Ecography

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## Supplementary material

**Supplementary material**

*Habitats of Pleistocene megaherbivores reconstructed from frozen fauna remains*.

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**Appendix 1.**

Brief characterization of the vegetation types used in this study with the lists of diagnostic, constant and dominant species. Some descriptions are partly or entirely taken from Janská et al. (2017). All descriptions are based on the expert knowledge of the authors and the references listed below. Species names follow Cherepanov (1995).

Species were considered diagnostic for a given vegetation type when their fidelity value measured as the phi coefficient of association was higher than 0.25 and corresponding Fisher's exact test indicated a significant concentration of species in the vegetation type at the level of 0.05. Highly diagnostic species (highlighted in bold) were those with phi coefficient higher than 0.40. As the fidelity values might be affected by differences in species numbers between vegetation types, we used standardization to equal sizes of all groups before calculation (Chytrý et al. 2002). Constant species or highly constant species (highlighted in bold) are those with a frequency in the dataset over 40% or 50%, respectively. Dominant species were those that reached higher cover values than 25% in at least 5% of plots. All analyses were performed in Juice software (Tichý 2002).

## 1. Blackish taiga

(75 vegetation plots)

Diagnostic species: ***Abies sibirica, Aconitum septentrionale, Aconitum volubile, Adoxa moschatellina, Aegopodium podagraria, Allium microdictyon,*** *Angelica sylvestris, Anthriscus sylvestris,* ***Asarum europaeum, Athyrium filix-femina,*** *Betula pendula,* ***Brachypodium sylvaticum,*** *Bupleurum longifolium,* ***Cacalia hastata, Calamagrostis obtusata,*** *Carex macroura,* ***Circaea alpina, Cirsium helenioides, Crepis lyrata, Crepis sibirica,*** *Cruciata krylovii, Daphne mezereum, Diplazium sibiricum, Dryopteris carthusiana, Dryopteris dilatata, Dryopteris expansa, Dryopteris filix-mas,* ***Equisetum sylvaticum, Euphorbia pilosa,*** *Festuca altissima,* ***Festuca gigantea,*** *Filipendula ulmaria,* ***Galium odoratum,*** *Geranium albiflorum, Heracleum dissectum, Impatiens noli-tangere,* ***Lamium album, Lathyrus gmelinii,*** *Lilium pilosiusculum, Lonicera xylosteum,* ***Maianthemum bifolium, Matteuccia struthiopteris,*** *Melica nutans,* ***Milium effusum, Myosotis krylovii, Oxalis acetosella, Padus avium, Paeonia anomala, Paris quadrifolia, Phegopteris connectilis, Pleurospermum uralense,*** *Polemonium coeruleum, Polystichum braunii, Populus tremula, Primula pallasii, Pteridium aquilinum,* ***Pulmonaria mollis,*** *Ranunculus grandifolius, Ranunculus monophyllus, Ribes hispidulum, Ribes nigrum, Ribes spicatum, Rubus matsumuranus, Saussurea latifolia,* ***Senecio nemorensis, Sorbus sibirica,*** *Spiraea chamaedrifolia,* ***Stachys sylvatica, Stellaria bungeana,*** *Thalictrum minus, Tilia sibirica,* ***Urtica dioica,*** *Veratrum lobelianum,* ***Viburnum opulus,*** *Vicia sylvatica, Viola biflora,* ***Viola uniflora;*** *Atrichum undulatum, Brachythecium reflexum, Brachythecium salebrosum, Callicladium haldanianum,* ***Cirriphyllum piliferum,*** *Eurhynchium angustirete, Eurhynchium hians, Fissidens taxifolius, Lophocolea heterophylla,* ***Plagiochila porelloides,*** *Plagiomnium confertidens,* ***Plagiomnium drummondii, Plagiothecium denticulatum, Rhodobryum roseum,*** *Rhytidiadelphus subpinnatus, Rhytidiadelphus triquetrus*

Constant species: ***Abies sibirica, Aconitum septentrionale,*** *Aconitum volubile,* ***Adoxa moschatellina, Aegopodium podagraria,*** *Angelica sylvestris,* ***Athyrium filix-femina, Betula pendula, Cacalia hastata, Calamagrostis obtusata,*** *Crepis lyrata,* ***Crepis sibirica,*** *Cruciata krylovii, Equisetum sylvaticum,* ***Euphorbia pilosa,*** *Filipendula ulmaria,* ***Lamium album, Lathyrus gmelinii, Maianthemum bifolium, Milium effusum, Oxalis acetosella, Padus avium, Paris quadrifolia,*** *Pleurospermum uralense, Polemonium coeruleum,* ***Pulmonaria mollis,*** *Senecio nemorensis,* ***Sorbus sibirica, Stellaria bungeana, Thalictrum minus, Urtica dioica,*** *Viola uniflora;* ***Plagiochila porelloides,*** *Plagiomnium drummondii, Rhodobryum roseum*

