RESEARCH PAPER

ZONING OF DESERT, STEPPE, STEPPE-FOREST AND FOREST ECOSYSTEMS BY CARBON AND NITROGEN ISOTOPE IN MONGOLIA AND WESTERN TRANSBAIKALIA

Anna M. Khubanova[1], Valentin B. Khubanov[1*], Denis A. Miyagashev[2]
[1]Dobretsov Geological Institute of Siberian Branch of Russian Academy of Sciences (GIN SB RAS), 6a, Sakh'yanovoy str., Ulan-Ude, Buryatia, Russia, 670047,
[2]Institute of Mongolian, Buddhist and Tibetan Studies of Siberian Branch of Russian Academy of Sciences (IMBTS SB RAS), 6, Sakh'yanovoy str., Ulan-Ude, Buryatia, Russia, 670047
*Corresponding author: +79246501514, khubanov@mail.ru
Received: January 18th, 2023 / Accepted: September 4th, 2023 / Published: October 10th, 2023
https://DOI-10.24057/2071-9388-2023-2720

ABSTRACT. The Mongolian–Transbaikalian region of the Central Asia is known for its wide range of intracontinental ecosystems from desert through steppe to taiga forest and mountain tundra. Data on the isotopic composition of carbon and nitrogen in the bone and dental tissues of herbivorous animals inhabiting the desert, steppe, and forest–steppe landscapes of Outer Mongolia and Western Transbaikalia are presented. The maximum values of the carbon isotope ratio are observed in animals from the desert (Gobi Desert) and the semi-desert landscapes, median (mean) $\delta^{13}C$ is -17.9‰. The minimum values of $\delta^{13}C$ were obtained by herbivorous animals of the forest-steppe and the forest landscapes (Transbaikalia), which median $\delta^{13}C$ is -23‰. The fauna of the steppes (median $\delta^{13}C$ is -21.7‰) has intermediate values of the carbon isotopic composition. According to the isotope composition of nitrogen, the isotope-geochemical isolation of ecosystems is less pronounced.

KEYWORDS: herbivorous animals, carbon and nitrogen stable isotope, ecosystem zoning, Mongolia, Western Transbaikalia

CITATION: Khubanova A. M., Khubanov V. B., Miyagashev D. A. (2023). Zoning of Desert, Steppe, Steppe-Forest and Forest Ecosystems By Carbon And Nitrogen Isotope in Mongolia And Western Transbaikalia. Geography, Environment, Sustainability, 3(16), 14-31
https://DOI-10.24057/2071-9388-2023-2720

ACKNOWLEDGEMENTS: This work was supported by Russian Science Foundation grant #23-28-01348.
We thank professor Valentin N. Golosov, professor Yaroslav V. Kuzmin and the anonymous reviewer for useful comments that helped to improve the paper.

Conflict of interests: The authors reported no potential conflict of interest.

INTRODUCTION

In biogeographic, paleogeographic and paleontological (zooarchaeological) studies, the stable isotope ($^{13}C/^{12}C$, $^{15}N/^{14}N$) analysis is widely used for reconstruction of diet, landscape and climatic conditions for the growth of plant food resources and animal habitat, including disappeared animals (Bocherens et al. 1991; Fernandez et al. 1991; Fizet et al. 1995; Germonpre and Lbova 1996; Bocherens et al. 1996; Koch 1998; Bocherens 2003; Palmqvist et al. 2003; Barberena et al. 2009; Drucker et al. 2010; Drucker et al. 2011; Di Matteo et al. 2013; Britton et al. 2013; France et al. 2014; Krylovich et al. 2020; Skippington et al. 2021; Kradin et al. 2021; Kuzmin et al. 2021; Kuzmin et al. 2023).

The ratio of carbon isotopes in animals depends on the plants they consume. Plants are divided into three main groups according to the type of photosynthesis: C3-plants, C4-plants and CAM-plants. Plants of temperate and cold natural zones belong to the first type of photosynthesis (C3), they are characterized by an average $\delta^{13}C$ of about -27‰. The second type includes C4 plants, predominantly growing in hot and arid climates, with $\delta^{13}C$ about -13‰. The third group of plants includes cacti and succulents, $\delta^{13}C$ values that are in the range between $\delta^{13}C$ values in plants with C3- and C4-type photosynthesis. In addition, a relatively light isotope composition of carbon is observed in forest vegetation, and a relatively heavy isotopic composition is due to a decrease in the effect of isotope fractionation in the case of growth in open spaces, for example, in the steppe (O'Leary 1988; Bocherens 2003; Svyatko 2016).

The ratios of stable nitrogen isotopes in animals are affected by various physiological (hunger, dehydration, lactation period) and ecological processes (drought, soil salinization, manure) during which $\delta^{15}N$ values are enriched or depleted. For example, when there is a shortage of food and water, the composition of the tissues of herbivores is characterized by enrichment in the heavy isotope of nitrogen; under favorable conditions, on the contrary, the amount of the heavy isotope of nitrogen is relatively reduced. In addition, due to the effects of fractionation, the values of $\delta^{13}C$ and $\delta^{15}N$ in the collagen of the bones of herbivores differ by an increase of 5‰ and 3-5‰, respectively, from the isotopic composition of their food. And further along the food chain, these values increase with each trophic level by 1‰ for $\delta^{13}C$ and by 3-5‰ for

$\delta^{15}N$ (Bocherens 2003; Gorlova et al. 2015; Svyatko 2016; Krajcarz et. al. 2016). Thus, using this method of the ratio of stable isotopes of carbon and nitrogen, it is possible to reconstruct the diet and ecological environment of animals.

The earth sciences widely use the principle of actualism, which is based on the analogy of modern geological processes and settings, including ecosystems, with those that took place in the past. Therefore, for paleogeographic reconstructions with an actualistic approach and the use of stable isotopes, it is necessary to know the ratio of carbon and nitrogen isotopes in modern animals inhabiting various landscape zones with a characteristic food supply.

One example of such studies is the work of H. Bocherens (Bocherens 2003), who compared the isotopic composition of ancient animals with the characteristics of animals from modern biocenoses in order to reconstruct the paleoecosystem of the mammoth steppe based on Upper Pleistocene sites in Eurasia and Alaska. In particular, he carried out isotopic studies of modern vegetation and megafauna in order to quantify the relative contribution of various food resources to the isotopic composition of the bone and dental tissues of animals. What served as the basis for comparing and reconstructing the feeding and living conditions of the following animals in the past: Equus sp., *Rangifer tarandus*, Bos or Bison, Alces sp., *Coelodonta antiquitatis, Mammuthus primigenius*. It should also be noted the work of F. Tahmasebi et al. (Tahmasebi et al. 2018), in which they studied modern and fossil plants and animals to track the dynamics of changes in the nitrogen isotopic composition of flora and fauna in the Yukon Territory, northwestern North America, between the Late Pleistocene and present. N. Fox et al. (Fox et al. 2023) used stable isotope analysis combined with radiocarbon dating for modern and fossil small fauna (squirrels, rabbits) in reconstructions of their ecological niches over the last > 55,000 years.

In the scientific literature for modern animals of Central Asia, there is a lack of such isotope studies (for example, Makarewicz 2017; Makarewicz et al. 2018; Ventressa Miller et al. 2019). Most of the previous work has focused mainly on a specific trophic group or species to analyze their diet. For example, C. Makarewicz and N. Tuross compared the diet between domestic and wild caprines, and M. Burnic Strum et al. investigated the dietary niches between domestic horse (*Equus caballus*) and wild horses (*Equus (ferus) przewalskii and Equus hemionus*) (Makarewicz and Tuross 2006; Burnic Strum et al. 2017). A. Kohzu et al. described food relationships by analyzing the isotopic composition of plants, arthropods, wild and domestic animals, and humans in Central Mongolia (Kohzu et al. 2009). H. Davie et al. studied the isotopic composition of several mammal and plant species from the Ikh Nart Natyre Reserve (Davie et al. 2014). V. Dambaev et al. studied the carbon isotopic composition of vegetation and soils of steppe pastures in Mongolia and Western Transbaikalia (Dambaev et al. 2016.). They also showed that against the backdrop of increasing degradation of pasture ecosystems, the main reason for which is the constant increase in the number of livestock, there is competition between wild and domestic animals for pasture niches.

The insufficiency of isotopic data does not allow one to reliably trace the relationship between variations in the isotopic characteristics of animals and the physiographic zonality of their habitats. At the same time, it should be noted that the region covering Mongolia and Western Transbaikalia is characterized by wide variations in intracontinental landscape settings from deserts-through-steppes to taiga forests and mountain tundra.

The purpose of this study is to compare variations in the isotope characteristics of herbivores with the landscape setting of their habitat. This paper presents the results of a study of carbon and nitrogen isotope composition of bone and dental tissues of livestock (*Bos taurus, Equus ferus caballus,* and *Ovis aries*) pastured in the Outer Mongolia and the Western Transbaikalia, as well as some wild animals (*Capreolus pygargus, Moschus moschiferus*). The sampling of animals done does not reflect the entire species composition of the herbivorous fauna and has a local character from desert, steppe and forest-steppe regions, i.e., does not cover all the diversity of ecosystems. Nevertheless, the data obtained make it possible to get an idea of the possibilities of applying isotope methods for isotope-landscape zoning of the territories of the Central Asia.

ECOSYSTEMS AND MATERIALS

We focused the research on animals grazing on the territory of Mongolia and Western Transbaikalia. This vast region contains various ecosystems stretching as sublatitudinal belts: from deserts through steppes to taiga forests and mountain tundra. The territory division into natural zones (Fig. 1) is based on the landscape (ecosystem) distribution schemes developed by the predecessors (Atlas of Transbaikalia 1967; The Ecological Atlas… 2015; Atlas of ecosystem… 2019; Ecological and Geographical… 2019). The current study covered the following main ecosystems: desert, semi-desert, steppe, forest-steppe, and forest (taiga).

The desert and semi-desert zones occupy about 40% of the Outer Mongolia and represent northern part of the Gobi Desert. The relief combines plains of different heights, low and medium-altitude mountains, as well as desert foothills of bald mountains (Simukov 2007; Petukhov et al. 2018).

The climate is characterized by an average amount of precipitation from 50 to 150 mm with uneven distribution throughout the year with an average annual air temperature of +4 to +8°C in deserts and from 0 to +4°C in the semi-deserts. Summers are dry and warm in the desert, arid and moderately cool in the semi-desert, in both cases with cold winters (Petukhov et al. 2018; Atlas of ecosystems… 2019).

According to botanical and geographic zoning, the desert zone includes various deserts and desert, petrophytic and psammophytic steppes with weakly humus light brown and gray-brown saline soils. These soils are dominated by perennial plants (*Stipa gobica, S. Glareosa*, Allium, *Eurotia ceratoides*), small shrubs (*Anabasis brevifolia, Nanophyton erinaceum, Éphedra*, short Halóxylon, Potaninia, *Artemisia terrae-albae*) are widespread there as well. Such plant species and subspecies as Kalidium, Halóxylon, Reaumuria, Caroxylon *Salsola passerina*, Brachanthemum, Nitraria are widespread on highly saline soils.

The semi-desert zone covers dry and desert steppes dominated by light chestnut soils, as well as brown sandy soils and sands, and often saline soils. The following plant communities mostly grow here: Artemisia - bunchgrass, bunchgrass (Stipa, Cleistogénes, Agropyron) wish Caragána, Stipa–Cleistogénes, Nanophyton, Artemisia, Ajania, Allium, Stipa glareosa. Brown saline soils are planted with communities with bunchgrass (Stipa gobica, S. glareosa), perennial saltworts (Salsola passerine, Reaumuria songarica) and with Stipa – Allium plant communities.

