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Erforschung biologischer Ressourcen der  
Mongolei / Exploration into the Biological  
Resources of Mongolia, ISSN 0440-1298

Institut für Biologie der Martin-Luther-  
Universität Halle-Wittenberg

2021

## The House Mouse *Mus musculus* in Mongolia: Taxonomy, Status, and Ecology of a Neglected Species

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Appenborn, Rico; Lammers, Katrin; Harr, Bettina; Lkhagvasuren, Davaa; Samiya, Ravchig; Stubbe, Michael; and Ansoerge, Hermann, "The House Mouse *Mus musculus* in Mongolia: Taxonomy, Status, and Ecology of a Neglected Species" (2021). *Erforschung biologischer Ressourcen der Mongolei / Exploration into the Biological Resources of Mongolia*, ISSN 0440-1298. 245.

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## The house mouse *Mus musculus* in Mongolia – taxonomy, status and ecology of a neglected species<sup>1</sup>

R. Apenborn, K. Lammers, B. Harr, D. Lkhagvasuren, R. Samiya, M. Stubbe & H. Ansorge

### Abstract

Although the house mouse as a common and widely distributed species is probably best-studied among small mammals, there is a lack of fundamental knowledge regarding species identity, morphology and ecology in Mongolia. Consequently, this study provides results of basic biological research on the Mongolian house mouse. A total of 172 specimens have been studied based on samples collected during the period 1962 to 2016. Using genetic and morphological markers, the taxonomic examination resulted in classification as *Mus musculus musculus* LINNAEUS, 1758. To characterise the Mongolian house mouse, three fur colour traits and 23 metric body and skull traits were analysed. Two obviously different morphotypes were identified: (1) light individuals with a distinct demarcation line, which occur in most parts of the country, (2) dark individuals with a diffuse demarcation line, which are mainly found in the northern part of the Selenge province. Furthermore, these morphotypes differ in five metric body and skull traits. In general, Mongolian house mice seem to be consistent with reference specimens from Eastern Europe according to metric traits, although exhibiting a shorter tail. In Mongolia *Mus musculus* lives hemisynanthropically. Habitat preferences are human settlements, but also in natural habitats such as oases, dunes and lakeshores. The population epigenetic analysis by using nonmetric cranial traits exposed three main populations: northcentral, southeast, and west. The latter seems to be more isolated from the other populations, probably due to the Altai Mountains as a natural barrier. The resulting epigenetic distances of the Mongolian house mice are rather low in comparison to other rodents, which indicates that house mice are quite talented in terms of dispersal. The western, southern, and eastern populations show lower values of fluctuating asymmetry (6.5 to 9.0 %), than the northern and central populations (11.5 to 13.1 %). Therefore, the latter seems to be more influenced by environmental or genetic stress factors.

**Key words:** *Mus musculus*, Mongolia, taxonomy, morphology, reproduction, ecology

### 1. Introduction

The house mouse *Mus musculus* LINNAEUS, 1758 is a worldwide distributed and well-known species within the small-mammal fauna (FREYE & FREYE 1960, ELLERMANN & MORRISON-SCOTT 1966, MUSSER & CARLETON 2005). However, its systematics has been subject of many debates in the last decades and is still not entirely clear (MARSHALL & SAGE 1981, BOURSOT et al. 1993, PRAGER et al. 1998, MUSSER & CARLETON 2005, HARDOUIN et al. 2015). Currently, at least three subspecies are widely accepted: *Mus musculus domesticus*, *Mus musculus musculus*, and *Mus musculus castaneus*.

Considering the biological research of mammals in Mongolia so far, the house mouse was rather neglected. BANNIKOV (1954) first recapped some information about the morphology, the habitats, and the living behaviour. Furthermore, he mentioned four subspecies, which are distributed in various parts of the country: (a) *Mus musculus raddei* KASTSCHENKO, 1910 (north-western Mongolia, Transbaikalia); (b) *Mus musculus mongolium* THOMAS, 1908 (eastern Gobi, central Mongolia, eastern Khangai); (c) *Mus musculus decolor* ARGIROPULO, 1932 (Khangai without eastern and northern part, Gobi Altai, Transaltai Gobi, Mongolian Altai without north-western part); (d) *Mus musculus variabilis* ARGIROPULO, 1932 (northern-western edge of the Mongolian Altai).

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<sup>1</sup> Ergebnisse der Mongolisch-Deutschen Biologischen Expeditionen

After that, some authors took over this systematics (DULAMT SEREN 1970, BATSAIKHAN et al. 2014); others did not consider any subspecies of *Mus musculus* in Mongolia (SOKOLOV & ORLOV 1980, MALLON 1985, STUBBE et al. 1989, HOFMANN et al. 2005, CLARK et al. 2006). STUBBE & CHOTOLCHU (1968) considered *M. m. mongolium* and *M. m. decolor* as *M. m. wagneri* following ELLERMAN & MORRISON-SCOTT (1951). Currently, all these mentioned subspecies are considered as synonyms of *Mus musculus musculus*, which occurs in the large parts of the Palearctic including Mongolia (MUSSER & CARLETON 2005).

Thus, the aim of this study was to characterise morphology and ecology of the house mouse in Mongolia and to analyse its taxonomic state. This publication is based on an unpublished thesis (LAMMERS & APENBORN 2017).

## 2. Material and Methods

This study is based on 172 specimens from the Senckenberg Museum of Natural History Görlitz and the Martin-Luther-University Halle (Zentralmagazin Naturwissenschaftlicher Sammlungen, ZNS), that were collected from 1962 to 2016 in Mongolia in different sample localities (fig. 1).

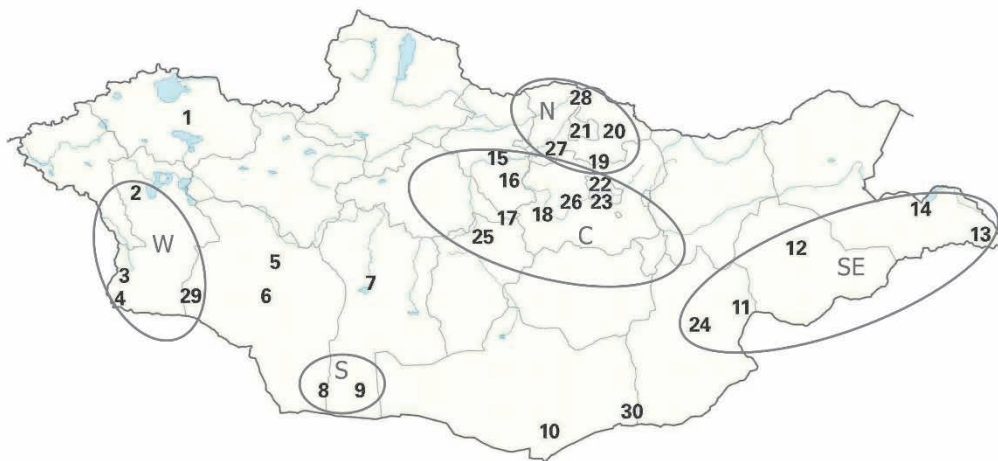


Fig. 1: Sample localities and defined geographical populations of house mice caught from 1962 until 2016 in Mongolia (1: Malchin sum, Uvs province; 2: Khovd khot and Ulaan uul, Khovd province; 3: Bulgan gol, Khovd province; 4: Baitag Bogd region, Khovd province; 5: Altai khot, Gobi-Altai province; 6: Tseel sum, Gobi-Altai province; 7: Baidrag gol, Bayankhongor province; 8: Shar Khulsni bulag, Bayankhongor province; 9: Ekhiin gol, Bayankhongor province; 10: Borzongiin Gobi, Umnugovi province; 11: 85 km NE of Ongon sum, Sukhbaatar province; 12: Baruun Urt khot, Sukhbaatar province; 13: Nomrogiin gol, Dornod province; 14: Buir nuur, Dornod province; 15: Bulgan sum, Bulgan province; 16: Buregkhangai sum, Bulgan province; 17: Rashaant soum, Bulgan province; 18: Ondorshireet sum, Tov province; 19: Tunkhel tosgon Selenge province; 20: Bugant sum, Selenge province; 21: Darkhan khot, Darkhan-Uul province; 22: Ulaanbaatar and northern periphery; 23: Bogd uul, Ulaanbaatar southern periphery; 24: Sainshand, Dornogobi province; 25: Kharkhorin, Uvurkhangai province; 26: Khustain nuruu National Park, Tov province; 27: Village 20 km SW of Saikhan sum, Selenge province; 28: Sukhbaatar khot, Selenge province; 29: Takhiiin Tal, Gobi-Altai province; 30: Galbin Gobi, Umnugovi province).