Dominant species: *Abies sibirica, Aegopodium podagraria, Allium microdictyon, Athyrium filix-femina, Betula pendula, Carex macroura, Matteuccia struthiopteris, Populus tremula, Tilia sibirica; Hylocomium splendens*

Blackish (in Russian *chernevaya*) taiga is a forest composed of a mixture of coniferous and deciduous trees and both nemoral and boreal species in the herb and shrub layers. They occur especially in the southern subtaiga and southern-taiga zone of western Siberia, but they also occur in the precipitation-rich northern front ranges

of the southern Siberian mountain systems such as the Altai and smaller mountain ranges north of the Altai. These forests are dominated by *Abies sibirica*, *Betula pendula*, *B. pubescens*, *Populus tremula*, with an occasional admixture of *Picea obovata,* especially on the valley bottoms. Unlike in the boreal forests, herb layer is often rather dense and dominated by herbs and grasses, whereas dwarf shrubs, as well as mosses and lichens, are less abundant or even absent.

**2. Hemiboreal forest**

(278 vegetation plots)

Diagnostic species: *Atragene sibirica,* ***Betula pendula,*** *Brachypodium pinnatum, Calamagrostis arundinacea, Calamagrostis pavlovii, Carex macroura, Cimicifuga foetida, Dianthus superbus, Fragaria vesca, Galium boreale, Geranium pseudosibiricum, Iris ruthenica, Larix sibirica, Lathyrus humilis, Lathyrus pisiformis, Lathyrus vernus, Melica nutans, Pinus sylvestris, Polygonatum odoratum, Populus tremula, Pulmonaria mollis, Rosa majalis,* ***Rubus saxatilis,*** *Stellaria holostea, Thalictrum minus, Vicia sepium, Vicia unijuga, Viola collina, Viola mirabilis*

Constant species: ***Betula pendula, Galium boreale, Rubus saxatilis,*** *Thalictrum minus*

Dominant species: *Betula pendula, Betula pubescens, Carex macroura, Larix sibirica, Pinus sylvestris, Populus tremula*

Hemiboreal forests are either coniferous, dominated by *Pinus sylvestris*, *Larix gmelinii* or *L. sibirica*, or deciduous, dominated by *Betula pendula* or *Populus tremula*. Their tree layer is similar to that of the light taiga, but the herb layer is very different and species-rich, consisting of the herbs and graminoids typical of temperate forests and grasslands. Dwarf shrubs and bryophytes are much less abundant than in boreal forests. This forest type forms a belt stretching approximately from the Southern Urals across the forest-steppe zone of the West Siberian Plain to the mountainous systems of southern Siberia and to the Transbaikal area. To a smaller extent, it also occurs as extrazonal vegetation in dry areas of central Yakutia.

**3. Taiga**

(204 vegetation plots)

Diagnostic species: *Festuca jacutica,* ***Larix cajanderi,*** *Ledum palustre,* ***Linnaea borealis,*** *Picea obovata, Pinus sibirica, Trientalis europaea, Vaccinium myrtillus,* ***Vaccinium vitis-idaea***

Constant species: ***Pinus sibirica, Vaccinium vitis-idaea***

Dominant species: *Bergenia crassifolia, Larix cajanderi, Ledum palustre, Vaccinium vitis-idaea; Hylocomium splendens, Pleurozium schreberi, Sphagnum balticum*

Taiga is the zonal forest of the boreal zone. In wetter places it is represented by dark taiga dominated by *Abies sibirica*, *Picea obovata* and *Pinus sibirica*, occasionally with an admixture of *Betula pendula*, *B. pubescens* or *Populus tremula.* The herb layer contains abundant dwarf shrubs such as *Ledum palustre*, *Vaccinium myrtillus* and *V. vitis-idaea*, and the soil is usually covered by extensive moss mats. Light taiga is dominated by either *Pinus sylvestris* or different species of *Larix. Pinus sylvestris* forests occur in drier places and on poorer soils, especially on sandy deposits, higher rivers terraces and on shallow soils on slopes and crests. The herb

layer is dominated by dwarf shrubs, e.g. *Vaccinium vitis-idaea*, *Empetrum nigrum* and *Arctostaphylos uva-ursi*. Moss layer is usually well developed, with both bryophytes and lichens attaining a high cover. *Larix* forests often occur on permafrost. Their herb layer contains abundant dwarf shrubs such as *Ledum palustre*, *Vaccinium uliginosum*, *V. vitis-idaea* and *Arctous alpina* together with grasses, herbs and abundant mosses and lichens.