The steppe zone occupies most of northern half of the Outer Mongolia, and is also present in the southern and central parts of the Western Transbaikalia. It covers the

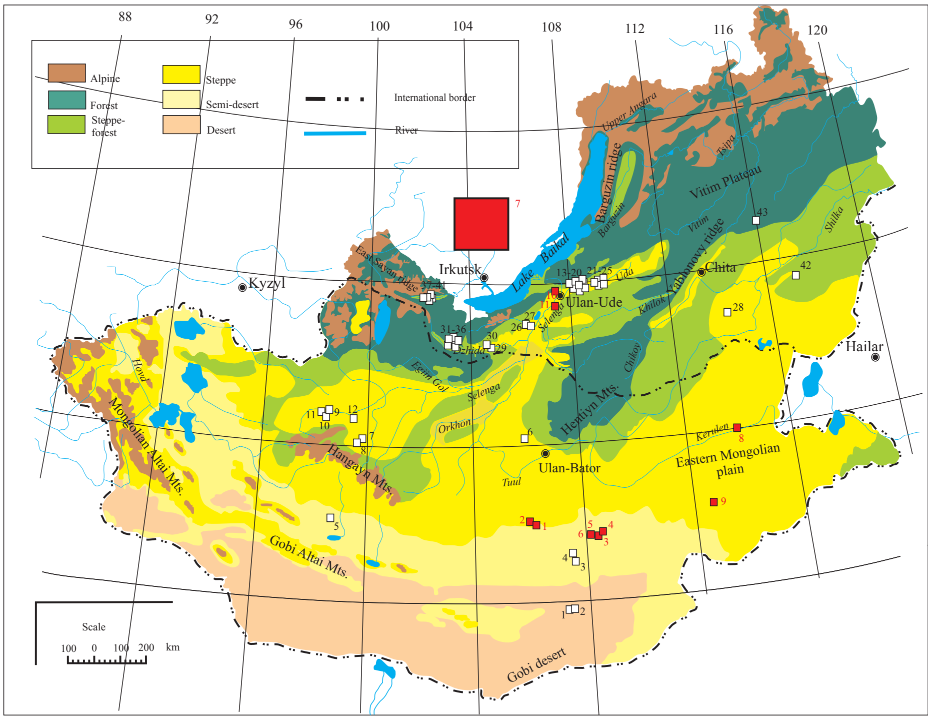

Fig. 1. Landscape zones of Mongolia and Western Transbaikalia (Russian Federation) (by Atlas of Transbaikalia, 1967; The Ecological Atlas…, 2015; Atlas of ecosystems…, 2019; Ecological and Geographical…, 2019) and sampling locations for isotopic analysis. Research sites are presented as squares: white - this study (see Table 1); red - research by other authors: 1 – *Capra sibirica* (Makarewicz, Tuross, 2006), 2 – *Ovis aries* (Makarewicz, Tuross, 2006), 3 – *Bos Taurus*, 4 – *Capra sibirica*, 5 – *Ovis aries*, 6 – *Equus ferus caballus* (Davie et al., 2014); 7 – *Capreolus pygargus* and *Moschus moschiferus* (Weber et al., 2011); 8-11 – plants (Dambaev et al., 2016): Dornod aimag (8), Sukhbaatar aimag (9), Mukhorshibirsky district (10), Ivolginsky district (11)

Khangai Range, the foothills of the Khentei Range, the East Mongolian Plain and the intermountain depressions of the basin of the middle and lower reaches of the Selenga River in the Transbaikalia. The climate is sharply continental, where the average annual air temperature ranges from -2 to +4°C with an average annual precipitation of 150–400 mm. Summers are moderately dry and cool, winters are harsh.

This zone includes moderately dry steppes and meadow steppes. The moderately dry steppes are characterized by dominance of dark chestnut soils, with inclusions of chernozem with the following types of vegetation: forb-bunchgrass and rhizome grass (Stipa, Leymus, Festuca, Carex), shurbs (Caragana) with forb-grass (Festuca ssp.) and Artemisia with shurbs (Caragana, Amygdalus).

The meadow steppes are developed on chernozems, carbonate-free and tundra peaty-gley soils and on sandy soils with forb-grass Filifolium sibiricum, Artemisia and such shrubs, as Armeniaca sibirica, Ribes ssp., Ulmus pumila.

The semi-desert steppe based on sandy loam and rubbly sandy loam soils are of subordinate importance with forb-grass (*Serratula centauroides, Astragalus brevifolius, Cleistogenes squarrosa, Asterothamnus heteropappoides, Vincetoxicum sibiricum)–gropyron criststum–Stipa glareosa, S. krylovii* communities and with shurbs *Eurotia ceratoides, Caragana bungei*. It should be noted that the steppes of Western Transbaikalia mainly occupy low-lying parts of intermountain depressions, which is why pasture lands are relatively limited in area than in the steppes of the Khangai and Khentei highlands. Accordingly, these small pastures may have a higher load from grazing small and large cattle, especially in the case of unsystematic year-round grazing (Boikov et al. 2002). Intensive use of these pastures leads to a change in phytocenoses (plants that are less eaten by livestock become widespread) and destruction of the soil cover (deflation, washout, salinization). In addition, from the increased density of livestock per unit area in the soil, water and plants of these pastures, a relatively increased amount of nitrogen-rich substances is recorded due to the abundance of animal waste. High pressures on rangelands also occur near relatively large settlements.

The forest-steppe zone is common in northern part of the Outer Mongolia and in southern half of the Transbaikalia. It predominantly occupies the foothills and spurs of mountain ranges, where the slopes of the northern exposure are covered with forests, while the southern slopes are represented by a steppe landscape and/or meadows. The Forest zone covers relatively small areas in north of the Outer Mongolia and is widespread in the Transbaikalia. The forest zone is developed along mountain ranges and within the Vitim Plateau.

For the forest-steppe and forest zone of the Transbaikalia, the average annual air temperature is about -2.5 ° C in the forest-steppe and from -2 to -6°C in the forest belts, in the bald mountain belt (on the ridges of the plateau periphery) - from -7 to -11°C, with an average annual precipitation of 400–600 mm in the forest-steppe and up to 800–1200 mm in the mountainous taiga and the bald mountains (Boykov et al. 2002; Osipov 2005; Plyusnin 2015).

Brown-colored, podzolic coarse-skeletal and soddy-carbonate-leached soils predominate in the forested area. The forest cover is represented by: *Pinus sibirica*, Picea, Larix and *Betula rotundifolia* with shurbs (*Rhododendron parvifolium, Vaccinium vitis-idaea, Duschekia fruticosa, Ledum palustre, Calamagrostis lapponica*), Larix with *Betula middendorffii* and *B. exilis*, woodland with Picea and Larix; grassy: *Pedicularis verticillata, Delfinium crassifolium, Carex amgunensis* with moss *Rhytidium rugosum, Geum aleppicum, Crepis praemorsa, Euphorbia jenisseiensis, Crepis praemorsa, Anemone crinita, Saussurea controversa*. The wetlands include peat-bog soils; the vegetation consists of shurbs *Vaccinium uliginosum, Chamaedaphne* *calyculata–Carex meyeriana–Drepanocladus vernicosus, Drepanocladus sendtneri, Meesia triquetra with grass and moss Tomenthypnum nitens, Thuidium abietinum, Rhytidium rugosum, Carex dioica, Carex limosa, Caltha palustris, Equisetum fluviatile, Cicuta virosa, Epilobium palustre*.

The meadow and steppe areas include chernozem, dark chestnut and less often tundra peaty-gley soils. The meadow communities are represented by the following grass: *Leymus secalinus, Poa pratensis, Elytrigia repens, Agrostis mongolica, Bromus secalinus, Sanguisorba officinalis, Medicago falcata with shurbs (Salix microstachya, Hippophae rhamnoides, Ulmus pumila*) and *Populus laurifolia*; with *Carex* and *Calamagrostis*. Forb-grass vegetation dominates in the steppe areas: *Rhinactinidia eremophila, Peucedanum morisonii, Dracocephalum foetidum, Oxytropis oligantha, Saussurea sajanensis, Potentilla fragarioides with Agropyron cristatum and Festuca lenensis; Stipa capillata, Stipa krylovii, Leymus chinensis, Bupleurum scorzonerifolium, Galium verum, Aconogonon angustifolium, Oxytropis filiformis, Astragalus melilotoides*.

The bald mountain zone occupies the watersheds of the Mongolian Altai, Khangai, Eastern Sayan, Barguzin and Northern Transbaikalia ranges. In botanical and geographical terms, these are tundra and light forests with gley and tundra soils. The tundra vegetation is dominated by lichens (*Cladonia alpestris, C. sylvatica, C. rangiferina*), shrubs (*Betula rotundifolia, Rhododendron aureum, Salix glauca, Empetrum sibiricum, Cassiope ericoides*), grass (*Festuca ovina, Carex ensifolia, Pedicularis oederi, Calamagrostis lapponica, Carex globularis, C. ensifolia, Hierochloe alpina*). The woodland vegetation is represented by *Pinus sibirica* and *Larix sibirica–Pinus sibirica –Betula rotundifolia* – shrubs (*Vaccinium vitis-idaea, Vaccinium uliginosum*) – mosses (*Dicranum scoparium, Pleurozium schreberi*) – lichens (*Cladonia turgida, Cladonia uliginosa*) plant communities.

METHODS

Sample collection

In Mongolia, sampling was carried out in the desert (South Gobi aimag), semi-desert (Middle Gobi and Bayankhongor aimags) and steppe (Central, Arkhangai and Dzabkhan aimags) landscape zones. In the Transbaikalia, samples were taken in the steppe (Zaigraevsky, Khorinsky and Selenginsky districts of Buryat Republic of Russia, Aginsky district of Zabaykalsky Krai of Russia), forest-steppe and forest (Dzhidinsky, Zakamensky and Tunkinsky regions of Buryat Republic, Tungokochensky and Baleisky regions of Zabaykalsky Krai) landscape systems (Fig. 1, Table 1).

The sampling was carried out in the central parts of landscape ecosystems (deserts/semi-deserts, forest-steppe/forest steppes) in order to best characterize the isotope composition of animals in their habitat. The geographical location of the sampling points was recorded by the GPS navigator (Table 1). The material was collected from the daylight surface. Samples devoid of muscle and cartilage tissue, and sufficiently preservated as observed by external signs (color, integrity, strength and density of the material, absence of secondary carbonation signs, etc.) were preferred. Basically, dental material was selected, since it turned out to be more accessible, and, in combination with jawbone fragments, it is good for identifying the type of the deceased animal. In addition, bone tissues, unlike dental tissues, are exposed to secondary transformation during fossilization and diagenesis, which to a greater extent affects the poor preservation of the primary isotope composition (Lee-Thorp 2008; Pidoplichko 1952). It should be noted that sampling of the remains of domestic animals in the forest-steppe and forest zones was carried out on open pastures (steppe or meadow) near settlements.

Dental and bone tissues (dentine, bone) of household herbivorous animals (*Bos taurus* (bull), *Bos mutus* (yak), *Equus ferus caballus* (horse), *Ovis aries* (sheep) and wild animals (*Capreolus pygargus* (roe deer), *Moschus moschiferus* (musk deer) were analyzed.

Sample preparation

The weighted amounts of the selected dental (dentin) and bone material for C-N isotope analysis varied from 0.5 to 4 g. The whole selected material was first brush-cleaned, washed in distilled water (ultrasonic bath), and dried in the open air. To calculate the collagen output, each sample was weighed on an Acculab (USA) analytical balance (model ATL- 220d4-I). Then the samples were soaked for 24 h in dichloromethane for degreasing, then dried and processed according to Longin's modified technique (Longin 1971; Arslanov 1987; Nikolaev et al. 2006). The technique included demineralization of the samples for 3–5 days in 0.5 M solution of HCl, until malaxation of the bone tissue, rectification from lipids and humic acids by soaking in 0.125 M solution of NaOH for 20 h, and dissolution of residue in a weak solution of HCl at 100°C for 17 h. The obtained colloid solution was separated into heavy and light fractions by centrifugal separation on an ELMI CM-50 centrifuge (Latvia) at 15000 RPM for 45 min. Then the light fraction (refined collagen) was dried in a drying closet at 70°C until solid residue was obtained. After that, the refined collagen was weighed on an analytical balance and the relative collagen output was calculated ($Y_{coll.}$, wt%) using the formula:

$Y_{coll.} = M_{coll.}/M_{bone.}*100\%$,

$M_{bone.}$ is the mass of the weighed amount of bone or dental tissue and $M_{coll.}$ is the mass of collagen.

Isotope analysis

The isotope analysis of the refined collagen samples was carried out on a Flash EA 1112 element analyzer ("Thermo Finnigan", Germany) in line with a Thermo Finnigan MAT 253 isotope mass-spectrometer at the Analytical Center of Mineralogical, Geochemical and Isotope Studies «Geospektr» of Dobretsov Geological Institute of the Siberian Branch of the Russian Academy of Sciences, Ulan-Ude, Russia. Before the analysis, dry collagen samples were tightly packed into aluminum foil tins and weighed on a Mettler Toledo MX-5 microbalance. The obtained isotope data were conveyed as $\delta^{13}C$ and $\delta^{15}N$ values in per mille (‰):

$\delta^{13}C = [(^{13}C/^{12}C\text{sample}/^{13}C/^{12}C\text{standard}) - 1] \times 1000‰$,

$\delta^{15}N = [(^{15}N/^{14}N\text{sample}/^{15}N/^{14}N\text{standard}) - 1] \times 1000‰$.

The $\delta^{13}C$ values were calculated regarding the isotopic composition of «Pee Dee Belemnite» (PDB) and $\delta^{15}N$ – of atmospheric air. And the international (USGS 40, IAEA-N-1) and intralaboratory (MCA-7, MCA-8) reference samples were analyzed as control samples. The measurement uncertainty in determining isotope ratios was (1σ) ± 0.2‰ for $\delta^{13}C$ and $\delta^{15}N$.

The percentage content of carbon (C, %) and nitrogen (N, %) was calculated on the basis of the control external standard USGS40 (L-Glutamic acid) in which carbon concentration was 40.82% and nitrogen – 9.52% according to the formulas:

$N_{sample} = S_{Nsample}*N_{stand}/S_{Nstand}*M_{stand}/M_{sample}$

$C_{sample} = S_{Csample}*C_{stand}/S_{Cstand}*M_{stand}/M_{sample}$

where S is a signal of nitrogen (N) or carbon intensity (C) of the sample (sample) or the standard (stand); N –

percentage of nitrogen in the sample (sample) or the standard (stand); C – percentage of carbon in the sample (sample) or the standard (stand); M_{stand} is the mass of the weighed amount of the standard, M_{sample} – the mass of the weighed amount of the sample.