For characterisation, the following measurements were taken at autopsy: body mass (BM) and length of body (BL), tail length (TL), ear length (EL) and hind foot length (HL) as well as sex and reproduction status (number of uterine scars or embryos and their size). The presence of embryos and/or uterine scars is considered as sign of reproductive activity, whereas a female without one of these signs is considered as reproductively inactive.

The coat colours of 138 study-skin specimens were documented in three variants:

1. the colour of ventral fur (chy: chrome yellow, och: ochre, lmgb: light to medium grey-brown, mdgb: medium to dark grey-brown, dob: dark ochre-brown)
2. the colour of dorsal fur (w/w: completely white, w/g: white hair length and grey base, y/b: yellowish/brownish colour in hair length and grey base) and
3. the demarcation line (diffuse, distinct). To identify morphotypes of Mongolian house mice, the frequencies of occurrence of the three variants were considered.

For this purpose, several categories were pooled appropriately to reduce the data complexity and to facilitate the identification of morphotypes.

Moreover, 158 skulls were examined to determine several information. To identify the subspecies, two morphological traits on the skull were considered as described by KRAFT (1984/85) (fig. 2):

1. the position of the masseteric bulge on the lower margin of the zygomatic plate
2. shape and position of the outer front hump of the first lower molar.

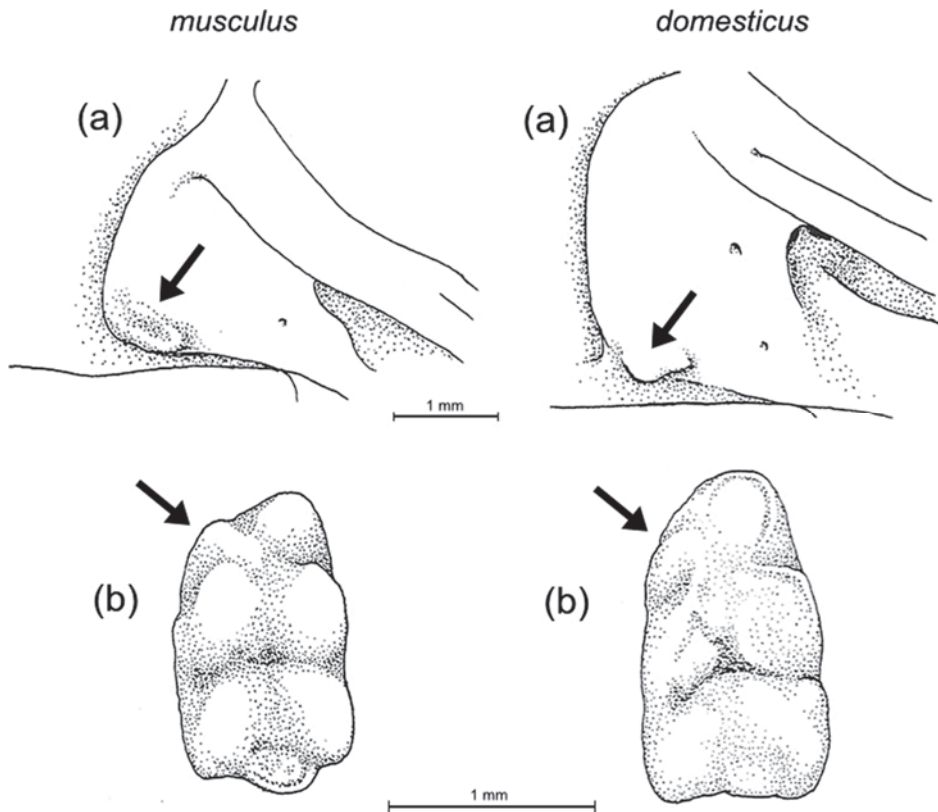


Fig. 2: The cranial traits of *Mus musculus musculus* and *Mus musculus domesticus* (JENRICH et al. 2010, modified). (a) *musculus*: the lower margin itself is thickened; *domesticus*: the bulge is obviously relocated from the margin. (b) *musculus*: the outer front hump of M1 tends to bend outwards, as a result of which the four frontal humps appear to be in the shape of a four-leaved clover; *domesticus*: the outer front hump of M1 is only slightly bent outwards and more rearwards, as a result of which the front margin appears rather slender.

The determination of age classes as a function of the abrasion rate of the upper molars was realised by the method of KELLER (1974). Specimens of the age classes 1 and 2 are defined as juveniles, whereas specimens of the age class 3 or higher are defined as adults.

Beside the body measurements, 16 metric cranial traits of 168 specimens were documented (fig. 3): CBL (condylobasal length), ZYB (zygomatic breadth), OCB (occipital breadth), ROB (rostral breadth), IOB (interorbital breadth), NAL (nasal length), SFL (sutura frontalis length), IFL (length of foramen incisivum), PFL (distance between palatine durum posterior and foramen occipitalis), UAL (upper alveoli length), UMB (breadth of first upper molar), MEL (meatus auditorius externus length), MEB (meatus auditorius externus breadth), ZMB (breadth of processus zygomaticus), RMB (minimum breadth of upper ramus of processus zygomaticus), and LAL (lower alveoli length). These metric cranial traits were chosen since they have been routinely used for differentiation of species within the genus *Mus* (GERASIMOV et al. 1990, LYALYUKHINA et al. 1991, SLÁBOVÁ & FRYNTA 2007, CSERKÉSZ et al. 2008, MACHOLÁN 2008, ČANÁDY et al. 2014). Additionally, two indices were calculated: the zygomatic index ( $ZYI = RMB / ZMB$ ) and the ratio of tail to body length ( $RTB = TL / BL$ ). Comparing body and skull measurements of the two sexes in each age class, the mean, the standard deviation, the minimum, and the maximum of the metric traits were calculated. Furthermore, the identified morphotypes (see above) were characterised by morphometrics. For this purpose, the differences between morphotypes in terms of metric body and skull traits that are independent of age and sex were examined using t-test for independent samples. After that, a principal component analysis (PCA) of the resulting significant traits was performed to enable a vivid depiction of the morphotype differences.