**4. Alluvial forest and scrub**

(41 vegetation plots)

Diagnostic species: *Aconitum septentrionale, Adoxa moschatellina, Alnus incana, Angelica decurrens, Anthriscus sylvestris, Athyrium filix-femina, Cacalia hastata, Cardamine impatiens, Cardamine macrophylla, Carex cespitosa, Coccyganthe flos-cuculi, Deschampsia cespitosa,* ***Elymus caninus,*** *Festuca gigantea, Filipendula ulmaria, Humulus lupulus, Chelidonium majus, Impatiens noli-tangere, Matteuccia struthiopteris, Melilotoides platycarpos, Milium effusum, Myosotis nemorosa, Padus avium, Poa remota, Populus laurifolia, Prunella vulgaris, Ranunculus grandifolius, Ranunculus repens, Ribes nigrum, Rubus caesius, Salix dasyclados,* ***Salix rorida,*** *Salix viminalis, Scirpus sylvaticus, Scrophularia nodosa, Senecio nemorensis, Stachys sylvatica, Stellaria bungeana, Stellaria nemorum, Tussilago farfara,* ***Urtica dioica,*** *Viburnum opulus; Brachythecium rivulare, Calliergon cordifolium, Climacium dendroides, Eurhynchium hians, Hypnum lindbergii*

Constant species: *Cacalia hastata, Filipendula ulmaria, Galium boreale, Padus avium,* ***Urtica dioica***

Dominant species: *Aegopodium podagraria, Alnus incana, Matteuccia struthiopteris, Salix rorida, Salix viminalis*

Alluvial forests and shrublands occur along streams on mineral alluvial soil with no or only superficial accumulation of peat. They are dominated especially by *Picea obovata, Betula pendula, B. pubescens, Larix* spp., several different species of *Salix* and *Alnus fruticosa*. Their herb layer contains grasses such as *Calamagrostis langsdorffii*, but also herb and dwarf-shrub species occurring in the adjacent forests.

**5. Fen and swamp woodland**

(51 vegetation plots)

Diagnostic species: *Betula pubescens, Carex cespitosa, Carex globularis, Epilobium palustre, Galium palustre, Galium uliginosum, Chamaedaphne calyculata, Ledum palustre, Salix bebbiana, Salix pyrolifolia; Bryum pseudotriquetrum*

Constant species: *Betula pubescens*

Dominant species: *Betula pendula, Betula pubescens, Calamagrostis langsdorffii, Chamaedaphne calyculata, Ledum palustre*

Peatland forests occur on the valley bottoms or in shallow depressions that are saturated with water from lateral groundwater flow, as in the case of minerotrophic fens. Dominant trees include *Betula pubescens*, *Picea obovata* and *Pinus sylvestris*. Herb layer is rich in grasses (e.g. *Calamagrostis canescens* and *C. langsdorffii*), sedges (e.g. *Carex cespitosa* and *C. juncella*) and bryophytes including some species of *Sphagnum.*

**6. Bog**

(65 vegetation plots)

Diagnostic species: ***Andromeda polifolia, Betula nana,*** *Betula pubescens, Carex globularis, Carex lasiocarpa, Carex pauciflora, Dactylorhiza maculata,* ***Drosera rotundifolia,*** *Empetrum nigrum,* ***Eriophorum vaginatum, Chamaedaphne calyculata, Ledum palustre, Oxycoccus microcarpus, Oxycoccus palustris,*** *Pinus sylvestris,* ***Rubus chamaemorus,*** *Vaccinium uliginosum, Vaccinium vitis-idaea; Cladonia amaurocraea, Cladonia stellaris,* ***Mylia anomala,*** *Polytrichum strictum,* ***Sphagnum angustifolium, Sphagnum fallax, Sphagnum fuscum, Sphagnum magellanicum,*** *Sphagnum rubellum, Sphagnum species*