For the assessment of the degree of collagen preservation in the fossil bones, the C/N ratio which is expected to be within the interval from 2.9 to 3.6 was used (DeNiro and Schoeninger 1983; Ambrose 1990; Brown et al. 1988).

Statistical analysis

For statistical comparison of the isotopic compositions of bone and dental tissues of herbivores from different ecosystems, we used the average (median) values calculated using the Bayesian bootstrap method (Rubin 1981). The algorithm is implemented in the environment R (Bååth 2018). It well suited this method for calculating statistical indicators (mean, standard deviation, quantiles, including median) with small samples. In addition, visualization with box plot is convenient for comparing data.

Since the amount of isotope data is small, the non-parametric comparison method of the Mann-Whitney U test was also used. This approach makes it possible to compare two independent small samples and is a nonparametric alternative to the Student's t-test (Mann and Whitney 1947).

RESULTS AND DISCUSSION

In total, the isotope composition of 43 samples was investigated (Table 1). For almost all of them, atomic ratios of carbon to nitrogen (C/Nat) were fixed in the range from 2.9 to 3.6, which indicates a satisfactory preservation of these samples (Ambrose 1990; Svyatko 2016). Samples MNG-05-16, C14(14)-2, C19(14)-1, C15(14)-2, and C10(14) are the exceptions, they are assumed to have their primary isotope composition altered under the influence of secondary processes. These samples were not used in the discussion. The percentages of carbon (C, %) and nitrogen (N, %) are within the range for well-preserved collagen, at least 16.4% and 6.2%, respectively (Ambrose 1990).

Carbone isotope ratio

It is known that carbon and nitrogen isotope composition can provide information on the sources of protein in the diet. The carbon isotope composition of collagen and dentin isolated from bone and dental tissues of herbivorous animals reflects the isotope composition of vegetation and, therefore, the basis of food chains (Nikolaev et al. 2006; Bocherens and Drucker 2003; LI et al. 2009; Ma et al. 2012). Depending on the photosynthesis type, the major part of the plants is divided into C3– and C4–plants. In steppes, boreal forests of the temperate climatic zone and tundra of moderately cold and cold regions, plants with C3-type photosynthesis form the basis of the biomass. On average, these plants are characterized by $\delta^{13}C$ value of about -27‰ (O'Leary 1988; Bocherens 2003; Svyatko 2016) which, however, can widely vary. The reasons for lightweight carbon isotope composition in the vegetation are reduction of illumination under the forest canopy, re-assimilation of CO_2 in a relatively closed space (in a dense forest) and/or depletion of nutrients in the soil. Whereas the relatively heavyweight isotope composition is due to a decrease in the effect of isotope fractionation in the case of growing in open spaces, for example, in steppe, as well as due to water and salt stress. C4 plants grow in hot and warm climates – in tropical humid forests, semi-deserts and deserts, $\delta^{13}C$ values from - 14‰ to - 10‰ are typical for them (O'Leary 1988; Bocherens 2003; Svyatko 2016). The carbon isotope composition for herbivorous animals will be weighted by 5‰ regarding the composition of their plant food (Bocherens 2003; Svyatko 2016).

In **the desert/semi-desert** landscapes, herbivorous animals have the maximum values of carbon isotope ratios (Fig. 2, Table 1). Values $\delta^{13}C$ for desert and semi-desert *Equus ferus caballus* and *Ovis aries* range from -18.8‰ to -15.4‰. The indicators for horses living in semi-deserts are lower and are -18.6‰ and -18.4‰. The isotope values for sheep from semi-deserts are $\delta^{13}C$ = -18.8‰. The obtained values of carbon isotope ratios indicate a diet consisting of plants with C3– and C4–type photosynthesis. The following C4 plants are known in this area: *Cleystogenes squarrosa, Eragrostis minor, Enneapogon borealis, Setaria viridis, Tribulus terrestris,* etc. (Table 2), which have a carbon isotope composition varying from -14.6 to -11.4‰. Plants with C3–type of photosynthesis are characterized by lighter indicators, varying from -29.8 to -24.3‰ (Table 2). Taking into account the correction for isotope fractionation from producers to consumers of the first order, for herbivorous animals with a mixed diet (C3 and C4), δ13C will vary approximately in the range from -21.5 to -7.5‰ (van der Merwe 1992).

The values of dentin carbon isotope ratios of horses inhabiting in the deserts and semi-deserts are within this range, and they are also well compared with the carbon isotope data of horses of the semi-deserts in the Ikh Nart reserve (East Gobi aimag) located in the eastern part of the Gobi Desert ($\delta^{13}C_{hair}$ / $\delta^{13}C_{bone}$ = -18.8±1.1‰ / -16.8±1.1‰) (Davie et al. 2014). It should be noted that in (Davie et al. 2014) the values of carbon and nitrogen isotopes are given for hair samples. Therefore, to correctly compare $\delta^{13}C$ and $\delta^{15}N$ hair keratin and bone collagen for herbivores, the following corrections were used: $\delta^{13}C_{bone} = \delta^{13}C_{hair}$ + 2.0‰ and $\delta^{15}N_{bone} = \delta^{15}N_{hair}$ + 2.1‰ (Kohzu et al. 2009). Similar values of carbon isotope ratios are observed in horses that lived in the arid landscapes of Southeast Kazakhstan during the Bronze Age ($\delta^{13}C_{bone}$ = -18.9±0.9‰) (Table 3) (Ananyevskaya et al. 2020).

The observed $\delta^{13}C$ of a single individual sheep is within the range of isotope variations of small cattle (*Ovis aries*) (-17.5±0.8‰) from the semi-desert landscape of the Baga Gazryn Chuluu, Middle Gobi Aimak (Makarewicz and Tuross 2006) and the Ikh Nart reserve ($\delta^{13}C_{hair}$ / $\delta^{13}C_{bone}$ = -19.3±1.4‰ / -17.3±1.4‰) (Table 3) (Davie et al. 2014).

In **the steppe** landscapes, herbivorous animals have a relatively light carbon isotope composition compared to the herbivores of arid landscapes. The values of carbon isotope ratios of cows and sheep vary from -22.4‰ to -20.2‰, which indicates the predominance of steppe grass with C3 photosynthesis (possibly xerophytic plants) in their diet growing in open areas with a temperate climate, where C4 plants have a sharply subordinate position (Bocherens 2003).

The carbon isotope compositions of animals of the steppes of Mongolia and Western Transbaikalia are comparable to each other. Values $\delta^{13}C$ in bone and dental collagen of herbivorous animals of the steppe landscapes of Mongolia and Western Transbaikalia vary from -22.1 to -20.0‰ and from -22.9 to -20.4‰, respectively. The carbon isotope composition of horses (-22.9 to -20.0‰) is relatively lightweight, suggesting an extended diet that included grass from meadows and/or forest-steppes. This

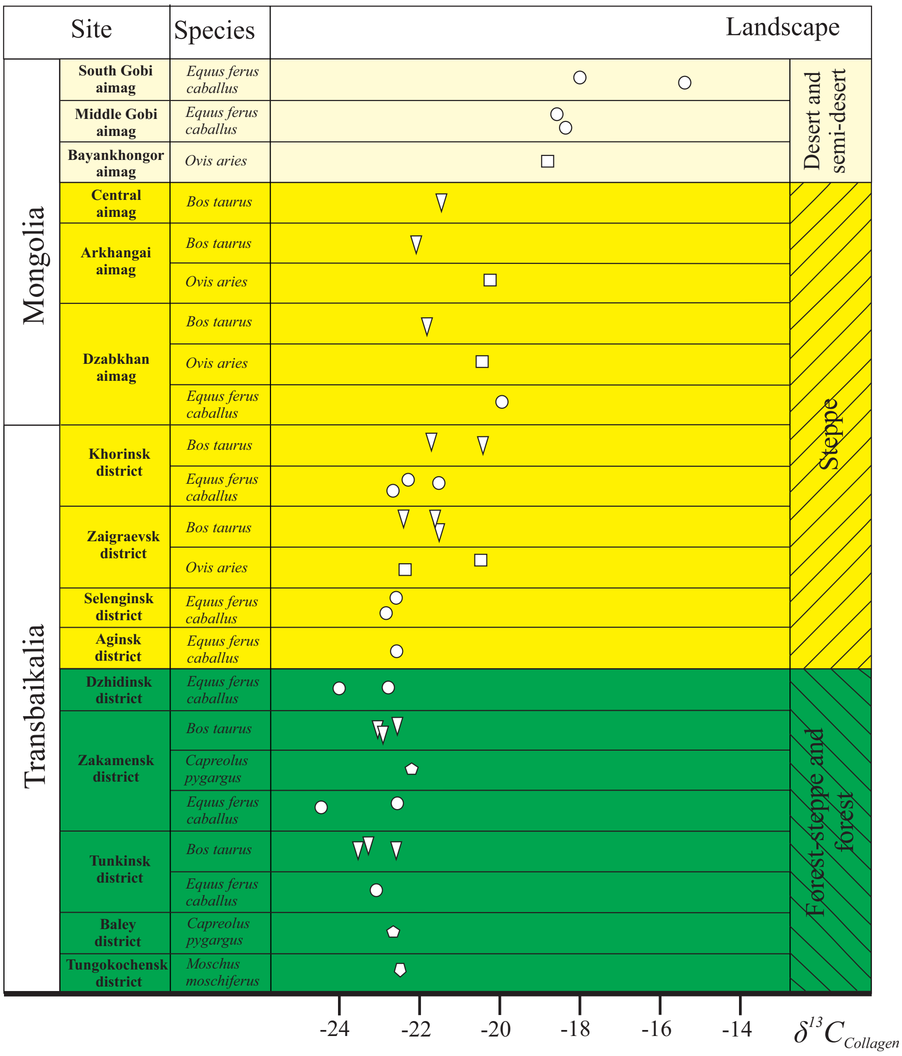

Fig. 2. Carbon isotope composition ($\delta^{13}C$) of collagen from the herbivorous fauna of Mongolia and Western Transbaikalia. Square - *Ovis aries* ; circle - *Equus ferus caballus*; triangle - *Bos taurus*; pentagon - *Capreolus pygargus*; elongated pentagon - *Moschus moschiferus*

Table 2. Mongolian and Transbaikalian forage plants and carbon isotope composition

Latin name	Life form	Abudance			C3/C4 type	$\delta^{13}C$ (‰)
		Mongolia		Transbaikalia		
		Desert, Semi-desert	Steppe			
Poaceae						
Agropyron cristatum	Ph	++	+++	+	C3	-27.1
Achnatherum splendens	Ph	++	+	+	C3	-26.9
Cleistogenes squarrosa	Ph	++	++	+	C4	-14.6
Eragrostis minor	Ah		+		C4	-11.6 (for *Eragrostis sp.*)
Eragrostis pilosa	Ah	++	+		C4	-14.1
Enneapogon borealis	Ph	++	+		C4	-13.3
Festuca lenensis	Ph		+	+++	C3	-27±0.17
Festuca sibirica	Ph		+++		C3	-
Koeleria cristata	Ph		+++		C3	-28.8
Leymus chinensis	Ph		+++	+++	C3	-26.4
Poa attenuata	Ph		+		C3	-24.6 (for *P.pratensis*)

Poa botryoides	Ph			+	C3	-
Setaria viridis	Ah	+			C4	-12.3
Stipa krylovii	Ph	+	+++		C3	-25.2
Stipa glareosa	Ph	++	+++		C3	-
Stipa gobica,	Ph	++	++		C3	-
Stipa klemenzii	Ph	+	++		C3	-
Stipa baicalensis	Ph			+	C3	-25.7
Stipa sibirica	Ph		+		C3	-
Carex						
Carex duriuscula	Ph		+++	+++	C3	-27.5 (*Carex spp.*)
Carex pediformis	Ph		+	+	C3	
Fabaceae						
Astragalus adsurgens	Sh			+	C3	-26.5 (for *A. melilotoides*)
Astragalus brevifolius	Sh		++			
Caragana eucophloea	Sh	+	++		C3	-24.3
Caragana microphylla	Sh	+	++		C3	-24.5
Caragana pygmaea	Sh	+	++	+	C3	-
Caragana stenophylla	Sh	+	++		C3	-24.6
Oxytropis oxyphylla	Sh			+	C3	-
Oxytropis myriophylla	Sh			+	C3	-27.5
Forbs						
Allium bidentatum	Ph			+	C3	-25.1
Allium mongolicum	Ph	++			C3	-25
Allium polyrhizum	Ph	++			C3	-25.8
Amblynotus rupestris	Ph			+	C3	-
Arenaria capillaris	Ph	++	+	+	C3	-
Artemisia anethifolia	Bh	+		+	C3	-
Artemisia frigida	Se		+	+++	C3	-28.1
Artemisia commutata	Ph			+	C3	-
Artemisia dracunculus	Ph		+		C3	-26.9
Artemisia scoparia	Bh	+	+++	+	C3	-29.8 to -25.1
Artemisia terrae-albae	Se	++			C3	-
Arctogeron gramineum	Ph			+	C3	-
Aster alpinus	Se		+		C3	-28
Bupleurum scorzonerifolium	Ph		+	+	C3	-
Chamaerhodos erecta	Bh			+	C3	-
Convolvulus ammannii	Ph		+	+	C3	-25
Dasiphora fruticosa	Sh		+		C3	-
Ephedra sinica	Sh	++			C3	-24.4