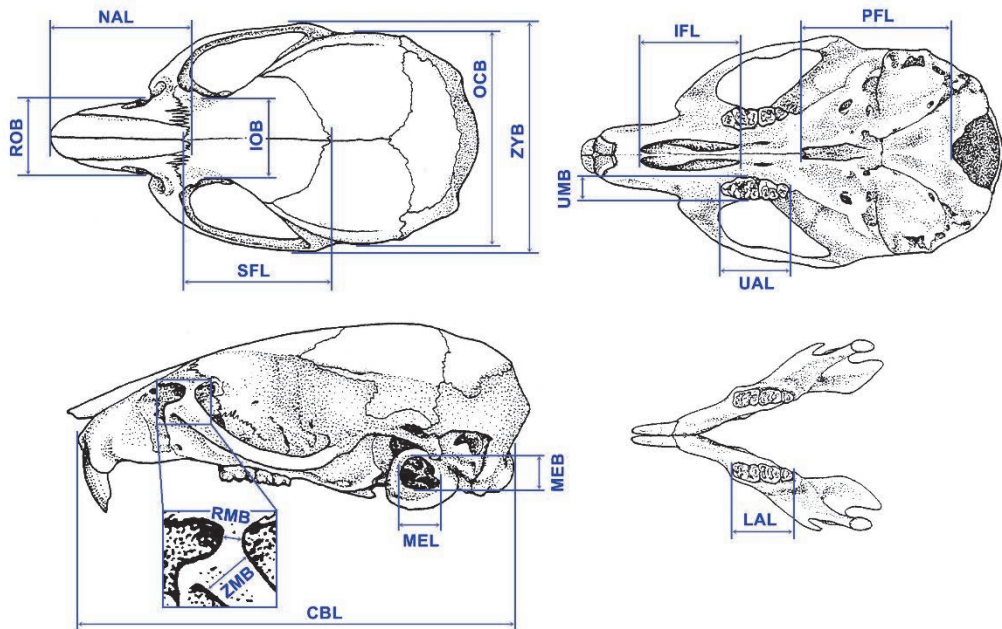


Fig. 3: Overview of the sixteen metric cranial traits (JENRICH et al. 2010, modified).

Investigating possibly present genetic variability among populations, 36 non-metric cranial traits were analysed on 170 skulls (1: foramen praeorbitale double, 2: os interfrontale present, 3: ossa frontalia parted, 4: ossa frontalia fused, 5: fontanella frontale present, 6: intra sutural bones present, 7: foramen frontale present, 8: foramen ethmoideum present, 9: foramen ethmoideum double, 10: accessory foramen ethmoideum anterior present, 11: accessory foramen ethmoideum



posterior I present, 12: accessory foramen ethmoideum posterior I double, 13: accessory foramen ethmoideum posterior II present, 14: foramen maxillare I present, 15: foramen maxillare I double, 16: foramen maxillare II present, 17: foramen maxillare III present, 18: foramen maxillare III double, 19: foramen palatinum majus double, 20: alae palatinae present, 21: foramen sphenoidale medium present, 22: foramen sphenoidale laterale ventrale present, 23: processus pterygoideus present, 24: foramen ovale minor present, 25: accessory foramen ovale present, 26: accessory foramen ovale double, 27: foramen pterygoideum double, 28: sutura preoptica present, 29: metoptic roots abnormal, 30: foramen hypoglossi present, 31: foramen hypoglossi double, 32: accessory foramen mentale double, 33: foramen alpha present, 34: foramen beta present, 35: foramen beta double, 36: foramen mandibulare double). The choice of the traits based mainly on BERRY (1963); SIKORSKI (1982); ZAKHAROV & SIKORSKI (1997); LAZAROVÁ (1999). A trait being bilaterally present, was documented separately. Fig. 4 shows the position of all traits observed, except for trait number 6 'wormian bones', which is described in detail in SIKORSKI (1982).

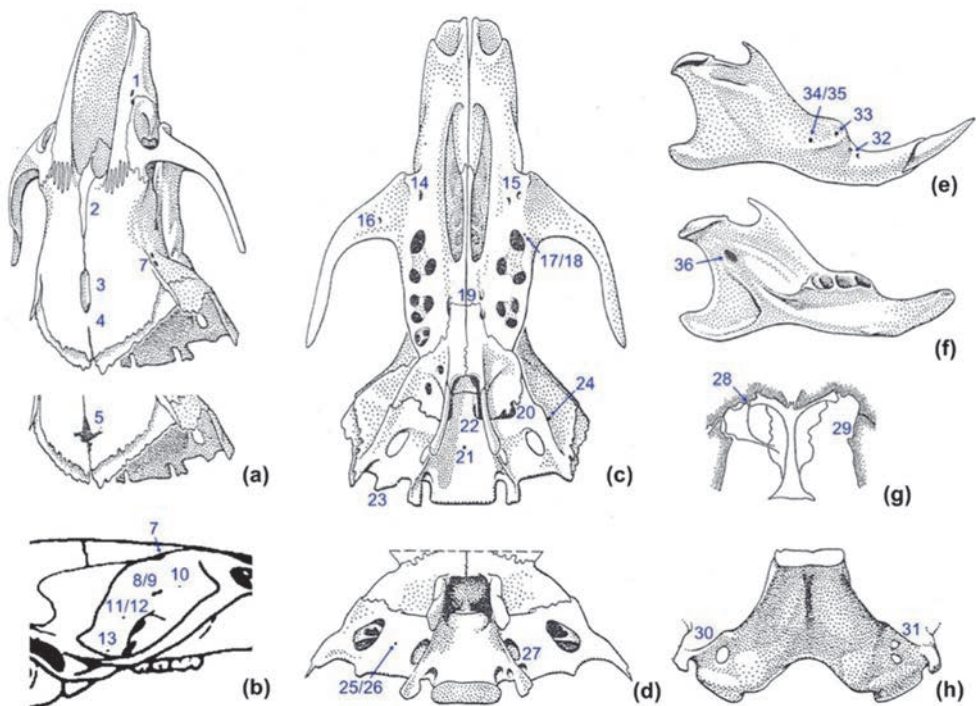


Fig. 4: The non-metric traits according to BERRY (1963), TRUSLOVE (1954) and SIKORSKI (1982), modified: (a) dorsal and right lateral surface of the skull, (b) right lateral surface of the skull, (c) ventral surface of the skull, (d) ventral view of the sphenoidal region of the skull, (e) lateral view of the right mandible, (f) medial view of the left mandible, (g) dorso-cranial view of the preoptic and metoptic roots (internal bones of the skull), (h) obliquely ventral view of the occiput.

Primarily, the frequencies of the trait expressions were analysed for their homogeneity in age and sex using the exact Fischer test ( $\chi^2$  distribution) - as recommended for small sample sizes (MCDONALD 2014) - at a significance level of  $\alpha = 0.05$ . The traits independent of sex and age were used for further analysis, whereas the age- and sex-dependent traits were rejected. If a

bilateral trait was not age- or sex-independent on one side, the other side (therefore the whole trait) is treated as such. For analysis, the geographic populations were defined (fig. 1): West (W: sample localities 2 - 4, 29), North (N: sample localities 19 - 21, 27, 28), Central (C: sample localities 15 - 18, 22, 23, 25, 26), South (S: sample localities 8, 9), and Southeast (SE: sample localities 11 - 14, 24).

Evaluating the potential genetic variability, the index of epigenetic variability ( $I_{ev}$ ) for a population sample was calculated using the formula of SMITH (1981):

$$I_{ev} = \sum_{i=1}^h \left( \frac{p_i \cdot q_i}{h} \right) \quad \begin{array}{l} h - \text{number of traits examined} \\ p_i - \text{frequency of trait } i \\ q_i = 1 - p_i \end{array}$$

If  $p_i$  reached extreme proportions, Bartlett's adjustment was applied as recommended by HARRIS & SJØVOLD (2004). More precisely, if  $p_i = 0$ , it was set to  $1/(4 \cdot n_i)$  and if  $p_i = 1$ , it was set to  $1/(4 \cdot n_i)$  with  $n_i$  being the number of observations for trait  $i$  in a sample.