Constant species: ***Andromeda polifolia,*** *Betula nana,* ***Eriophorum vaginatum, Chamaedaphne calyculata, Ledum palustre,*** *Oxycoccus microcarpus, Pinus sibirica, Pinus sylvestris,* ***Rubus chamaemorus,*** *Vaccinium uliginosum,* ***Vaccinium vitis-idaea***

Dominant species: *Eriophorum vaginatum, Ledum palustre; Cladonia stellaris, Polytrichum species, Sphagnum fallax, Sphagnum fuscum, Sphagnum magellanicum, Sphagnum species*

These are rainwater-fed mires occurring mainly in the lowlands of the boreal zone of Siberia, especially on the West Siberian Plain. They are dominated by peat mosses (*Sphagnum* spp.) and contain a significant amount of dwarf shrubs such as *Chamaedaphne calyculata*, *Ledum palustre*, *Rubus chamaemorus, Oxycoccus* spp. and *Vaccinium uliginosum*). They are either open or covered by sparse stands of *Pinus sylvestris*. In the permafrost zone of northern Siberia, they often form small elevations with ice cores (palsas).

**7. Open fen**

(117 vegetation plots)

Diagnostic species: *Andromeda polifolia,* ***Carex concolor, Carex chordorrhiza,*** *Carex limosa,* ***Carex rotundata,*** *Carex williamsii,* ***Comarum palustre,*** *Eriophorum polystachyon,* ***Eriophorum russeolum,*** *Pedicularis albolabiata, Salix fuscescens, Utricularia intermedia*

Constant species: ***Carex concolor,*** *Carex chordorrhiza, Comarum palustre, Eriophorum russeolum*

Dominant species: *Hypnum species, Tomentypnum nitens*

This type of open mire, occurring in valleys, shallow depressions or around springs, is saturated by groundwater. It is dominated by sedges (e.g. *Carex chordorrhiza*, *C. diandra*, *C. lasiocarpa* and *C. rostrata*), herbs (e.g. *Comarum palustre* and *Menyanthes trifoliata*) and mosses, although the species of the genus *Sphagnum* are less abundant than in ombrotrophic bogs or even absent.

**8. Arctic or alpine deciduous scrub**

(42 vegetation plots)

Diagnostic species: *Arctagrostis arundinacea, Arctagrostis latifolia, Artemisia tilesii, Astragalus alpinus,* ***Duschekia fruticosa,*** *Equisetum arvense, Pedicularis sceptrum-carolinum,* ***Petasites frigidus,*** *Poa alpigena,* ***Polemonium acutiflorum,*** *Salix boganidensis,* ***Salix glauca,*** *Salix hastata, Salix lanata, Salix lapponum, Salix phylicifolia, Salix pulchra,* ***Salix richardsonii,*** *Saxifraga hieracifolia, Valeriana capitata, Viola epipsiloides, Wilhelmsia physodes*

Constant species: *Equisetum arvense,* ***Salix glauca***

Dominant species: *Betula exilis, Duschekia fruticosa, Salix glauca, Salix phylicifolia, Salix pulchra, Salix richardsonii; Hylocomium splendens, Tomentypnum nitens*

This vegetation type occurs in moist habitats in northern Siberia, especially in the Arctic tundra zone, and in the high mountains in the south. Its characteristic feature is an abundance of deciduous shrubs, especially willows (*Salix glauca*, *S. krylovii*, *S. lanata* and *S. phylicifolia*), *Alnus fruticosa* and *Pentaphylloides fruticosa*.

**9. Arctic or alpine heatland**

(93 vegetation plots)

Diagnostic species: *Aconogonon tripterocarpum,* ***Achoriphragma nudicaule,*** *Alopecurus alpinus,* ***Arctagrostis latifolia,*** *Arctous alpina,* ***Betula exilis,*** *Bistorta elliptica, Calamagrostis holmii, Carex arctisibirica, Carex vaginata,* ***Cassiope tetragona,*** *Draba species,* ***Dryas punctata,*** *Eriophorum vaginatum, Festuca brachyphylla,* ***Hierochloe alpina,*** *Lagotis minor,* ***Ledum decumbens, Luzula confusa, Luzula nivalis,*** *Luzula tundricola,* ***Minuartia arctica, Minuartia macrocarpa,*** *Oxytropis nigrescens, Pedicularis alopecuroides, Pedicularis capitata,* ***Poa arctica,*** *Salix glauca, Salix polaris, Salix pulchra,* ***Saussurea tilesii, Saxifraga nelsoniana,*** *Saxifraga nivalis, Saxifraga serpyllifolia,* ***Saxifraga spinulosa,*** *Sieversia species,* ***Stellaria peduncularis,*** *Tephroseris heterophylla, Tofieldia coccinea,* ***Vaccinium uliginosum,*** *Vaccinium vitis-idaea,* ***Valeriana capitata; Alectoria nigricans, Alectoria ochroleuca,*** *Aulacomnium turgidum,* ***Bryocaulon divergens,*** *Bryoria nitidula,* ***Cetraria laevigata,*** *Cetraria nigricans,* ***Dactylina arctica,*** *Dicranum species,* ***Flavocetraria cucullata,*** *Peltigera aphthosa, Polytrichum species, Ptilidium ciliare, Racomitrium lanuginosum, Sphaerophorus globosus, Stereocaulon alpinum, Stereocaulon species,* ***Thamnolia vermicularis,*** *Tomentypnum nitens*