Euphorbia discolor	Ph		+		C4	-12.1 to -13.5 (for *Euphorbia* sp.)
Filifolium sibiricum	Ph		++		C3	-26.8
Heteropappus altaicus	Ph			+	C3	-26.9
Heteropappus biennis	Bh			+	C3	-
Iris potaninii	Ph		+	++	C3	-26.7 (for *I.lactea*)
Lappula squarrosa	Ph			+	C3	-
Orostachus malacophylla	Bh			+	C3	-25
Polygonum aviculare	Ah		+		C3	-28.7
Potaninia mongolica	Se	++			C3	-26.6
Potentilla acaulis	Ph		+	+	C3	-27.3
Potentilla sericea	Ph			+	C3	-26.14±0.17
Potentilla bifurca	Ph		+	+	C3	-25.6
Ptilotrichum tenuifolium	Se			+	C3	-26.5
Ptilotrichum canescens	Se		+		C3	-
Taraxacum dissectum	Ph			+	C3	-
Taraxacum mongolicum	Ph			+	C3	-26
Thymus baicalensis	Se			+	C3	-29.1 (for *T. serphyllum*)
Thymus gobicus	Se	+	++		C3	
Tribulus terrestris	Se	++	+		C4	-13.4
Salicornia perennans	Se			+	C3	-26.6 (for *S. brachiata*)
Scorzonera austriaca	Ph			+	C3	-25.4
Silene chlorantha	Ph			+	C3	-25.4 (for *S. acaulis*)
Reaumuria soongorica	Sh	++			C3	-24.6
Vincetoxicum sibiricum	Ph		++	+	C3	-
Chenopodioideae						
Anabasis brevifolia	Sh	++	+		C4	-13.3
Bassia dasyphylla	Ah	++	+		C3	-25.1
Chenopodium aristatum	Ah		+	+	C3	-26.1
Eurotia ceratoides	Se	++	++		C3	-28.8
Halogeton glomeratus	Ah	++	+		C4	-14.6
Haloxylon ammodendron	Sh	++			C4	-13.5
Salsola collina	Ah	++	+		C4	-11.4
Salsola passerina	Ah	++			C4	-13.6
Kochia prostrata	Se		+	+	C4	-14
Nanophyton erinaceum	Sh	++			C4	-13.5

«+», «++», «+++» – presence of this plant species in this region in small, medium and larger quantities, respectively.
Ph : Perennial herb; Bh-biennial herb; Ah : Annual herb; Sh : Shrub; Se : Semishrub
C3/C4 type and $\delta^{13}C$ (‰) by (Boikov et al., 2002; Petukhov et al., 2018; Safronova et al., 2018; Danzhalova, Bazha, 2008; Structure and dynamics…, 2018; Urtnasan, Lyubarskiy, 2013; Golovanov et al., 2004; Tsognamsrai, Dugarzhav, 2016; Naidanov, 2009; Yudina et al., 2015; Pyankov et al., 2000; Chen et al., 2007; Codron et al., 2005; Goldman, 2010; Kalapos et al., 1997 ; Khatri et al., 2021; Li et al., 2006; Liu et al., 2004; Liu et al., 2009; Martin, Thorstenson, 1988; Oyungerel et al., 2004; Pearcy, Troughton, 1975; Spasojevic, Weber, 2021; Su et al., 2019; Tanaka-Oda et al., 2018; Wang et al., 2006; Wen, Zhang, 2011; Winter, 1981).

Table 3. Carbon and nitrogen isotope rations for Mongolian, Transbaikalian and Angarian herbivorous animals by other authors

#	Aimag or disrict	Specie	Material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	Location
Desert/semi-desert (Mongolia)						
1	Middle Gobi[1]	*Capra sibirica*	*Molar*	-19.5±0.7	8.1±1.0	N 46°12´0´´ E 106°0´0´´ ~1450-1750 m high
2	Middle Gobi[1]	*Ovis aries*	*Molar*	-17.5±0.8	11.2±1.1	
3	Dornogobi[2]	*Bos Taurus*	*Hair / bone**	-18.0±1.1 / -16.0±1.1	10.2±0.7 / 12.3±0.7	N 45°25´48´´ E 108°23´24´´ ~1570 m high
4	Dornogobi[2]	*Capra sibirica*	*Hair / bone*	-20.9±0.9 / -18.9±0.9	9.3±0.8 / 11.4±0.8	
5	Dornogobi[2]	*Ovis aries*	*Hair / bone*	-19.3±1.4 / -17.3±1.4	10.6±0.4/12.7±0.4	
6	Dornogobi[2]	*Equus ferus caballus*	*Hair / bone*	-18.8 ±1.1 / -16.8 ±1.1	8.1±0.7 / 10.2±0.7	
Steppe (Mongolia)						
7	Dornod[3]	*Stipa krylovii, Artemisia frigida, Allium teniussum, Potentilla acaulis*	*Plant / bone***	~ -25,43 /~ -20,43	–	N 48°2´24´´ E 114°18´0´´ ~720 m high
8	Sukhbaatar[3]	*Stipa krylovii, Cleistogenes squarrosa, Agropyron cristatum*	*Plant / bone*	~ -25,94 /~ -20,94	–	N 46°24´36´´ E 113°10´12´´ ~1000 m high
Steppe (Transbaikalia)						
9	Mukhorshibirsky[3]	*Stipa krylovii, Artemisia frigida, Carex duriuscula, Potentilla acaulis*	*Plant / bone*	~ -27,16 /~ -22,16	–	N 51°02´50´´ E 107°49´25´´ ~950 m high
10	Ivolginsky[3]	*Stipa krylovii, Artemisia frigida, Potentilla acaulis*	*Plant / bone*	~ -27,57/~ -22,57	–	N 51°44´50´´ E 107°16´45´´ ~550 m high
Forest-steppe/forest (Angara)						
11	Angara[4]	*Capreolus pygargus*	Bone	-21.7±1.3	6.2±2.4	–
12	Angara[4]	*Moschus moschiferus*	Bone	-20.4±0.4	6.2±0.6	–

[1]Makarewicz, Tuross, 2006; [2]Davie et al., 2014; [3]Dambaev et al., 2016; [4]Weber et al., 2011.
* $\delta^{13}C_{bone} = \delta^{13}C_{hair} + 2.0‰$ and $\delta^{15}N_{bone} = \delta^{15}N_{hair} + 2.1‰$ (Kohzu et al., 2009).
** $\delta^{13}C_{bone} = \delta^{13}C_{plant} + 5.0‰$ (Bocherens, 2003; Svyatko, 2016)

may be due to the fact that horses graze far away from human habitation and accordingly seek better pastures, while cows and sheep graze near shepherds' camps, within a kilometer radius, in degraded pastures (Davie 2014). It is also possible that horses chose floodplains, with a tree and shrub canopy, for grazing. In this case, the isotope composition of the grass would be close to that of the forest vegetation.

It should be noted that since carbon isotope ratios in the bone and dental collagen of the first-order consumers are enriched by 5‰ compared to the producers, the $\delta^{13}C$ of the steppe vegetation is expected to be between -28‰ and -25‰. It is these $\delta^{13}C$ values (from -27.6 to -25.4‰) that are observed in the vegetation of the steppes of Mongolia and Transbaikalia (Dambaev et al. 2016) (Table 2).

Horses ($\delta^{13}C$ from -24.5 to -22.5‰) and cattle (from -23.6 to -22.6‰) from **the steppe-forest/forest** landscapes are characterized by relatively lightweight carbon isotope composition. It indicates a decrease in their diet of steppe grass and an increased proportion of forest herbaceous and possibly shrub vegetation. Carbon isotope values of roe deer (-22.7‰; -22.2‰) from the forest-steppe and/or the forest landscape are within the range of variability of modern individuals of the Angara region inhabiting also the forest and forest-steppe biocenoses (from -18.9‰ to -23.8‰) (Weber et al. 2011). In contrast to the roe deer, the Siberian musk deer (-22.6‰) from the Transbaikalia have relatively lightweight carbon isotope values than modern individuals from the Angara region (from -20.9 to -20.3‰). It is possible that the Siberian musk deer from the Angara region inhabited more open area.

For statistical comparison of the carbon isotope composition in animals from different ecosystems, we calculated statistical criteria such as mean, standard deviation, quantiles including medians using Bayesian bootstrap (Table 4). This method works well with small sample sizes. In addition, since the median, in contrast to the mean, is less affected by extreme values, this approach allows us to exclude the influence on the sample of individual animals that had grazing outside a certain ecosystem. The display of quantiles and medians for $\delta^{13}C$ values using box diagrams (Fig. 3) clearly shows the difference in the isotopic composition of carbon in animals of desert/semi-desert, steppe, and forest-steppe/forest landscapes.

The Mann-Whitney U-test (Table 5) also shows the difference in the nutritional conditions of herbivores that had grazing in different ecosystems. In all three cases of comparison of U($\delta^{13}C$)-criterion for pair of independent samples (desert/semi-desert vs Steppe; steppe vs forest-steppe/forest; forest-steppe/forest vs desert/semi-desert) with critical U_{Cr} values we observe that $U_{Cr} > U(\delta^{13}C)$.

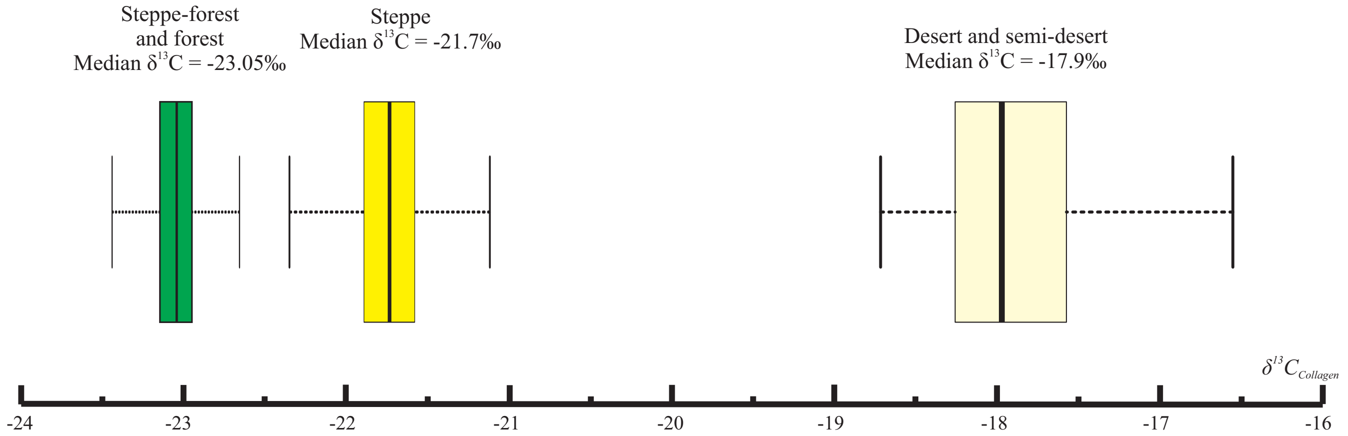

Fig. 3. Box plot (by Bayesian bootstrap method) demonstrating the landscape isolation by carbon isotope composition of the herbivorous fauna in Mongolia and Western Transbaikalia

Table 4. Bayesian bootstrap results*. Herbivore data by landscape.

Landscape (number of samples)	Summary of the posterior (with 95% Highest Density Intervals)				Quantiles				
	Min	Max	Mean	SD	2.5	25	Median	75	97.5
$\delta^{13}C$‰									
Desert/semi-desert (5)	-18.6	-16.8	-17.9	0.5	-18.9	-18.3	-17.9	17.6	-16.6
Steppe (23)	-22.2	-21.3	-21.7	0.2	-22.7	-21.9	-21.7	-21.6	-21.3
Steppe-forest/forest (15)	-23.4	-22.8	-23.1	0.2	-23.4	-23.1	-23.05	-22.9	-22.8
$\delta^{15}N$‰									
Desert/semi-desert (5)	6	7.9	6.9	0.5	6	6.6	6.9	7.3	7.9
Steppe (23)	6.3	7.9	7.1	0.4	6.3	6.8	7.1	7.3	7.9
Steppe-forest/forest (15)	5.5	7.2	6.3	0.4	5.6	6	6.3	6.6	7.2

*Number of posterior draws: 4000

This suggests that the divergence of carbon isotope composition in animals from different landscapes is statistically reliable.

