Yurij Iliukhin for the photo of collected specimens.

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Резюме

Артем'єва Є. & І. Загороднюк. **Морфологічні особливості *Pipistrellus nathusii* зі східної частини ареалу (Середнє Поволжя).** — Досліджено морфометричні показники *P. nathusii* з Середнього Поволжя як східної частини його ареалу. Загалом метричні показники типові для виду; виразні відмінності виявлено у забарвленні крилових болон. Правобережна вибірка відповідає типовій (північній, лісовій) формі *P. nathusii*. Лівобережна (східна) вибірка відповідає більш південній і степовій формі, для неї характерні світлий тон забарвлення тіла та добре виразна вузька біла смужка по краю крила, яка позначена як кольоровий тип *pargaré*. Очевидно, що особливість забарвлення є маркером найбільш південно-східних *P. nathusii*. Понад те, подібна особливість характеризує всю групу нетопирів і добре відома для пустельної форми *P. pipistrellus bactrianus*, а найбільше проявляється у східних *P. kuhlii lepidus*. Відмічено оригінальні дані про факти виявлення підласості в інших видів кажанів Поволжя (*Vespertilio murinus* and *Myotis daubentonii*). Отже, pangare-стиль у забарвленні крилових мембран у різних видів рукокрилих є регіональною ознакою. Загалом це відповідає екогеографічному правилу Глогера про висвітлення забарвлення в аридних умовах.