Constant species: ***Arctagrostis latifolia,*** *Betula exilis, Cassiope tetragona,* ***Dryas punctata, Ledum decumbens, Luzula confusa,*** *Luzula nivalis,* ***Poa arctica,*** *Stellaria peduncularis,* ***Vaccinium uliginosum, Vaccinium vitis-idaea;*** *Cetraria laevigata, Dactylina arctica,* ***Flavocetraria cucullata,*** *Ptilidium ciliare*

Dominant species: *Dryas punctata, Eriophorum vaginatum, Ledum decumbens, Vaccinium vitis-idaea; Abietinella abietina, Alectoria ochroleuca, Aulacomnium species, Aulacomnium turgidum, Dicranum species, Flavocetraria cucullata, Hylocomium splendens, Ptilidium ciliare, Tomentypnum nitens*

Arctic and alpine heathland occurs especially in the tundra zone of northern Siberia as well as in the areas above the timberline of the Siberian mountain systems. It is dominated by dwarf shrubs (e.g. *Empetrum* spp., *Vaccinium myrtillus* and *V. vitis-idaea*) associated with perennial herbs, graminoids, and with significant participation of bryophytes and lichens.

**10. Tundra grassland**

(114 vegetation plots)

Diagnostic species: ***Bistorta vivipara,*** *Carex fuscidula, Carex redowskiana, Carex rupestris, Crepis chrysantha, Dryas crenulata, Dryas punctata, Eremogone formosa, Eritrichium villosum, Eutrema edwardsii, Gastrolychnis apetala, Gentiana algida, Gentiana grandiflora, Kobresia species, Lagotis minor, Luzula nivalis, Minuartia arctica, Minuartia rubella, Minuartia verna, Pedicularis amoena, Pedicularis oederi, Poa glauca, Potentilla gelida, Salix polaris, Saussurea schanginiana, Saxifraga hirculus, Schulzia crinita, Thalictrum alpinum, Thymus oxyodontus; Cetraria islandica, Dactylina arctica, Flavocetraria cucullata, Thamnolia vermicularis*

Constant species: ***Bistorta vivipara; Flavocetraria cucullata***

Dominant species: *Dryas oxyodonta, Dryas punctata, Eriophorum polystachyon, Eriophorum vaginatum, Salix polaris; Hylocomium splendens, Ptilidium ciliare, Tomentypnum nitens*

Grasslands in the tundra zone occur especially at grazed sites or in the surroundings of snow beds. More frequently occurring graminoids include *Kobresia myosuroides* and species of the genera *Carex* and *Festuca*. Herbs include *Bistorta vivipara*, *Gentiana algida* and *Thalictrum alpinum*. Bryophyte and lichens are well developed in these grasslands.

**11. Betula nana s. l. scrub**

(54 vegetation plots)

Diagnostic species: *Betula nana,* ***Betula rotundifolia,*** *Calamagrostis lapponica, Callianthemum sajanense, Carex globularis, Carex sabynensis, Festuca altaica, Festuca ovina, Festuca sphagnicola, Gentiana grandiflora, Hedysarum consanguineum, Kobresia myosuroides, Lagotis integrifolia, Luzula sibirica, Pachypleurum alpinum, Pedicularis compacta, Pedicularis labradorica, Potentilla gelida, Salix glauca, Salix phylicifolia, Salix rectijulis, Saussurea alpina, Schulzia crinita, Spiraea alpina, Swertia obtusa, Vaccinium uliginosum, Vaccinium vitis-idaea, Viola altaica; Aulacomnium palustre, Aulacomnium turgidum, Cetraria islandica, Cladonia amaurocraea, Cladonia cornuta, Cladonia gracilis, Cladonia chlorophaea, Cladonia rangiferina, Cladonia stellaris, Dicranum elongatum, Dicranum spadiceum, Nephroma arcticum, Peltigera aphthosa, Peltigera scabrosa, Pohlia nutans*