Thus, the values of the carbon isotopic composition are increased in animals of desert landscapes, and the lowest values are in animals of forest-steppe landscapes. This may be because the diet of the herbivorous fauna of deserts and semi-deserts includes C4 and C3 plants. At the same time, C3 plants may have a relatively heavy isotopic composition of carbon because of the openness of the landscape and the prevalence of dry climate. For mammals of the steppe landscape, the diet comprises plants with the C3 type of photosynthesis (mainly herbaceous plants). In the forest-steppe/forest landscapes, the diet of animals contains woody, shrubby, and herbaceous plants with the C3-type of photosynthesis, but with a relatively light carbon isotopic composition. Therefore, forest-steppe/forest animals have the lightest carbon isotopic composition. The results got correlate well with the carbon isotopic composition of modern desert, steppe, and forest herbivores in other regions of the Earth (Bocherens 2003).

Nitrogen isotope ratio

The nitrogen isotopic composition ($\delta^{15}N$) of animals from different landscape zones varies from 4 to 11‰ (Fig. 4, Table 1). This indicator is controlled by the intake of N_2 (and the excretion of nitrogen metabolism products), which depends on the degree of acidity, salinity and depletion of the soils on which vegetation grows, the composition of the plant diet and the trophic level. In addition, nitrogen isotope composition is also sensitive to water and food

Table 5. Mann-Whitney U-test results. Herbivore data by landscape

Landscape (number of samples)	*U_{Cr}	Carbon isotope ratio		Nitrogen isotope ratio	
		**U($\delta^{13}C$)	Result	U($\delta^{15}N$)	Result
Desert/semi-desert (5) vs Steppe (23)	24	6	UCr > U($\delta^{13}C$) The differences are statistically significant	64.5	UCr < U($\delta^{15}N$) The differences are not statistically significant and are random.
Steppe (23) vs Forest-steppe/forest (15)	106	39.7		118	
Forest-steppe/forest (15) vs Desert/semi-desert (5)	14	4		46	

*U_{Cr} – Table Critical Values for the Mann – Whitney U-Test https://real-statistics.com/statistics-tables/mann-whitney-table/
**U – calculated according to (Mann, Whitney, 1947).

stress (Schoeninger and DeNiro 1984; DeNiro and Epstein 1981; Bocherens and Drucker 2003). At each transition to a higher trophic level, the δ15N values of animals change by 2-6‰ (Gorlova et al. 2015; Svyatko 2016; Krajcarz et. al. 2016).

For horses of **the desert/semi-desert** landscapes, the nitrogen isotopic composition obtained from dentin ranges from 5.5 to 8.3‰ (Fig. 4, Table 1). These values are relatively lightweight compared to the ratios of nitrogen isotopes of modern horses from the Ikh Nart Reserve ($\delta^{15}N_{hair}$ / $\delta^{15}N_{bone}$ = 8.1±0.7 / 10.2±0.7‰) (Davie et al. 2014) and Holocene horses ($\delta^{15}N_{bone}$ = 8.5± 2.0‰) from the semi-desert landscapes of Southeast Kazakhstan (Ananyevskaya et al. 2020) (Fig. 5, Tables 1, 3).

The isotope composition of nitrogen in sheep from the semi-desert landscape ($\delta^{15}N$ = 8.4‰) is also lighter relative to the range of isotopic characteristics of sheep (Ovis aries, domestic, provisioned) from the Middle Gobi aimag ($\delta^{15}N$ from 8.6 to 12.9‰, with an average of 11.2±1.1‰) (Makarewicz and Tuross 2006) (Fig. 5, Tables 1, 3).

The relatively lightweight nitrogen isotopic composition in the studied animals, especially Equus ferus caballus, may be due to the fact that these individuals experienced food and water stress to a lesser extent.

Horses from **the steppe** landscapes are characterized by relatively lightweight values of the nitrogen isotope ($\delta^{15}N$ from 5.0 to 7.9‰) compared to animals of the desert and the semi-desert. At the same time, cows ($\delta^{15}N$ from 4.6‰ to 10.0‰) and sheep ($\delta^{15}N$ from 5.2‰ to 11.0‰) show wide variations of $\delta^{15}N$ values (Fig. 4, Table 1).

Perhaps one reason for the high nitrogen isotope value in some cows and sheep is that they grazed near human habitations, where pastures are depleted and soils and waters are enriched with nitrogen waste (Davie 2014). Whereas horses grazed in larger areas and/or away from dwellings, where pastures are less degraded. Other hand, higher values of the nitrogen isotope of sheep may be because they need less water and can do without it for a long time (Burnik Sturm et al. 2017). Also, the heavyweight nitrogen composition in herbivores can be observed when they are fed with mother's milk (Fogel et al. 1989; Bocherens 2003). Usually, in sheep farms, individuals of the first and second years of life, who have not reached full maturity and the change of milk teeth, are slaughtered to obtain meat products (Ulyanov et al. 2011). Therefore, high values of δ15N in dentin can be explained by lactose nutrition and δ15N may be overestimated by 4–5‰, considering the trophic fractionation of isotopes (Jenkins et al. 2001; Svyatko 2016).

Horses of **the forest-steppe/forest** landscapes are characterized by a relatively lightweight nitrogen isotopic composition ($\delta^{15}N$ from 3.6 to 7.1‰). The isotopic composition of nitrogen of cow varies from 5.5 to 7.1‰ (Fig. 4, Table 1).

The ratios of nitrogen isotopes of roe deer and musk deer are increased and vary from 6.0 to 10.0‰. These

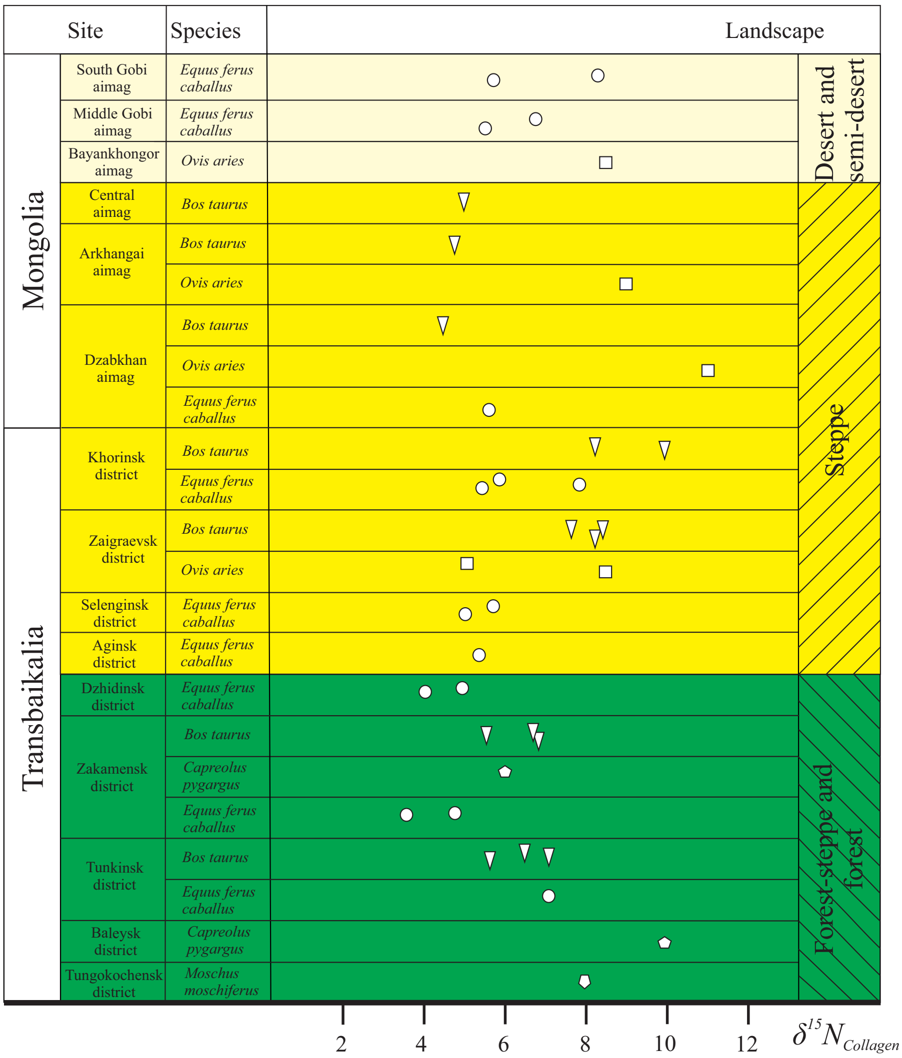

Fig. 4. Nitrogen isotope composition of collagen ($\delta^{15}N$) of the herbivorous fauna of Mongolia and Western Transbaikalia. Square - *Ovis aries*; circle - *Equus ferus caballus*; triangle - *Bos taurus*; pentagon - *Capreolus pygargus*; elongated pentagon - *Moschus moschiferus*

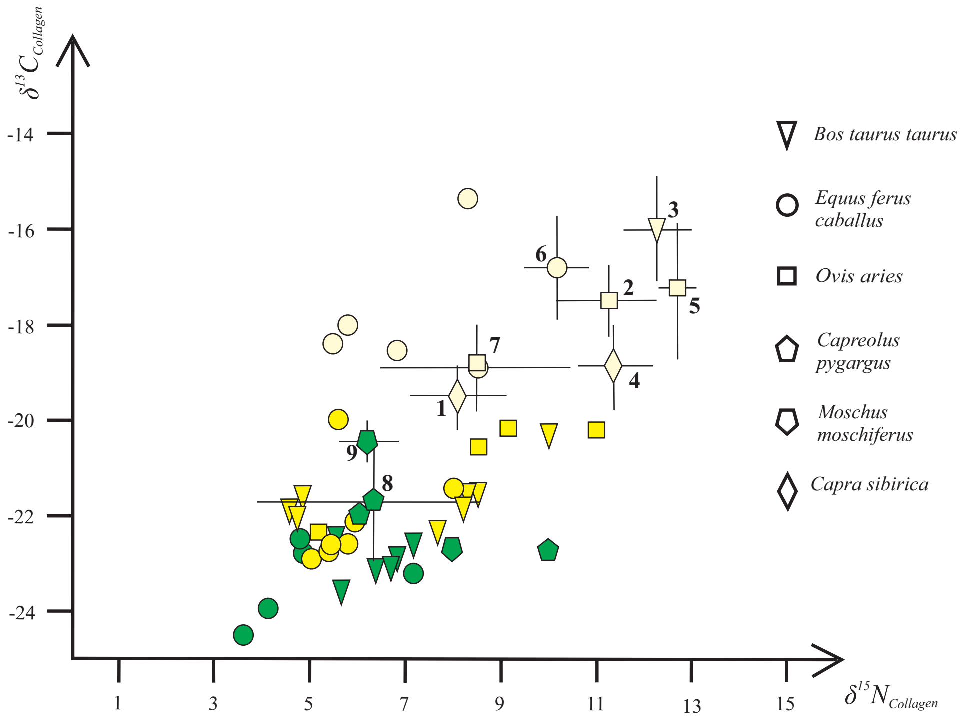

Fig. 5. Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope composition of collagen of the herbivorous fauna of Mongolia and Western Transbaikalia. Pale yellow marks – desert/semi-desert animals, yellow – steppe, green – steppe-forest/forest. Extra data presented with one standard deviation: Central Asian desert and semi-Desert: 1 – *Capra sibirica* (Makarewicz, Tuross, 2006), 2 – *Ovis aries* (Makarewicz, Tuross, 2006), 3 – *Bos taurus*, 4 – *Capra sibirica*; 5 – *Ovis aries*; 6 – *Equus ferus caballus* (Davie et al., 2014); 7 – *Equus sp*. (Ananyevskaya et al., 2020); Central Asian steppe-forest and forest: 8 – *Capreolus pygargus*, 9 – *Moschus moschiferus* (Weber et al., 2011)

values are in diapason of nitrogen isotope composition of roe deer and musk deer ($\delta^{15}N$ from 2.6 to 10.6‰) from the Angara region, where Forest and Forest-Steppe landscapes dominate (Weber et al. 2011). Probably, such scatter of isotope characteristics is associated with the heterogeneity of the diet and feeding on food with a heavy nitrogen isotope composition, for example, fungi and near-water plants (O'Regan et al. 2016; Khubanova et al. 2017).

The close mean and median values of $\delta^{15}N$ (Table 4, Fig. 6) show the absence of differences in this index between animals from different landscape zones. $U_{Cr} < U(\delta^{15}N)$ according to the Mann-Whitney U-test (Table 5) also shows that differences in the nitrogen isotope composition in animals from desert/semi-desert, steppe, forest-steppe/forest are not statistically significant and are random. Thus, the isotope-geochemical isolation of landscapes in terms of the nitrogen isotopic composition is less pronounced. However, there is some tendency of heavier average isotopic composition of nitrogen of forest-steppe/forest animals (median $\delta^{15}N$ = 6.3‰) relative to steppe and desert/semi-desert ungulates (median $\delta^{15}N$ = 6.9 and 7.1‰) (Table 4). Especially this small difference is expressed in horses from forest-steppe/forest ($\delta^{15}N$ from 3.6 to 7.1‰) to desert and semi-desert horses ($\delta^{15}N$ from 5.5 to 8.3‰) (Table 1).