To determine epigenetic differences between population samples, the mean measure of divergence ( $MMD$ ) was calculated according to SJØVOLD (1977):

$$MMD = \frac{1}{h} \sum_{i=1}^h [(\Theta_{1i} - \Theta_{2i})^2] - \left( \frac{1}{n_{1i}} + \frac{1}{n_{2i}} \right) \quad \Theta_i = \arcsin(1 - 2p_i)$$

$n_i$  – number of observations for trait  $i$  in a sample

as well as its standard deviation ( $SD_{MMD}$ ):

$$SD_{MMD} = \sqrt{\frac{2}{h^2} \sum_{i=1}^h \left( \frac{1}{n_{1i}} + \frac{1}{n_{2i}} \right)^2}$$

Two samples differ significantly at  $\alpha = 0.05$  when the  $MMD$  is more than twice of  $SD_{MMD}$ . If the value of  $MMD$  was lower or even negative, it was set to zero (SJØVOLD 1977). The level of correspondence between  $MMD$  values of geographic populations and the distances between location centroids was estimated with the Mantel test. For that reason, location centroids were calculated and the distances between these centroids were measured using *Google MyMaps*.

For indication of developmental instability of a population, fluctuation asymmetry ( $FA$ ) was calculated as the relation of the number of asymmetric occurrences of a single trait to the sample size (following ANSORGE et al. 2012):

$$FA_i = \frac{n_{asym,i}}{n_i} \quad n_{asym,i} - \text{number of asymmetric occurrence of the trait } i \text{ in a sample}$$

The value of  $FA$  within a population results from the unscaled mean of  $FA_i$  of all traits. Before, McNemar tests between the left and the right side of each bilateral trait were performed to indicate directional asymmetry following LEAMY (1997). In case a trait revealed directional asymmetry, it was rejected from the analysis of  $FA$ .

Finally, a molecular genetic analysis of the mtDNA D-loop region was performed to identify the subspecies. The primer used are D-loopF (5'-CAT-TAC-TCT-GGT-CTT-GTA-AAC-C-3') and D-loopR (5'-GCC-AGG-ACC-AAA-CCT-TTG-TGT-3') resulting in a sequence size of about 1100 bp. Reference data of *Mus musculus musculus* (AB025348), *M. m. domesticus* (AM182713) and *M. m. castaneus* (AJ286322) was taken from GenBank, NCBI. A ClustalW alignment of all sequences ( $n = 146$ ) and reference data were performed.



## 4. Results and Discussion

### **Identification and morphological characterisation**

The house mouse in Mongolia was identified as *Mus musculus musculus*. All specimens showed a thickened, not relocated masseteric bulge on the lower margin of the zygomatic plate, and the shape of the four frontal humps of the first lower molar appeared as a four-leaved clover. Furthermore, the sequence analysis of the D-loop region of the mtDNA revealed that all specimens correspond to the reference of *Mus musculus musculus*.

The colouration of mice appeared to be very diverse with rather bright, dark and intermediate forms in between (fig. 5). Obviously, dark dorsal fur (medium to dark grey-brown) was determined mainly in the northern part of Mongolia, in the Selenge province. Light to medium grey-brown mice are widely distributed throughout Mongolia, except in the very south and southwest regions. However, the main area seems to be in the centre and north. Apparently, mice with ochre dorsal fur colour are even more widely distributed: from the South to the North of Mongolia with their main area in the centre. The lightest colour (chrome yellow) was found only in the Southwest and West. Considering the ventral fur colourisation, yellowish/brownish bellies occur from the centre to the North and the West. Mice with white belly hairs and a grey base were found mainly in the centre of Mongolia, but only very few in the North and none in the South. Pure white ventral colouration occurs mainly in the South with a few individuals found in the centre and North. The demarcation line seems to be rather diffuse in the northern part, while the centre is dominated by a distinct line. In the south distinct lines were identified exclusively.



Fig. 5: Five different groups of dorsal fur colourations.

The coat colour is an adaptation to local conditions. The southern house mice have a coat colour, which is often quite close to the colour of the soil. In the north, mice are exposed to areas with more vegetation and show a darker coat colour. Caused by the vegetation zones, the North is a more humid region in contrast to the arid region in the South. This pattern corresponds to Gloger's rule and was also determined in a study for house mice in Asia (LAI et al. 2008). The main reason for this phenomenon is probably that soil-coloured mice are less obvious for predators (concealment effect).

The consideration of the subspecies (*raddei*, *mongolium*, *decolor*, *variabilis*) mentioned by BAN-NIKOV (1954) as morphological types of the house mouse in different regions of Mongolia is difficult to implement for the following reasons: (1) the initial descriptions are not sufficiently precise and (2) too many conformities between these descriptions exist. These factors make it difficult to distinguish the variants clearly from each other. (3) Moreover, too many unconformities exist between the new observations of this study and the initial descriptions.

For that reason, two morphotypes were identified based on the fur characteristics of this study. The greatest number of samples (65 %) was identified as morphotype 1, which are generally light individuals with a clear demarcation line. They were found in all parts of the country except the central north. Fewer samples (13 %) were identified as morphotype 2, which are generally dark with a diffuse transition between back and belly. They occur in the northern part of Selenge-Orkhon region. The remaining samples (22 %) are intermediate morphotypes, which are divided up between the other combinations of categories.

Table 1: Metric parameters of the different age classes (abbreviations see chapter 3)

Age class	2		3		4		5	
Sex	♂	♀	♂	♀	♂	♀	♂	♀
	n							
	mean ± SD							
	min. - max.							
BM [g]	38 11 ± 3 5 - 20	21 11 ± 4 5 - 25	31 14 ± 4 8 - 21	19 14 ± 4 8 - 21	11 13 ± 3 8 - 20	12 17 ± 5 9 - 26	5 15 ± 2 12 - 17	1 16
BL [mm]	37 67 ± 8 49 - 80	24 65 ± 7 51 - 78	32 71 ± 7 58 - 89	19 72 ± 6 57 - 82	12 70 ± 5 62 - 76	13 77 ± 8 65 - 92	5 78 ± 5 72 - 85	1 84
TL [mm]	38 48 ± 6 35 - 61	24 48 ± 8 37 - 70	32 52 ± 7 40 - 69	19 51 ± 8 36 - 65	12 52 ± 7 42 - 62	13 54 ± 9 42 - 70	5 48 ± 7 36 - 52	-
HL [mm]	35 15 ± 1 13 - 17	24 15 ± 1 13 - 17	31 15 ± 1 12 - 18	18 15 ± 1 14 - 18	12 15 ± 1 13 - 16	13 15 ± 1 13 - 16	5 15 ± 1 15 - 16	1 15
EL [mm]	37 12 ± 1 9 - 13	23 12 ± 1 10 - 15	32 12 ± 1 8 - 14	18 12 ± 1 9 - 14	12 12 ± 2 8 - 13	13 12 ± 2 8 - 13	5 12 ± 1 11 - 13	1 12
CBL [mm]	32 18.9 ± 1.2 16.3 - 21.2	23 18.8 ± 1.3 15.6 - 21.3	32 19.9 ± 1.1 17.6 - 22.1	18 19.8 ± 1.1 17.3 - 21.4	10 19.5 ± 1.0 17.7 - 20.3	10 20.7 ± 1.3 18.6 - 22.4	3 19.7 ± 0.5 19.4 - 20.3	1 20.1
ZYB [mm]	35 10.8 ± 0.6 9.5 - 12.0	26 10.1 ± 0.6 9.2 - 11.9	32 11.0 ± 0.5 9.8 - 12.0	20 11.0 ± 0.5 10.0 - 11.8	12 11.0 ± 0.5 10.1 - 11.6	11 11.4 ± 0.5 10.4 - 12.3	4 11.1 ± 0.4 10.7 - 11.6	1 11.5
OCB [mm]	34 9.5 ± 0.4 8.7 - 10.2	25 9.4 ± 0.3 8.7 - 10.1	32 9.5 ± 0.3 8.7 - 10.3	20 9.6 ± 0.3 8.9 - 10.1	11 9.5 ± 0.3 9.0 - 9.9	12 9.7 ± 0.5 8.9 - 10.5	4 9.9 ± 0.2 9.6 - 10.1	1 10.1
ROB [mm]	39 4.0 ± 0.2 3.4 - 4.5	27 3.9 ± 0.3 3.5 - 4.5	31 4.1 ± 0.3 3.5 - 4.6	20 4.1 ± 0.2 3.7 - 4.4	12 4.1 ± 0.2 3.7 - 4.5	12 4.1 ± 0.3 3.7 - 4.5	3 4.0 ± 0.2 3.8 - 4.2	1 3.9
IOB [mm]	38 3.4 ± 0.1 3.2 - 3.7	27 3.4 ± 0.2 3.1 - 3.7	32 3.4 ± 0.1 3.2 - 3.7	21 3.4 ± 0.1 3.2 - 3.7	12 3.5 ± 0.1 3.2 - 3.7	13 3.5 ± 0.2 3.1 - 3.7	5 3.4 ± 0.1 3.4 - 3.5	1 3.5