Constant species: *Betula rotundifolia,* ***Vaccinium uliginosum, Vaccinium vitis-idaea;*** *Cetraria islandica, Cladonia rangiferina*

Dominant species: *Betula exilis, Betula nana, Betula rotundifolia; Cladonia stellaris, Hylocomium splendens, Pleurozium schreberi, Ptilidium ciliare*

This dwarf to medium-tall shrub formation, occupying especially the tundra zone in northern Siberia but occurring also in other areas of Siberia, is dominated by shrubby birches from the group of *Betula nana*, in particular *B. nana* in the Arctic tundra of northwestern Siberia, *B. exilis* in the tundra and taiga zone of northern-central and northeastern Siberia as well as Alaska, and *B. rotundifolia* in the alpine tundra of the southern Siberian mountain systems. Associated species include various shrubs and dwarf shrubs (e.g. *Empetrum* spp., *Ledum palustre*, *Salix glauca*, *Vaccinium myrtillus*, *V. uliginosum* and *V. vitis-idaea*), graminoids, dicot herbs, bryophytes and lichens. This vegetation often occurs at topographically wetter sites and in places with distinct snow accumulation in winter.

**12. Tall forbs**

(38 vegetation plots)

Diagnostic species: *Aconitum sajanense, Aconitum septentrionale, Alchemilla species, Allium microdictyon, Angelica decurrens, Anthoxanthum alpinum, Aquilegia glandulosa,* ***Athyrium distentifolium,*** *Bistorta major, Bupleurum longifolium, Calamagrostis langsdorffii, Cardamine macrophylla,* ***Carex aterrima,*** *Cerastium davuricum,* ***Cerastium pauciflorum,*** *Cirsium helenioides, Cirsium heterophyllum, Crepis lyrata, Delphinium elatum, Deschampsia cespitosa,* ***Doronicum altaicum, Euphorbia pilosa, Geranium albiflorum,*** *Geranium sylvaticum, Chamaenerion angustifolium, Lamium album, Myosotis krylovii, Myosotis nemorosa,* ***Pedicularis incarnata, Poa sibirica,*** *Primula pallasii, Ranunculus grandifolius, Rhodiola rosea,* ***Rumex alpestris, Saussurea latifolia, Saxifraga aestivalis,*** *Solidago dahurica, Stemmacantha carthamoides, Swertia obtusa, Trisetum altaicum, Trollius asiaticus,* ***Veratrum lobelianum,*** *Veronica densiflora,* ***Viola biflora;*** *Barbilophozia lycopodioides, Brachythecium reflexum, Conocephalum conicum, Hylocomiastrum pyrenaicum, Lescuraea saxicola, Plagiochila porelloides, Plagiomnium affine, Rhizomnium magnifolium*

Constant species: *Aconitum septentrionale, Bistorta major, Calamagrostis langsdorffii,* ***Cerastium pauciflorum,*** *Euphorbia pilosa, Geranium albiflorum, Pedicularis incarnata,* ***Poa sibirica,*** *Rumex alpestris, Trollius asiaticus,* ***Veratrum lobelianum, Viola biflora***

Dominant species: *Allium microdictyon, Athyrium distentifolium, Calamagrostis langsdorffii, Heracleum dissectum, Stemmacantha carthamoides, Veratrum lobelianum; Brachythecium rivulare*

High-productive tall-forb grasslands (also called subalpine meadows) are widespread in the precipitation-rich parts of the high-mountain systems of southern Siberia, particularly in the Altai-Sayan Mountains, but they also occur in the Arctic tundra zone. Dominant species include *Aconitum septentrionale*, *Aquilegia glandulosa*, *Cirsium heterophyllum*, *Doronicum altaicum*, *Pedicularis incarnata*, *Trollius asiaticus* and *Veratrum lobelianum*.