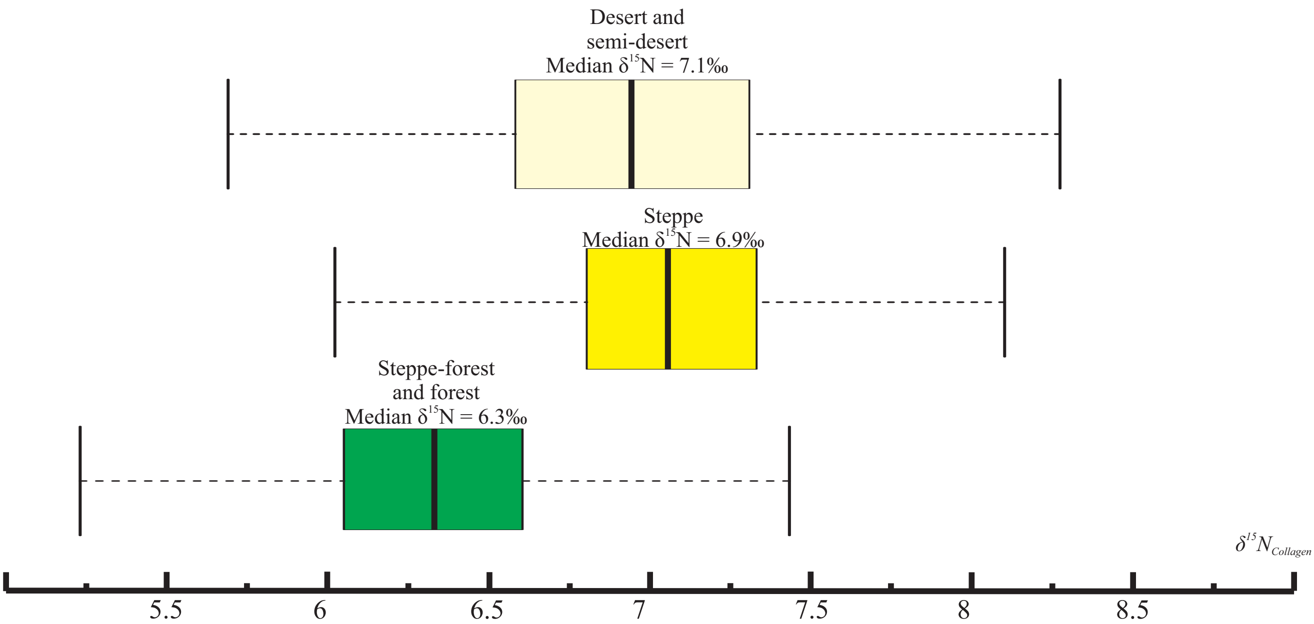

Fig. 6. Box plot (by Bayesian bootstrap method) of nitrogen isotope composition of the herbivorous fauna in Mongolia and Western Transbaikalia

CONCLUSION

In Mongolia and Transbaikalia, there is a wide variety of intracontinental landscape environments (ecological systems). From south to north, they form landscape-climatic zones from the desert and dry steppes through the steppes and meadows to the forest-steppes, taiga and high-mountain tundra. Their difference is due to the difference in average annual and seasonal temperatures, the amount and uniformity of annual distribution of precipitation. In these landscape zones, the species composition of vegetation, including forage vegetation, differs significantly: in warm and arid open landscapes (deserts and dry steppes), C4 plants are widtheely represented along with C3, the latter being strongly enriched in heavy carbon. In steppes, forest-steppes and forests, C3 plants dominate. However, in forest-steppes and forests, grass is under the canopy of woody and shrub vegetation, so it has a slightly lighter carbon isotope composition.

The isotope ratio of carbon in herbivorous animals reflects well the landscape conditions of their habitat. The maximum values of the carbon isotope ratio are observed in animals from the desert (Gobi Desert) and the semi-desert landscapes, median (mean) $\delta^{13}C$ is -17.9‰. The minimum values of $\delta^{13}C$ were obtained in herbivores of the forest-steppe and the forest landscapes (Transbaikalia), median $\delta^{13}C$ is -23‰. The fauna of the steppes (median $\delta^{13}C$ is -21.7‰) has intermediate values of the carbon isotopic composition.

The nitrogen isotope composition indicates that a large proportion of cattle and small cattle grazed in the dry steppe conditions, possibly on pastures with a depleted vegetation cover and a high degree of fertilization. Such conditions are typical near pastoral settlements. An insignificant part of domestic animals, including horses, was characterized by a less weighted nitrogen composition, which indicates more favorable conditions for their nutrition, without water and food stress, and the presence of shrub vegetation in their diet. This suggests that nitrogen isotope composition of animals is largely controlled by water and food sufficiency and is less dependent on the landscape setting.

REFERENCES

Ambrose S.H. (1990). Preparation and characterization of bone and tooth collagen for isotopic analysis. Journal of Archaeological Science, 17, 431–451.

Ananyevskaya E., Akhatov G., Loman V., Dmitriev E., Ermolayeva A., Evdokimov A., Garbaras A., Goryachev A., Kukushkin A., Kukushkin I., Kurmankulov Z., Logvin A., Lukpanova Y., Onggar A., Sakenov S., Sapolaite J., Shevnina I., Usmanova E., Utubayev Z., Varfolomeev V., Voyakin D., Yarygin S., Motuzaitė Matuzeviciute G. (2020). The effect of animal herding practices on the diversity of human stable isotope values in north central Asia. Journal of Archaeological Science: Reports, 34, 102615. DOI: 10.1016/j.jasrep.2020.102615.

Arslanov Kh A. (1987). Radiocarbon: Geochemistry and Geochronology. Leningrad, USSR: Publishing House of Leningrad University (in Russian).

Atlas of Transbaikalia. (1967). (Buryat Autonomous Soviet Socialist Republic and the Chita Region). Sochava V B (eds.) Moscow–Irkutsk: Izd-vo GUGK,. 176 p. (in Russian).

Atlas of ecosystems of Mongolia. (2019). Gunin P.D., Sandar M. (eds.) Ulaanbaatar. ADMON Print.. 264 p.

Bååth R. (2023). Bayesboot: An Implementation of Rubin's (1981) Bayesian Bootstrap. R package version 0.2.2, DOI: //CRAN.R-project.org/package=bayesboot.

Barberena R., Zangrando A.F., Gil A.F., Martínez G.A., Politis G.G., Borrero L.A., Neme G.A. (2009). Guanaco (Lama guanicoe) isotopic ecology in southern South America: spatial and temporal tendencies, and archaeological implications. Journal of Archaeological Science, 36(12), 2666–2675, DOI: 10.1016/j.jas.2009.08.003.

Bocherens H., Fizet M., Mariotti A., Lange-Badre B., Vandermeersch B., Borel J.P., Bellon G. (1991). Isotopic biogeochemistry (13C, 15N) of fossil vertebrate collagen: application to the study of a past food web including Neandertal man. Journal of Human Evolution, 20, 481- 492, DOI: 10.1016/0047-2484(91)90021-M.

Bocherens H., Pacaud G., Lazarev A. P., Mariotti A. (1996). Stable isotope abundances (13C, 15N) in collagen and soft tissues from Pleistocene mammals from Yakutia. Implications for the palaeobiology of the Mammoth Steppe. Palaeogeography, Palaeoclimatology, Palaeoecology, 126, 31-44, DOI: 10.1016/S0031-0182(96)00068-5.

Bocherens H. (2003). Isotopic biogeochemistry and the paleoecology of the mammoth steppe fauna. In: J.W.F. Reumer, J. De Vos, D. Mol ed., Advances in mammoth research. Proceedings of the Second Mammoth International Conference. Rotterdam, DEINSEA, 9, 57–76.

Bocherens H., Drucker D. (2003). Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. International Journal of Osteoarchaeology, 13(1/2), 46-53, DOI: 10.1002/oa.662.

Bocherens H., Drucker D.G., Madelaine S. (2014). Evidence for a 15N positive excursion in terrestrial foodwebs at the Middle to Upper Palaeolithic transition in south-western France: Implications for early modern human palaeodiet and palaeoenvironment. Journal of Human Evolution, 69, 31-43, DOI: 10.1016/j.jhevol.2013.12.015.

Boldanov T.A., Mukhin G.D. (2019). Ecological Adaptation of Agricultural Land Use Under the Climate Change in the Republic of Buryatia. Arid Ecosystems, 9(1), 7-14, DOI: 10.24411/1993-3916-2019-00040.

Boykov T.G., Kharitonov Yu. D., Rupyshev Yu. A. (2002). The Steppes of Zabaikalye: Productivity, forage value, rational management and conservation. Ulan-Ude: BCS SB RAS (in Russian).

Britton K., Knecht R., Nehlich O., Hillerdal C., Davis R.S., Richards M.P. (2013). Maritime adaptations and dietary variation in prehistoric Western Alaska: Stable isotope analysis of permafrost-preserved human hair. American journal of physical anthropology, 151(3), 448-461, DOI: 10.1002/ajpa.22284.

Brown T.A., Nelson D.E., Vogel J.S., Southon J.R. (1988). Improved collagen extraction method by modified Longin method. Radiocarbon, 30(2), 171-177, DOI: 10.1017/S0033822200044118.

Burnik Šturm M., Ganbaatar O., Voigt C. C., Kaczensky P. (2017). Sequential stable isotope analysis reveals differences in dietary history of three sympatric equid species in the Mongolian Gobi. Journal of Applied Ecology, 54(4), 1110-1119, DOI: 10.1111/1365- 2664.12825.

Chen S., Bai Y., Lin G., Huang J., Han X. (2007). Isotopic carbon composition and related characters of dominant species along an environmental gradient in Inner Mongolia, China. Journal of Arid Environments, 71(1), 12-28, DOI: 10.1016/j.jaridenv.2007.02.006.

Codron D., Codron J., Lee-Thorp J.A., Sponheimer M., de Ruiter D.D. (2005). Animal diets in the Waterberg based on stable isotopic composition of faeces. South African Journal of Wildlife Research, 35(1), 43–52, DOI: 10.5167/uzh-25362.

Dambaev V.B., Banzaraktsaeva T.G., Buyantueva L.B., Namsaraev B.B., Zyakun A.M. (2016). Carbon isotope variations of vegetation and soils in steppe pastures of Inner Asia. Geography and Natural Resources, 2, 118-124 (in Russian).

Davie H., Murdoch J.D., Lini A., Ankhbayar L., Batdorj S. (2014). Carbon and nitrogen stable isotope values for plants and mammals in a semi-desert region of Mongolia. Mongolian Journal of Biological Sciences, 12(1-2), 33-43, DOI: 10.22353/mjbs.2014.12.04.

Danzhalova E.V., Bazha S.N. (2008). Transformation of the main types of steppe ecosystems of Central Mongolia under the influence of grazing. The bulletin of KSAU, 2, 98-104.

DeNiro M.J., Epstein S. (1981). Influence of diet on the distribution of nitrogen isotopes in animals. Geochimica et cosmochimica acta, 45(3), 341-351, DOI: 10.1016/0016-7037(78)90199-0.

DeNiro M.J., Schoeninger M.J. (1983). Stable Carbon and Nitrogen Isotope Ratios of Bone Collagen: Variations within Individuals, Between Sexes, and Within Populations Raised on Monotonous Diet. Journal of Archaeological Science, 10(3): 199-203, DOI: 10.1016/0305-4403(83)90002-X.

Di Matteo A., Kuznetsova T.V., Nikolaev V.I., Spasskaya N.N., Jakumin P. (2013). Isotope studies of fossil bones of Pleistocene Yakut horses. Ice and Snow, 53(2), 93-101, DOI: 10.15356/2076-6734-2013-2-93-101.

Drucker D.G., Hobson K. A., Ouellet J.-P., Courtois R. (2010). Influence of forage preferences and habitat use on 13C and 15N abundance in wild caribou (Rangifer tarandus caribou) and moose (Alces alces) from Canada. Isotopes in Environmental and Health Studies, 46 (1), 107-121, DOI: 10.1080/10256010903388410.

Drucker D.G., Bridault A, Cupillard C., Hujic A., Bocherens H. (2011). Evolution of habitat and environment of red deer (Cervus elaphus) during the Late-glacial and early Holocene in eastern France (French Jura and the western Alps) using multi-isotope analysis ($\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$, $\delta^{34}S$) of archaeological remains. Quaternary International, 245(2), 268-278, DOI: 10.1016/j.quaint.2011.07.019.

Ecological and Geographical Atlas-monograph «Selenga – Baikal». (2019). N.S. Kasimov, ed., Lomonosov Moscow State University Publ. (in Russian).

Fernandez J., Markgraf V., Panarello H.O., Albero M., Angio1ini F.E., Valencio S., Arriaga M. (1991). Late Pleistocene/Early Holocene environments and climates, fauna, and human occupation in the Argentine Altiplano. Geoarchaeology: An International Journal, 6(3), 251-272. DOI: 10.1002/gea.3340060303.