Age class	2		3		4		5	
Sex	♂	♀	♂	♀	♂	♀	♂	♀
	n mean±SD min. - max.							
NAL [mm]	37 <b>6.9±0.4</b> 6.0 - 7.7	27 <b>6.8±0.5</b> 5.8 - 7.9	31 <b>7.2±0.5</b> 6.0 - 8.0	21 <b>7.2±0.4</b> 6.2 - 7.9	12 <b>7.3±0.5</b> 6.3 - 7.8	12 <b>7.5±0.5</b> 6.6 - 8.7	4 <b>7.2±0.6</b> 6.8 - 8.0	1 <b>7.3</b>
SFL [mm]	39 <b>6.5±0.3</b> 5.7 - 7.1	28 <b>6.3±0.4</b> 5.5 - 7.3	32 <b>6.5±0.3</b> 5.8 - 7.1	20 <b>6.4±0.5</b> 5.6 - 7.7	12 <b>6.4±0.3</b> 5.9 - 6.8	13 <b>6.6±0.4</b> 6.1 - 7.9	5 <b>6.6±0.2</b> 6.3 - 6.9	1 <b>6.7</b>
IFL [mm]	39 <b>4.6±0.3</b> 4.0 - 5.1	27 <b>4.5±0.3</b> 4.0 - 5.1	30 <b>4.7±0.2</b> 4.2 - 5.2	21 <b>4.8±0.3</b> 4.2 - 5.3	12 <b>4.8±0.4</b> 4.0 - 5.5	12 <b>4.9±0.2</b> 4.5 - 5.2	4 <b>4.9±0.2</b> 4.8 - 5.2	1 <b>4.9</b>
UAL [mm]	39 <b>3.5±0.1</b> 3.3 - 4.1	28 <b>3.5±0.1</b> 3.1 - 3.7	32 <b>3.6±0.2</b> 3.1 - 4.3	21 <b>3.5±0.2</b> 3.2 - 3.8	12 <b>3.5±0.2</b> 3.2 - 3.8	13 <b>3.6±0.1</b> 3.4 - 3.8	5 <b>3.7±0.2</b> 3.5 - 3.9	1 <b>3.8</b>
PFL [mm]	32 <b>7.0±0.5</b> 5.7 - 8.0	22 <b>6.9±0.5</b> 5.5 - 7.8	32 <b>7.4±0.5</b> 6.3 - 8.5	18 <b>7.4±0.5</b> 6.3 - 8.3	8 <b>7.1±0.6</b> 5.9 - 7.7	9 <b>8.0±0.6</b> 6.8 - 8.9	3 <b>7.1±0.3</b> 6.9 - 7.4	1 <b>7.1</b>
UMB [mm]	39 <b>1.1±0.0</b> 1.0 - 1.2	28 <b>1.1±0.0</b> 1.0 - 1.2	32 <b>1.1±0.0</b> 1.1 - 1.2	21 <b>1.1±0.0</b> 1.1 - 1.2	12 <b>1.1±0.0</b> 1.1 - 1.1	12 <b>1.1±0.0</b> 1.1 - 1.2	5 <b>1.1±0.0</b> 1.1 - 1.1	1 <b>1.1</b>
MEL [mm]	33 <b>1.6±0.1</b> 1.3 - 1.8	25 <b>1.6±0.1</b> 1.4 - 1.8	32 <b>1.6±0.1</b> 1.4 - 1.8	21 <b>1.6±0.1</b> 1.4 - 1.8	11 <b>1.6±0.1</b> 1.4 - 1.7	11 <b>1.6±0.1</b> 1.4 - 1.7	4 <b>1.6±0.1</b> 1.5 - 1.6	1 <b>1.6</b>
MEB [mm]	33 <b>1.7±0.1</b> 1.4 - 1.9	25 <b>1.7±0.1</b> 1.4 - 1.8	32 <b>1.7±0.1</b> 1.4 - 1.9	21 <b>1.7±0.1</b> 1.5 - 1.9	11 <b>1.6±0.1</b> 1.5 - 1.8	11 <b>1.7±0.1</b> 1.5 - 1.9	4 <b>1.6±0.2</b> 1.5 - 1.9	1 <b>1.9</b>
ZMB [mm]	39 <b>1.0±0.1</b> 0.7 - 1.4	28 <b>1.0±0.1</b> 0.8 - 1.2	32 <b>1.1±0.1</b> 0.7 - 1.3	21 <b>1.1±0.1</b> 0.8 - 1.4	12 <b>1.0±0.1</b> 0.9 - 1.3	13 <b>1.1±0.2</b> 0.9 - 1.6	5 <b>1.0±0.1</b> 0.9 - 1.1	1 <b>1.0</b>
RMB [mm]	39 <b>0.4±0.1</b> 0.3 - 0.6	28 <b>0.4±0.1</b> 0.3 - 0.6	32 <b>0.4±0.1</b> 0.3 - 0.6	21 <b>0.4±0.1</b> 0.3 - 0.6	12 <b>0.4±0.1</b> 0.3 - 0.5	13 <b>0.5±0.1</b> 0.4 - 0.7	5 <b>0.4±0.1</b> 0.3 - 0.5	1 <b>0.4</b>
LAL [mm]	39 <b>3.0±0.1</b> 2.6 - 3.2	28 <b>2.9±0.1</b> 2.7 - 3.2	30 <b>3.0±0.1</b> 2.7 - 3.4	21 <b>3.0±0.1</b> 2.7 - 3.2	13 <b>2.9±0.1</b> 2.7 - 3.1	13 <b>3.0±0.1</b> 2.9 - 3.2	5 <b>2.9±0.1</b> 2.7 - 3.1	1 <b>3.2</b>
ZYI	40 <b>0.41±0.08</b> 0.26 - 0.61	28 <b>0.42±0.06</b> 0.25 - 0.52	32 <b>0.42±0.08</b> 0.29 - 0.64	21 <b>0.40±0.05</b> 0.30 - 0.50	12 <b>0.44±0.08</b> 0.28 - 0.52	13 <b>0.43±0.06</b> 0.32 - 0.53	5 <b>0.42±0.07</b> 0.36 - 0.53	1 <b>0.44</b>
RTB	37 <b>0.73±0.10</b> 0.55 - 1.00	24 <b>0.75±0.11</b> 0.53 - 1.00	32 <b>0.74±0.09</b> 0.56 - 0.89	19 <b>0.71±0.11</b> 0.55 - 0.96	12 <b>0.75±0.09</b> 0.59 - 0.86	13 <b>0.71±0.11</b> 0.49 - 0.89	5 <b>0.62±0.10</b> 0.45 - 0.70	-