**13. Saline grassland**

(212 vegetation plots)

Diagnostic species: *Glaux maritima,* ***Knorringia sibirica, Puccinellia tenuiflora,*** *Saussurea amara,* ***Suaeda corniculata***

Constant species: ***Puccinellia tenuiflora,*** *Saussurea amara*

Dominant species: *Alopecurus arundinaceus, Artemisia jacutica, Elytrigia repens, Glaux maritima, Hordeum brevisubulatum, Puccinellia tenuiflora, Suaeda corniculata*

Inland saline grasslands are meadow-like or steppe-like communities on saline soils. More productive types develop on solonchaks, occurring in river valleys, in shallow depressions and in the surroundings of lakes, while the less productive types develop on solonetz soils in flat lowlands and on river terraces. Common species include the herbs *Glaux maritima*, *Halerpestes salsuginosa*, *Potentilla anserina*, *Saussurea amara* and *Triglochin palustre*, the grasses *Agrostis stolonifera*, *Alopecurus arundinaceus* and *Puccinellia* spp., and succulent halophytes of the genera *Salicornia* or *Suaeda*.

**14. Marsh**

(217 vegetation plots)

Diagnostic species: *Beckmannia syzigachne, Carex vesicata, Eleocharis palustris, Equisetum fluviatile,* ***Glyceria triflora,*** *Hippuris vulgaris, Scirpus lacustris, Scolochloa festucacea, Sparganium emersum*

Constant species: *Glyceria triflora*

Dominant species: *Beckmannia syzigachne, Carex aquatilis, Eleocharis palustris, Equisetum fluviatile, Glyceria triflora, Scirpus lacustris, Scolochloa festucacea*

This is an azonal vegetation type occurring at topographically wet sites in the lowlands and river valleys. The dominant species include tall wetland grasses, especially *Phragmites australis* and *Typha* spp., and tall sedges. The occurrence of bryophytes and accumulation of moss peat are insignificant features in this habitat.

**15. Wet meadow**

(223 vegetation plots)

Diagnostic species: *Alopecurus arundinaceus, Calamagrostis neglecta, Caltha palustris,* ***Carex juncella, Carex lithophila,*** *Lathyrus pilosus, Persicaria amphibia,* ***Poa palustris,*** *Potentilla anserina, Ptarmica cartilaginea*

Constant species: *Alopecurus arundinaceus, Caltha palustris*

Dominant species: *Alopecurus arundinaceus, Calamagrostis langsdorffii, Calamagrostis neglecta, Caltha palustris, Carex juncella, Carex lithophila, Filipendula ulmaria, Hordeum brevisubulatum, Sanguisorba officinalis*

Wet grasslands are usually confined to bottoms of river valleys in various parts of Siberia, probably being most common in south-western Siberia. They are composed of herbs (e.g. *Filipendula ulmaria*, *Galium boreale*, *Silaum silaus* and *Thalictrum simplex*) and graminoids (e.g. *Carex vulpina*, *Deschampsia cespitosa* and *Poa palustris*).

**16. Mesic meadow**

(76 vegetation plots)

Diagnostic species: *Achillea millefolium, Allium schoenoprasum, Amoria repens, Artemisia mongolica, Cnidium davuricum, Elytrigia repens, Geranium pratense, Hordeum brevisubulatum, Poa pratensis, Potentilla anserina, Potentilla stipularis, Ptarmica alpina, Ranunculus propinquus, Rhinanthus vernalis, Rumex thyrsiflorus, Sanguisorba officinalis, Stellaria dahurica, Tanacetum vulgare, Taraxacum ceratophorum,* ***Thalictrum simplex,*** *Veronica longifolia, Vicia cracca*

Constant species: *Achillea millefolium,* ***Elytrigia repens, Galium boreale,*** *Galium verum,* ***Geranium pratense, Hordeum brevisubulatum, Poa pratensis,*** *Potentilla anserina,* ***Sanguisorba officinalis, Thalictrum simplex,*** *Veronica longifolia,* ***Vicia cracca***

Dominant species: *Agrostis clavata, Elytrigia repens, Hordeum brevisubulatum, Potentilla anserina, Sanguisorba officinalis, Thalictrum simplex, Vicia cracca*

Mesic meadows typically occur on river terraces which are rarely flooded. Their species composition consists of both graminoids and dicot herbs. Productivity is lower than in the wet meadows, but the swards are often dense and tall and used for grazing or haymaking by local farmers.