Fizet M., Mariotti A. M., Bocherens H., Lange-Badre B., Vandermeersch B., Borel J.P., Bellon G. (1995). Effect of diet, physiology and climate on carbon and nitrogen stable isotopes of collagen in a late Pleistocene anthropic palaeoecosystem: Marillac, Charente, France). Journal of Archaeological Science, 22: 67-79, DOI: 10.1016/S0305-4403(95)80163-4.

Fogel M.L., Tuross N., Owsley D.W. (1989). Nitrogen isotope tracers of human lactation in modern and archaeological populations. Annual report of the director, geophysical laboratory. Carnegie Inst. Wash. 89, 111-117.

Fox N.S., Southon J.R., Howard C.M., Takeuchi G.T., and Potze S. and Farrell A.B., Lindsey E.L., Blois J. L. (2023). Millennial-scale drivers of small mammal isotopic niche dynamics in Southern California. Palaeogeography, Palaeoclimatology, Palaeoecology, 612, 111378, DOI: 10.1016/j.palaeo.2022.111378.

France C.A.M., Owsley D.W., Hayek L.C. (2014). Stable isotope indicators of provenance and demographics in 18th and 19th century North Americans. Journal of Archaeological Science, 42, 356-366, DOI: 10.1016/j.jas.2013.10.037.

Germonpre M., Lbova L. (1996). Mammalian Remains from the Upper Palaeolithic Site of Kamenka, Buryatia (Siberia). Journal of Archaeological Science, 23, 35-57, DOI: 10.1006/jasc.1996.0004.

Goldman R. (2010). Spatial Variation of Stable Carbon and Nitrogen Isotope Ratios and C:N of Perennial Plant Species in the Steppe Grassland of Northern Mongolia. Master of Environmental Studies Capstone Projects [online]. 38. Available at: https://repository.upenn.edu/mes_capstones/38.

Golovanov D.L., Kazantseva T.I., Yamnova I.A. (2004). Natural and anthropogenic degradation processes of the soil cover of the desert steppes of Mongolia (on the example of somon Bulgan). Arid ecosystems, 10, 24-25.

Gorlova E.N., Krylovich O.A., Tiunov A.V., Khasanov B.F., Vasyukov D.D., Savinetskiy A.B. (2015). Stable-isotope analysis as a method of taxonomical identification of archaeozoological material. Archaeology, Ethnology and Anthropology of Eurasia, 43(1): 110–121, DOI: 10.17746 / 1563-0102.2015.43.1.110–121 (in Russian).

Jenkins S.G., Partridge S.T., Stephenson T.R., Farley S.D., Robbins C.T. (2001). Nitrogen and carbon isotope fractionation between mothers, neonates, and nursing offspring. Oecologia, 129, 336-341, DOI: 10.1007/ s004420100755.

Kalapos T., Baloghne-Nyakas A., Csontos P. (1997). Occurrense and ecological characteristiks of C4 dicot and Cyperaceae species in the Hungarian flora. Photosynthetica, 33 (2), 227–240, DOI: 10.1023/A:1022112329990.

Khatri P.K., Larcher R., Camin F., Ziller L., Tonon A., Nardin T., Bontempo L. (2021). Stable Isotope Ratios of Herbs and Spices Commonly Used as Herbal Infusions in the Italian Market. ACS Omeg, 6, 11925–11934, DOI: 10.1021/acsomega.1c00274.

Khubanova A.M., Khubanov V.B., Novoseltseva V.M., Sokolova N.B., Klementyev A.M., Posokhov V.F. (2017). Features of the composition of carbon and nitrogen isotopes in teeth collagen of Equus ferus and Alces americanus from archaeological location Ust-Keul I (Northern Angara region). The Bulletin of Irkutsk State University. Series "Geoarchaeology. Ethnology. Anthropology", 21, 33–59.

Koch P.L., Hoppe K.A., Webb S.D. (1998). The isotopic ecology of late Pleistocene mammals in North America: Part 1. Florida. Chemical Geology, 152(1-2), 119-138, DOI: 10.1016/S0009-2541(98)00101-6.

Kohzu A., Iwata T., Kato M., Nishikawa J., Wada E., Amartuvshin N.,

Namkhaidorj B., Fujita N. (2009). Food webs in Mongolian grasslands: The analysis of 13C and 15N natural abundances. Isotopes in Environmental and Health Studies, 45(3), 208-219, DOI: 10.1080/10256010902871887.

Kradin N.N., Khubanova A.M., Bazarov B.A., Miyagashev D.A., Khubanov V.B., Konovalov P.B., Klementiev A.M., Posokhov V.F., Ventresca Miller A.R. (2021) Iron age societies of Western Transbaikalia: Reconstruction of diet and lifeways. Journal of Archaeological Science: Reports, 38, 102973, DOI: 10.1016/j.jasrep.2021.102973.

Krajcarz M., Pacher M., Krajcarz M.T., Laughlan L., Rabeder G., Sabol M., Wojtal P., Bocherens H. (2016). Isotopic variability of cave bears ($d^{15}N$, $d^{13}C$) across Europe during MIS3. Quaternary Science Reviews, 131, 51-72, DOI: 10.1016/j.quascirev.2015.10.028.

Krylovich O.A., Boeskorov G.G., Shchelchkova M.V., Savinetsky A.B. (2020). Trophic position of pleistocene and modern brown bears (Ursus arctos) of Yakutia based on stable isotope analyses. Biology Bulletin, 47, 1013-1021, DOI: 10.31857/S0044513420050074.

Kuzmin Y.V., Bondarev A.A., Kosintsev P.A., Zazovskaya, E.P. (2021). The Paleolithic diet of Siberia and Eastern Europe: evidence based on stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) in hominin and animal bone collagen. Archaeological and Anthropological Sciences, 13, 1-12, DOI: 10.1007/s12520-021-01439-5; WoS: 000702780200001.

Kuzmin, Y.V., Shpansky, A.V. (2023).The Late Pleistocene megafauna of the Chulym River basin, southeastern West Siberian Plain: chronology and stable isotope composition. Journal of Quaternary Science, 38, 1, 2–7, DOI:10.1002/jqs.3470.

Lee-Thorp J. A. (2008). On isotopes and old bones. Archaeometry, 50(6), 925-950, DOI:10.1111/j.1475-4754.2008.00441.x.

Li M. C., Liu H. Y., Yi X. F., Li L. X. (2006). Characterization of photosynthetic pathway of plant species growing in the eastern Tibetan plateau using stable carbon isotope composition. Photosynthetica, 44(1), 102-108, DOI: 10.1007/s11099-005-0164-1.

Li M.C., Zhu J.J., Li L.X. (2009). Occurrence and altitudinal pattern of C4 plants on Qinghai Plateau, Qinghai province, China. Photosynthetica, 47(2), 298-303, DOI:10.1007/s11099-009-0046-z.

Liu X. Q., Wang R. Z., Li Y. Z. (2004). Photosynthetic pathway types in rangeland plant species from Inner Mongolia, North China. Photosynthetica, 42, 339–344, DOI: 10.1023/B:PHOT.0000046150.74045.46.

Liu X.Z., Wang G.A., Li J.Z., Wang Q. (2009). Nitrogen isotope composition characteristics of modern plants and their variations along an altitudinal gradient in Dongling Mountain in Beijing. Science in China Series D-Earth Sciences, 53(1), 128-140, DOI: 10.1007/s11430-009-0175-z.

Longin R. (1971). New method of collagen extraction for radiocarbon dating. Nature, 230, 241–242, DOI: 10.1038/230241a0.

Ma J. Y., Sun W., Liu X. N., Chen F. H. (2012). Variation in the Stable Carbon and Nitrogen Isotope Composition of Plants and Soil along a Precipitation Gradient in Northern China. PLoS ONE, 7(12), e51894, DOI: 10.1371/journal.pone.0051894.

Makarewicz C., Tuross N. (2006). Foddering by Mongolian pastoralists is recorded in the stable carbon (d13C) and nitrogen (d15N) isotopes of caprine dentinal collagen. Journal of Archaeological Science, 33(6), 862-870, DOI: 10.1016/j.jas.2005.10.016.

Makarewicz C. (2017). Winter is coming: seasonality of ancient pastoral nomadic practices revealed in the carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopic record of Xiongnu caprines Archaeological and Anthropological Sciences, 9, 405-418, DOI: 10.1007/s12520-015-0289-5.

Makarewicz C., Winter-Schuh C., Byerly H., Houle J.-L. (2018). Isotopic evidence for ceremonial provisioning of Late Bronze age khirigsuurs with horses from diverse geographic locales. Quaternary International 476 (20): 70–81, DOI: 10.1016/j.quaint.2018.02.030.

Mann H.B., Whitney D.R. (1947). On a test of whether one of two random variables is stochastically larger than the other. Annals of Mathematical Statistics, 18, 50-60. DOI: 10.1214/aoms/1177730491.

Martin B, Thorstenson Y.R. (1988). Stable Carbon Isotope Composition (δ13C), Water Use Efficiency, and Biomass Productivity of Lycopersicon esculentum, Lycopersicon pennellii, and the F1 Hybrid. Plant Physiol, 88, 213–217, DOI: 10.1104/pp.88.1.213.

Naidanov B.B. (2009). The saline habitat flora of Southwestern Transbaikalia: feed assessment. The Bulletin of KSAU, 11(38), 39-43.

Nikolaev V.I., Ryskov Ya. G., Yakumin P. (2006). Stable isotope investigation of bone remains from archaeological excavations (methodological aspects). Stable isotopes in palaeoecological studies. Moscow, Institute of Geography RAS Publ. (in Russian).

O'Leary M.H. (1988). Carbon isotopes in photosynthesis. Bioscience, 38(5), 328-336, DOI: 10.2307/1310735.

Osipov K.I. (2005). Flora of the Vitim Plateau (Northern Transbaikal region). Ulan-Ude: BSC SB RAS (In Russian).

O'Regan H.J., Lamb A.L., Wilkinson D.M. (2016). The missing mushrooms: searching for fungi in ancient human dietary analysis. Journal of Archaeological Science, 75, 139-143, DOI: 10.1016/j.jas.2016.09.009.

Oyungerel S., Tsendeekhuu T., Tserenkhand G. (2004). A Study to Detect CAM Plants in Mongolia. Mongolian Journal of Biological Sciences, 2(1), 29-37, DOI: 10.22353/mjbs.2004.02.04.

Palmqvist P., Grocke D.R., Arribas A., Farina R.A. (2003). Palaeoecological reconstruction of a lower Pleistocene large mammal community using biogeochemical (δ13C, δ15N, δ18O, Sr:Zn) and ecomorphological approaches. Paleobiology, 29(2), 205-229, DOI: 10.1666/0094-8373(2003)029<0205:PROALP>2.0.CO;2.

Pearcy R.W., Troughton J. (1975). C4 photosynthesis in tree form Euphorbia species from Hawaiian rainforest sites. Plant Physiology, 55(6), 1054-1056, DOI: 10.1104/pp.55.6.1054.

Petukhov I.A., Bazha S.N., Danzhalova E.V., Drobyshev Yu.I., Syrtypova S.-Kh.D., Bogdanov E.A., Enkh-Amgalan S., Gunin P.D. (2018). Long-term Dynamics of Pasture Ecosystem Conditions in the Ecotone Zone of Dry and Desert Steppes of Central Mongolia (Middle Gobi Aimag). Ecosystems: Ecology and Dynamics, 2(2), 5-39 (in Russian).

Pidoplichko I.G. (1952). A New Determination Method for Geological Age of Fossil Bones of the Quaternary System), Kiev: Akad. Nauk USSR. (In Russian).

Pyankov V.I., Gunin P.D., Tsoog S., Black C.C. (2000). C4 plants in the vegetation of Mongolia: their natural occurrence and geographical distribution in relation to climate. Oecologia, 123, 15–31, DOI: 10.1007/s004420050985.

Rubin D.B. (1981). The bayesian bootstrap. The Annals of Statistics, 9 (1), 130–134.

Safronova I. N., Karimova T. Y., Zhargalsaikhan L. (2018). Current state assessment of the vegetation cover in the Khentei Aimag of Mongolia. Arid ecosystems, 24(1/74), 68-78.

Simukov A.D. (2007). Publications about Mongolia and for Mongolia. Edited by Yuki Konagaya, Sanjaasüren Bayaraa, and Ichinkhorloo Lkhagvasüren. Osaka: National Museum of Ethnology, 1 (in Russian).

Skippington J., Manne T., Veth P. (2021). Isotopic Indications of Late Pleistocene and Holocene Paleoenvironmental Changes at Boodie Cave Archaeological Site, Barrow Island, Western Australia. Molecules, 26 (9), 2582, DOI: 10.3390/molecules26092582.

Spasojevic M.J., Weber S. (2021). Variation in δ13C and δ15N within and among plant species in the alpine tundra. Arctic, Antarctic, and Alpine Research, 53(1), 340-351, DOI: 10.1080/15230430.2021.2000567.

Svyatko S.V. (2016). Stable Isotope Analysis: Outline of Methodology and a Review of Studies in Siberia and the Eurasian Steppe. Archaeology, Ethnology and Anthropology of Eurasia, 44(2), 47–55, DOI: 10.17746/1563-0110.2016.44.2.047-055.