The characterisation of the sexes and the different age classes relating to the metric traits is presented in table 1. It shows a remarkable degree of agreement with specimens from Eastern Europe (DYNOWSKI 1963, LYALYUKHINA et al. 1991). Minor deviations were observed for the skull dimensions CBL and ZYB, which were slightly larger in Mongolian specimens, whereas EL, HL and BL are little shorter. The only visual difference is that the Mongolian specimens have a

markedly shorter tail (36 to 70 mm) than their Eastern European relatives (52 to 94 mm). These comparatively shorter-tailed morphotypes are already known from Kazakhstan (SPIRIDONOVA 2014) and North China (PRAGER et al. 1998).

Table 2 shows the metric traits, which exhibit significant differences between morphotype 1 and morphotype 2. Summing up, morphotype 1 shows in comparison to morphotype 2 a higher mean value of ZYI, whereas the other traits (HL, IOB, MEL, RMB) are higher in morphotype 2.

Table 2: Significant metric traits of the morphotypes (abbreviations see chapter 3)

Significant metric traits		Morphotype 1	Morphotype 2
HL [mm]	n	77	17
	mean ± SD	14.9 ± 1.0	16.0 ± 0.9
	min. - max.	13.0 - 18.0	15.0 - 18.0
IOB [mm]	n	77	16
	mean ± SD	3.39 ± 0.14	3.54 ± 0.09
	min. - max.	3.10 - 3.72	3.41 - 3.72
MEL [mm]	n	72	16
	mean ± SD	1.58 ± 0.09	1.67 ± 0.11
	min. - max.	1.33 - 1.82	1.48 - 1.82
ZYI [mm]	n	79	17
	mean ± SD	0.44 ± 0.06	0.35 ± 0.06
	min. - max.	0.31 - 0.64	0.28 - 0.48
RMB [mm]	n	71	16
	mean ± SD	0.71 ± 0.08	0.83 ± 0.11
	min. - max.	0.45 - 0.92	0.53 - 1.00

In the principal component analysis (PCA), these five traits have been reduced to three components to illustrate the difference between the two morphotypes. Fig. 6 and 7 show clearly the separated distribution of the samples that mirror the respective morphotype.

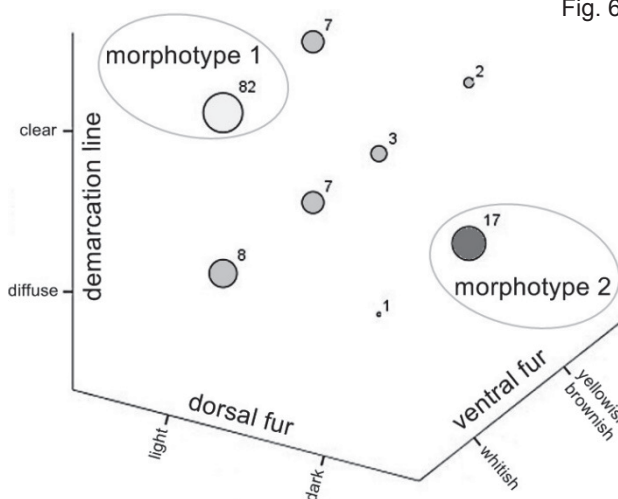


Fig. 6: Identification of morphotypes based on frequencies of fur traits.

Dorsal fur categories were grouped as 'light' (chy, och, lmgb) and 'dark' (mdgb, dob), and ventral fur categories were grouped as 'whitish' (ww, wg). The ventral fur category 'yellowish/brownish' remained unchanged. The number at the circles represents the number of specimens of the respective fur characters. The light grey circle indicates light individuals with a whitish belly and a clear demarcation line (morphotype 1), whereas the dark grey circle indicates dark individuals with a yellowish/brownish belly and a diffuse demarcation line (morphotype 2). Medium grey circles indicate intermediate morphotypes.

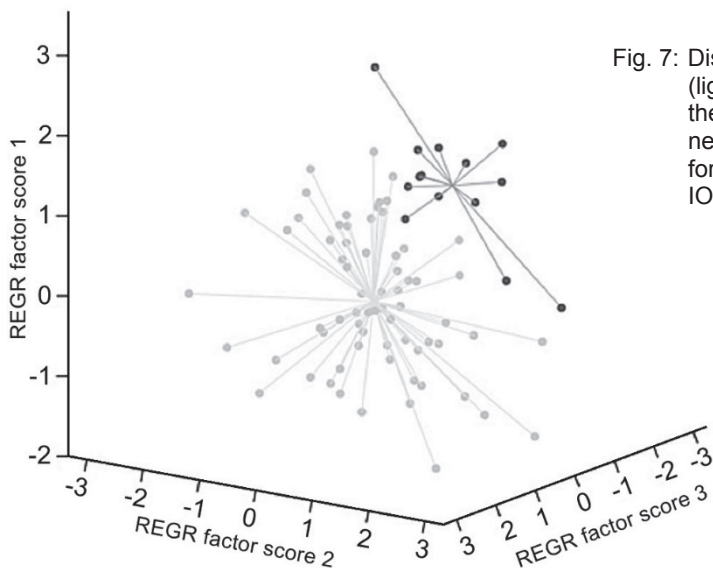


Fig. 7: Distribution of morphotypes 1 (light grey) and 2 (dark grey) on the three first principal components of an analysis (PCA) performed on five metric traits (HL, IOB, MEL, ZYI, RMB).

### Age structure and reproduction

The age structure of the Mongolian house mouse is a pyramidal shape with relatively straight converging edges, which indicates a stable, consistent population structure (fig. 8). This is also reflected in rather low mortality rates (45 % on average) from one age class to the next. An entirely different picture is shown for a house mouse population in Poland (DYNOWSKI 1963). Here, the shape of the age structure is more 'dented' due to the high mortality rates (64% on average). In this study as well as in the study of DYNOWSKI (1963), it is obvious that the mortality rates tend to increase with increasing age, however the mortality rates of the house mouse population in Poland are even higher especially with the transition to the penultimate age class (almost 80 %). These differing results can be most likely attributed to the fact that the sample size was not sufficient to provide a representative picture of the actual age structure of the Mongolian house mouse population.

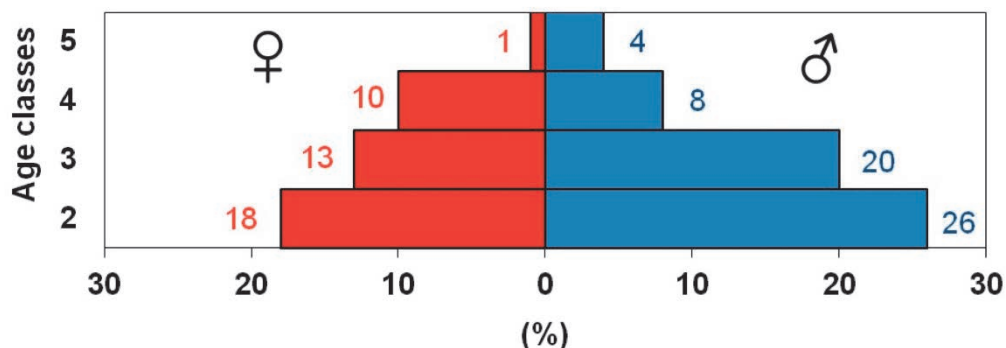


Fig. 8: Age structure of female (n = 70) and male (n = 93) house mice from Mongolia.

Out of 163 animals, 70 (43 %) are females and 93 (57 %) are males, which results in a total sex ratio of 1 : 1.3 in favour of the males. However, there was no significant difference tested ( $\chi^2 = 3.24 < 3.84; \alpha = 0.05$ ). These findings correspond roughly to a house mouse population in Poland

(1.0 : 1.2, DYNOWSKI 1963) as well as to populations in Germany (1.0 : 1.0, ANSORGE 1991; 1.0 : 1.2, DIETZE et al. 2005). However, this is in sharp contrast to the existing expectation that in wild populations the sex ratio shifts favouring females (FREYE & FREYE 1960). One main cause could be that male house mice exhibit higher activity outside the nest than females (FREYE & FREYE 1960, REICHSTEIN 1978, GERLACH 1990). Therefore, the probability of catching male mice is higher.

Reproduction data were documented for 36 female mice (table 3). The results show that the litter size as well as the amount of the females participating in reproduction depends on age. Both parameters firstly increase from age class 2 (5.3 pups, 31 %) to age class 3 (7.7 pups, 85 %), but decreases slightly in age class 4 (6.0 pups, 56 %). Only a single female that showed no reproductive activity represents age class 5. The low sexual maturity of the females in age class 2 is very likely attributable to the fact that the majority is not yet mature, since sexual maturity arises at 6 to 8 weeks of age (SILVER 1995). The young females rather invest into growth before becoming sexually mature (BRONSON 1979), whereas males can reach sexual maturity between 5 and 6 weeks of age (SILVER 1995) and enter sexual maturity under adverse circumstances. Furthermore, in cases of high population density the sexual maturity of young females can be delayed through older females (BRONSON 1979).

Table 3: Reproduction data of the house mouse in Mongolia

Age classes	n	Litter size													reproductive females [%]	
		1	2	3	4	5	6	7	8	9	10	11	12	13		mean
2	13	1	-	-	-	-	1	2	-	-	-	-	-	-	5.3	31
3	13		-	-	-	3	-	2	3	1	1	-	-	1	7.7	85
4	9	1	-	1	-	-	-	-	2	-	1	-	-	-	6.0	56
5	1	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0	0
<b>total</b>	<b>36</b>	<b>2</b>		<b>1</b>		<b>3</b>	<b>1</b>	<b>4</b>	<b>5</b>	<b>1</b>	<b>2</b>		<b>1</b>	<b>6.8</b>	<b>56</b>	

Several commensal house mouse populations from Eastern Germany show almost the same reproductive pattern with a little lower average in litter size only (ANSORGE 1991). On the other hand, the apparent decrease of the litter size and the number of reproductive females in higher age classes seem to contradict the results of DIETZE et al. (2005), but based on a too small sample size. Moreover, it was deduced that older females usually mate before younger (GERLACH 1990), which results in an increasing proportion of reproductive females with the age.

### Habitats and socialisation

It is well known, that house mice are very adaptable mammals (JENRICH et al. 2010) and they do not behave strictly commensally (BRONSON 1979), although they probably appreciate the benefits of human vicinity. Therefore, both natural and human associated habitats were observed, particularly single yurts (in Mongolian: 'rəp') (sample locality 3) and yurt settlements (sample locality 26) as well as modest dwellings in rural areas (sample localities 24, 27, 28). The benefits are obvious: Yurts usually offer a substantial number of advantages for house mice. Some of these are relevant hiding places inside the yurt, an open cooking area and accessible food sources, open paths to the exterior around the yurt (in summer), while still very well shielded from atmospheric conditions, and protection from predators. It was observed that the population density of house mice seems to be very high in areas of food production like harvesting centres and storage depots (sample locality 25). Other small mammals associated with *Mus musculus* in such places are for instance *Meriones unguiculatus* (sample localities 24, 26, 27) and *Lasiopodomys brandtii* (sample locality 25).



In the capital, nowadays mice do not occur very often since rat poison is put out. Nevertheless, some mice were caught or at least seen in apartments and dormitories. The peripheral yurt vicinity of Ulaanbaatar feature more mice appearances, though: in the meadow steppe of *Thalictrum petaloidei*-*Helictrotrichetum schelliani* association (sample locality 22) for instance, in the northern periphery of Ulaanbaatar, which is at the lower mountain level with a slight to moderate hill slope. The soil is mostly fresh, and the floristic composition is rich in species. Here, *Mus musculus* was found associated with *Cricetulus barabensis*, *Apodemus peninsulae*, *Crocidura spec.*, *Microtus mongolicus*, *Myodes rutilus* and other voles.

However, the house mouse does not only live in anthropogenic habitats in Mongolia, but also in a broad range of natural ones. It was observed that they occur in isolated outposts of the Manchurian deciduous forests (sample locality 13), associated with *Apodemus agrarius*, *A. peninsulae*, *Rattus norvegicus* and *Tamias sibiricus*. This open and dry type of small-area forest is usually found in zones of forest-steppe-borders in central Mongolia. It corresponds roughly to the *Betula platyphyllae*-*Populetum tremulae* association.

In Transaltai Gobi, house mice populated reedbed (*Phragmites spec.*) in light *Populus diversifolia*-oasis (sample locality 8), associated with *Cricetulus migratorius*, *Crocidura sibirica* and *Alticola semicanus*. These ecosystems are typically located at springs at the foot of the mountains and in dry valleys, where the groundwater comes to the surface. In the past, these rare oases were well known by humans as caravan routes and resting spots. Nowadays, they are often used agriculturally and horticulturally (sample locality 9), where *Mus musculus* is associated with *Cricetulus migratorius*.

Open gallery forests of the *Betula fusca*-bush association (sample locality 23) also present habitats for house mice (fig. 9), here associated with *Apodemus peninsulae*. The mossy and swampy valley grounds are characterised by degradation caused by grazing.

Obviously, the house mouse is also living in the river oasis of the Depression of the Great Lakes (Chono-Kharaikhyngol, STUBBE et al. 1989) and the Dzungarian Gobi (Bulgan-gol, HOFMANN et al. 2005) outside of the yurts because the remains of at least 27 specimens were found in eagle owl (*Bubo bubo*) pellets from these regions.

Furthermore, evidence was found at lake shores with reed and dunes (sample locality 14, fig. 10) and pastures (sample locality 7) with *Achnatherum splendens* in transition zones of semi-desert to desert, where the soil is mostly sandy and saline, and the vegetation is often less biodiverse and influenced by groundwater. Here, *Mus musculus* was associated with *Cricetulus barabensis*, *Phodopus campbelli*, *Microtus gregalis*, and *Meriones unguiculatus*.

Sub saline meadows in the mountain steppe zone (sample locality 4) and pastures with *Populus* forests (sample locality 3) are also house mouse habitats. Here, *Mus musculus* was associated with *Microtus oeconomus*.

It is obvious by the described habitats where house mice occurred – from moisture to dry grounds, from light woodlands to semi-deserts and natural oases – how adaptable house mice are, which is stated quite often (e.g. BERRY & JAKOBSON 1975; BRONSON 1979). Besides that, house mice colonise urban areas, which are avoided by many other species, thus they do escape interspecific competition.