Structure and Dynamics of the Steppe Ecosystems of Eastern Mongolia (by an example of the Tumentsogt Station). (2018). Moscow: Tovarishchestvo Nauchnykh Izdaniy KMK (in Russian).

Su Y., Chen L., Li Y., Meng W., Zhu Z., Uan C., Wang S., Zhu L. (2019). Relationship between Growth Characteristics and Stable Carbon Isotope of Artemisia scoparia in a Desert Steppe. Acta Agrestia Sinica, 27(4), 859-866, DOI: 10.11733/j.issn.1007-0435.2019.04.009.

Tahmasebi F., Longstaffe F.J., Zazula G. (2018). Nitrogen isotopes suggest a change in nitrogen dynamics between the Late Pleistocene and modern time in Yukon, Canada. PLoS ONE 13 (2), e0192713, DOI: 10.1371/journal. pone.0192713.

Tanaka-Oda A., Endo I., Ohte N., Eer D., Yamanaka N., Hirobe M., ... and Yoshikawa K. (2018). A water acquisition strategy may regulate the biomass and distribution of winter forage species in cold Asian rangeland. Ecosphere, 9(12), e02511, DOI: 10.1002/ecs2.2511.

The Ecological Atlas of the Baikal Basin. In: Plyusnin V M (eds.). Irkutsk: Sochava institute of geography press, 2015.

Tsogmansrai D., Dugarzhav Ch. (2016). The effectiveness of some restoration methods of degraded pastures of the desert-steppe zone of Mongolia. Arid ecosystems, 22(3-68), 56-62.

Ulyanov A.N., Kulikova A.Y., Grigoryeva O.G. (2011). Actual problems of modern sheep breeding in Russia. Sheep, goats, wool business, 3, 54-60.

Urtnasan M., Lyubarskiy E.L. (2013). Pasture digression in the steppes of central Mongolia (on the example of Somon Batsumbar of the central aimag of Mongolia). Scientific notes of Kazan University: series "Natural science", 155(1), 258-170.

Van der Merwe N. J. (1992). Light stable isotopes and the reconstruction of prehistoric diets. In: Pollard A M (eds.). New Developments in Archaeological Science. Proceedings of the British Academy 77, Oxford University Press, Oxford, UK, 247-264.

Ventresca Miller A.R., Bragina T.M., Abil Y.A., Rulyova M.M., Makarewicz C.A. (2019). Pasture usage by ancient pastoralists in the northern Kazakh steppe informed by carbon and nitrogen isoscapes of contemporary floral biomes. Archaeological and Anthropological Sciences, 11, 2151-2166. DOI: 10.1007/s12520-018-0660-4.

Wang G., Han J., Zhou L., Xiong X., Tan M., Wu Z., Peng J. (2006). Carbon isotope ratios of C 4 plants in loess areas of North China. Science in China: Series D Earth Science, 49(1), 97-102, DOI: 10.1007/s11430-004-5238-6.

Weber A.W., White D., Bazaliiskii V.I., Goriunova O.I., Saveliev N.A., Katzenberg M.A. (2011). Hunter–gatherer Foraging Ranges, Migrations, and Travel in the Middle Holocene Baikal Region of Siberia: Insights from Carbon and Nitrogen Stable Isotope Signatures. Journal of Anthropological Archaeology, 30(4), 523–548, DOI: 10.1016/j.jaa.2011.06.006.

Wen Z., Zhang M. (2011). Anatomical types of leaves and assimilating shoots and carbon 13C/12C isotope fractionation in Chinese representatives of Salsoleae s.l. (Chenopodiaceae). Flora, 206, 720–730, DOI: 10.1016/j.flora.2010.11.015.

Winter K. (1981). C4 Plants of High Biomass in Arid Regions of Asia -Occurrence of C4 Photosynthesis in Chenopodiaceae and Polygonaceae from the Middle East and USSR. Oecologia (Berl), 48,100-106, DOI: 10.1007/BF00346994.

Xu Y, He J, Cheng W, Xing X., Li L. (2010). Natural 15N abundance in soils and plants in relation to N cycling in a rangeland in Inner Mongolia. J. Plant Ecol., 3, 201–207, DOI: 10.1093/jpe/rtq023.

Yudina P.L., Ivanova L.A., Ronzhina D.A., Ivanov L.A. (2015). Intraspecific variation of leaf mesostructure indices of steppe plants in Western Transbaikalia. Problems of botany in Southern Siberia and Mongolia: materials of the XIV international scientific and practical conference. Barnaul: ASU. 466-469.

APPENDIX

Table 1. Bone and teeth collagen stable carbon and nitrogen isotope data of herbivorous animals of this study

#	Aimag or District	Sample	Specie	Bone/ Tooth	$\delta^{13}C$, ‰	$\delta^{15}N$, ‰	C,%	N,%	Yield (%)*	C/N_{at}**	Location
Desert and semi-desert (Mongolia)											
1	South Gobi	MNG-03-17	Equus ferus caballus	Molar	-15.4	8.3	40.2	15.1	4.2	3.1	N 43°56´43.6´´ E 107°25´36.9´´ ~1200 m high
2	South Gobi	MNG-04-17	Equus ferus caballus	Molar	-18.1	5.8	30.7	11.3	5.9	3.2	N 43°54´14´´ E 107°19´19´´ ~1400 m high
3	Middle Gobi	MNG-01-17	Equus ferus caballus	Molar	-18.6	6.8	32.9	12.4	5.6	3.1	N 45°43´15.8´´ E 106°18´31.8´´ ~1500 m high
4	Middle Gobi	MNG-02-17	Equus ferus caballus	Molar	-18.4	5.5	41.1	16	5.4	3	N 45°19´45.9´´ E 106°32´14.4´´ ~1400 m high
5	Bayankhongor	MNG-03-18	Ovis aries	Molar	-18.8	8.4	29.9	10.8	11.2	3.2	N 46°14´46.02´´ E 98°49´26.49´´ ~1950 m high
Steppe (Mongolia)											
6	Central	MNG-07-16	Bos taurus	Molar	-21.6	4.9	38.6	14	10	3.2	N 48°17´48.5´´ E 106°13´12.6´´ ~1100 m high
7	Arkhangai	MNG-01-16	Bos taurus	Molar	-22.1	4.8	19.4	7.4	1.9	3.1	N 48°15´23´´ E 99°53´12´´ ~2400 m high
8	Arkhangai	MNG-02-16	Ovis aries	Molar	-20.2	9.1	29.2	11.7	11.4	2.9	
9	Dzabkhan	MNG-03-16	Bos taurus	Molar	-21.9	4.6	16.4	6.2	0.5	3.1	N 48°44´08´´ E 98°04´28´´ ~1800 m high
10	Dzabkhan	MNG-04-16	Ovis aries	Molar	-20.4	11	44.6	16.9	11.8	3.1	
11	Dzabkhan	MNG-05-16	Ovis aries	Bone	-20.3	10.3	41.4	18.6	2	2.6	
12	Dzabkhan	MNG-06-16	Equus ferus caballus	Molar	-20	5.6	45.2	17.2	7.7	3.1	N 48°40´56.1´´ E 98°51´06.4´´ ~1700 m high
Steppe (Transbaikalia)											
13	Zaigraevsky	C14(14)-1	Ovis aries	Molar	-20.6	8.5	40.5	14.6	2.4	3.2	N 51°54´18.4´´ E 107°49´38.8´´ ~ 800 m high
14	Zaigraevsky	C14(14)-2	Ovis aries	Molar	-20.8	7.8	37.3	16.2	1	2.7	
15	Zaigraevsky	C19(14)-1	Ovis aries	Molar	-22.3	5.9	35.3	10.8	0.9	3.8	N 52°12´35´´ E 108°36´53´´ ~ 1000 m high
16	Zaigraevsky	C19(14)-1(2)	Ovis aries	Bone	-22.4	5.2	39	14.5	3.3	3.1	
17	Zaigraevsky	C15(14)-1	Bos taurus	Molar	-21.6	8.5	39.5	15.5	2.1	3	N 51°58´43´´ E 108°01´02´´ 820 m high
18	Zaigraevsky	C15(14)-2	Bos taurus	Molar	-25.1	7.1	25.1	11	1.5	2.7	
19	Zaigraevsky	C16(14)	Bos taurus	Molar	-21.6	8.2	33.3	13.1	6.2	3	N 52°01´53´´ E 108°23´59´´ ~ 950 m high
20	Zaigraevsky	C18(14)	Bos taurus	Molar	-22.4	7.7	34	12.9	3.6	3.1	N 52°06´ 40´´ E 108°34´ 25´´ ~ 1200 m high
21	Khorinsky	C10(15)	Bos taurus	Molar	-20.4	10	47.5	15.4	12.2	3.6	N 52°15´59.2´´ E 108°46´56.7´´ ~ 1150 m high

22	Khorinsky	C22(14)	Bos taurus	Molar	-21.8	8.2	38.5	15.5	5.3	2.9	N 52°16´53´´ E 108°52´18´´ ~ 1300 m high
23	Khorinsky	C5(15)	Equus ferus caballus	Molar	-21.5	7.9	40.3	13.1	8	3.6	N 52°09´58´´ E 108°36´56´´ ~ 1000 m high
24	Khorinsky	C21(14)-1	Equus ferus caballus	Molar	-22.2	5.9	26	9.4	4.6	3.2	N 52°20´0.7´´ E 108°43´44.7´´ ~ 1200 m high
25	Khorinsky	C21(14)-2	Equus ferus caballus	Molar	-22.7	5.4	27.4	9.5	3.9	3.4	
26	Selenginsky	C3(13)	Equus ferus caballus	Molar	-22.9	5	40	15.8	10.4	3	N 50°55´02´´ E 106° 14´08´´ ~ 600 m high
27	Selenginsky	C6(13)	Equus ferus caballus	Molar	-22.6	5.8	46.4	15.2	9.2	3.6	
28	Aginsky	C24(13)	Equus ferus caballus	Molar	-22.6	5.4	39.1	12.6	5.4	3.6	N 51°6´40.1´´ E 114°37´51.9´´ ~ 700 m high
Steppe-forest and forest (Transbaikalia)											
29	Dzhidinsky	C12(13)	Equus ferus caballus	Molar	-24	4.1	39.5	14.6	8	3.2	N 50°36´27´´ E 104°35´35´´ ~ 900 m high
30	Dzhidinsky	C13(13)	Equus ferus caballus	Molar	-22.8	4.9	46,1	15.6	6.3	3.4	
31	Zakamensky	C7(13)	Bos taurus	Molar	-22.6	5.5	40.9	13.8	3.7	3.5	N 50°30´46´´ E 102°55´21´´ ~ 1200 m high
32	Zakamensky	C4(14)	Bos taurus	Molar	-23.1	6.7	45.8	14.9	6.2	3.6	N 50°49´46´´ E 102°47´15´´ ~ 1250 m high
33	Zakamensky	C2(15)	Bos taurus	Molar	-22.9	6.8	33.71	12.14	2.4	3.2	N 50°19´14.7´´ E 103°31´13.9´´ ~ 1250 m high
34	Zakamensky	C1(15)	Equus ferus caballus	Molar	-24.5	3.6	48.6	15.1	4.6	3.6	
35	Zakamensky	C1(14)	Equus ferus caballus	Molar	-22.5	4.8	44	16	7.1	3.2	N 50°28´39´´ E 104°17´13´´ 900 m high
36	Zakamensky	C2(14)	Capreolus pygargus	Molar	-22.2	6	38.7	15.6	5	2.9	
37	Tunkinsky	C7(14)	Bos taurus	Molar	-23.2	6.4	33.85	12.17	4.4	3.2	N 51°47´15´´ E 103°00´41´´ ~ 800 m high
38	Tunkinsky	C10(14)	Bos taurus	Molar	-23.4	8.5	8.3	4.7	0.6	2.1	N 51°40´32´´ E 102°00´41´´ ~ 750 m high
39	Tunkinsky	C11(14)	Bos taurus	Molar	-22.6	7.1	41.2	14.1	4.6	3.4	N 51°40´04´´ E 102°17´06´´ ~ 750 m high
40	Tunkinsky	C13(14)	Bos taurus	Bone	-23.6	5.7	47.2	15.2	2.3	3.6	N 51°41´38´´ E 101° 40´38´´ ~ 1050 m high
41	Tunkinsky	C9(14)	Equus ferus caballus	Molar	-23.1	7.1	37.1	14	5.3	3.1	N 51°52´43´´ E 102°23´34´´ ~ 750 m high
42	Baleysky	C20(15)	Capreolus pygargus	Molar	-22.7	10	42.4	15.9	5.7	3.1	N 51°38´41.6´´ E 117°5´58.8´´ ~ 700 m high
43	Tungokochensky	C4(15)	Moschus moschiferus	Molar	-22.6	8	39.61	15.67	4.8	2.9	N 53°38´118´´ E 114°1´51.9´´ ~ 900 m high

* Collagen yields are calculated as relative part of collagen as a percentage of the weight of the original bone sample.
** C/N_{at} = (%C/%N) x (14/12), atomic ratio.