### **Geographical populations**

Geographical populations of the house mouse in Mongolia can be genetically characterized by the use of nonmetric cranial traits. The epigenetic variability ( $I_{ev}$ ), the epigenetic distances ( $MMD$  values) between the geographical populations, as well as the fluctuating asymmetry ( $FA$ ) values are shown in table 4. The  $I_{ev}$  values do not vary a lot and do not exhibit unambiguous geographical tendency. The highest is sample N (0.088) and the lowest SE (0.072). These values are relatively low in comparison to the results of other house mouse population analysis (LAZAROVÁ 1999, UHLÍKOVÁ 2004). Since it is assumed that this value reflects the genetic diversity of a population (SMITH 1981), it seems that the Mongolian house mouse populations show a relatively low genetic diversity.



Fig. 9: Open gallery forests at Bogd-uul (sample locality 23).



Fig. 10: Lake shore with *Achnatherum* and *Phragmites* at Buir-nuur (sample locality 14).

Table 4: Epigenetic variability ( $I_{ev}$ ) and fluctuating asymmetry ( $FA$ ) of the different geographical populations (see fig. 1) as well as the mean measure of divergence ( $MMD$ ) between them ( $MMD$  values in the lower left (significant values in bold); standard deviation of  $MMD$  ( $SD_{MMD}$ ) in the upper right)

region	C	N	S	W	SE
$I_{ev}$	0.080	0.088	0.086	0.084	0.072
$FA$	0.115	0.131	0.088	0.080	0.090
<b>C</b>	-	0.010	0.025	0.018	0.009
<b>N</b>	0.016	-	0.029	0.022	0.013
<b>S</b>	0.037	<b>0.063</b>	-	0.037	0.028
<b>W</b>	<b>0.085</b>	<b>0.059</b>	<b>0.097</b>	-	0.021
<b>SE</b>	<b>0.035</b>	<b>0.056</b>	0.027	<b>0.124</b>	-

The resulting dendrogram of the  $MMD$  values between the defined geographical populations (fig. 10) shows, that the populations S and SE exhibit a very low epigenetic distance to each other, thus were clustered closely together. This was not expected from the beginning, considering their great geographic distance from each other. Because of this fact, it could be concluded that in the Transaltai Gobi, Eastern Gobi, the Khalkha plains, Barga, and the Khingan forelands, close relationships prevail between house mouse subpopulations. Both populations, S more than SE, are rather closely connected with the populations N and C, which are clustered together as well. It is likely, that the house mouse conquers large geographic distances by passive transport through humans (BRONSON 1979). Apparently, some good interactions also occur between N, C, SE and S. The railway connection from Sukhbaatar in the north through Ulaanbaatar to Sainshand in the south and further down to China could play a notable role, likewise the road connection from Ulaanbaatar to Choibalsan in eastern Mongolia. A possibly key role for the passive distribution of house mice play the nomads, who have travelled the country for a long time (ASKAROV et al. 1992).

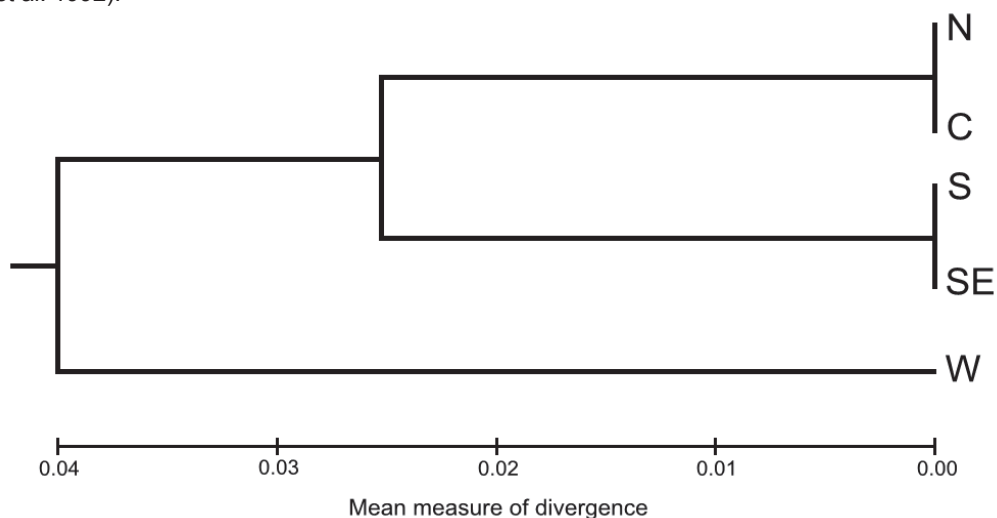


Fig. 10: Dendrogram of the epigenetic distances between different geographical populations of the house mouse in Mongolia (for geographic abbreviations see fig. 1).



In contrast, population W shows the highest *MMD* values in comparison with the others and thus it seems to be quite isolated. This could be an evidence for less connection by human transport routes from the east. Furthermore, the highest mountain ranges, the Mongolian Altai Mountains, are a natural barrier separating the westernmost part from the rest of the country.

The *MMD* values of the geographic samples correlate moderately (Mantel test,  $p = 0.001 < 0.050$ ) with the geographical distances between location centroids (correlation = 0.780), suggesting that house mice in Mongolia only disperse moderately. In the Czech Republic, on the other hand, substantially lower correlation and *MMD* values were assessed (LAZAROVÁ 1999). The reason for this may be the smaller size of the study area, as shorter geographic distances benefits genetic exchange. In contrast, Mongolia is a very large country in terms of area - especially in terms of its east-west extension -, which emerged obviously in the highest *MMD* value being east-west.

However, the *MMD* values found for the house mouse in Mongolia are relatively low in comparison to other rodent populations. For example, the common dormouse, *Muscardinus avellanarius* in eastern Germany, the Czech Republic and Lithuania (ANSORGE et al. 2012), the common vole, *Microtus arvalis* in the Czech Republic (UHLÍKOVÁ 2004), the forest dormouse, *Dyomys nitedula* in Bulgaria (MARKOV 2003), or the European sousliks, *Citellus citellus* in former Yugoslavia (KRYŠTUFEK 1990) show obviously higher *MMD* values. This is certainly because of the strong relationship to people and the resulting talent of dispersal of the house mouse.

The *FA* values of the geographical populations differ clearly: they are higher fluctuating asymmetries in the central-northern cluster than in the other localities. The reasons could be any kind of disturbance due to environmental or genetic stress factors (GRAHAM et al. 2010), such as environmental pollution, food deficit or overpopulation, which might play a role in these regions. Nevertheless, since the origin of *FA* is still not clear (RASMUSON 2002, LEAMY & KLINGENBERG 2005, GRAHAM et al. 2010); these valuations do not have a diagnostic character.

In comparison to Czech house mouse subpopulations (LAZAROVÁ 1999) the Mongolian values are rather low though. As the values generally reflect the developmental stability of a population (SMITH 1981), it appears that the Mongolian house mouse populations apparently are not exposed to considerable stress factors that would disrupt their progression.

### Acknowledgement

We would like to thank all the people who contributed in some way to this study. Especially, the students of the National University of Mongolia and their families, who collected or helped to collect the specimens in all the various parts of the country. Rico Apenborn and Katrin Lammers want to thank Margit Hanelt for the introduction and the expert advice in preparation work, as well as Diana Jeschke and Karsten Wesche for their kind support. They further thank Diethard Tautz and his team, who made the molecular genetic lab work possible, as well as Martin Stein and Ravchig Samiya for their support.

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