**17. Dry meadow**

(88 vegetation plots)

Diagnostic species: *Agrostis trinii, Achillea millefolium, Anemone sylvestris, Artemisia commutata, Artemisia mongolica, Carex duriuscula, Crepis tectorum, Elytrigia repens, Erigeron acris, Hordeum brevisubulatum, Linum perenne, Pedicularis venusta, Plantago canescens, Poa pratensis, Potentilla conferta, Potentilla stipularis, Senecio erucifolius, Silene repens, Taraxacum ceratophorum, Thalictrum simplex*

Constant species: *Achillea millefolium,* ***Artemisia commutata,*** *Carex duriuscula,* ***Elytrigia repens, Galium verum, Hordeum brevisubulatum, Poa pratensis,*** *Silene repens,* ***Thalictrum simplex,*** *Vicia cracca*

Dominant species: *Agrostis trinii, Anemone sylvestris, Elytrigia repens, Galium verum, Hordeum brevisubulatum, Puccinellia tenuiflora*

Dry meadow is a vegetation type occurring on the moisture gradient between the mesic meadow and the meadow-steppe. It contains various herbs typical of mesic meadows, dicot herbs and broad-leaved grasses typical of meadow-steppe, but typical steppe species such as those of the genus *Stipa* are missing.

**18. Steppe scrub**

(75 vegetation plots)

Diagnostic species: *Aconogonon alpinum, Artemisia armeniaca, Artemisia gmelinii, Artemisia sericea, Caragana frutex, Carex supina, Fragaria viridis, Galium verum, Melica transsilvanica, Origanum vulgare, Phlomoides tuberosa, Sedum hybridum, Spiraea crenata, Spiraea hypericifolia, Veronica spuria*

Constant species: *Fragaria viridis,* ***Galium verum, Phlomoides tuberosa***

Dominant species: *Caragana arborescens, Caragana frutex, Carex pediformis, Juniperus sabina, Sedum hybridum, Spiraea crenata, Spiraea media*

This vegetation type is formed of drought-adapted low shrubs, especially those of the genera *Caragana* and *Spiraea*. It occurs in relatively wetter places within the steppe and forest-steppe zones, usually in a mosaic with meadow-steppe or typical steppe, or at the forest edges. Steppe herbs and graminoids occur below the shrub canopy.

**19. Meadow steppe**

(267 vegetation plots)

Diagnostic species: ***Festuca lenensis,*** *Pulsatilla flavescens*

Constant species: *Artemisia commutata,* ***Galium verum***

Dominant species: *Pulsatilla flavescens*

Meadow-steppe is a vegetation type occupying an intermediate ecological position on the moisture gradient between dry meadows and dry steppes. This vegetation is common in the forest-steppe zone of the lowland parts of southern Siberia as well as in the mountain forest-steppe belt of the southern Siberian mountain systems. Plant communities of the meadow-steppe consist of a species-rich mixture of broad-leaved herbs and graminoids. Rhizomatous graminoids are more common than tussocky ones.

**20. Dry steppe**

(416 vegetation plots)

Diagnostic species: *Agropyron cristatum, Alyssum obovatum,* ***Artemisia frigida,*** *Caragana pygmaea,* ***Cleistogenes squarrosa,*** *Ephedra monosperma, Goniolimon speciosum, Chamaerhodos erecta, Kitagawia baicalensis, Koeleria cristata, Orostachys spinosa, Poa botryoides, Potentilla acaulis, Scorzonera austriaca, Stipa capillata, Stipa krylovii, Veronica incana; Xanthoparmelia camschadalis*

Constant species: *Artemisia frigida,* ***Koeleria cristata***

Dry (or typical) steppe is the dominant plant formation of the steppe zone of southern Siberia and adjacent areas in Kazakhstan, Mongolia and China. It occurs in drier habitats than meadow-steppe, and it is less productive and less species-rich than meadow-steppe, characterized by a sparser vegetation cover. The typical steppe is dominated by narrow-leaved tussocky grasses such as *Festuca valesiaca*, *Koeleria cristata*, *Stipa* (e.g. *Stipa capillata*, *S. lessingiana*, *S. krylovii*) and *Helictotrichon altaicum*, accompanied by sedges, non-tussocky graminoids, herbs and some low shrubs such as *Caragana* spp.

**21. Desert steppe**

(50 vegetation plots)

Diagnostic species: ***Agropyron cristatum,*** *Achnatherum splendens, Ancathia igniaria,* ***Artemisia frigida,*** *Artemisia obtusiloba, Artemisia semiarida,* ***Artemisia schrenkiana,*** *Atriplex cana, Caragana balchaschensis, Caragana bungei, Ceratocarpus arenarius, Convolvulus ammanii, Dontostemon perennis, Festuca valesiaca,* ***Kochia prostrata,*** *Krascheninnikovia ceratoides, Psathyrostachys juncea, Ptilotrichum canescens, Stellaria dichotoma,* ***Stipa glareosa,*** *Stipa orientalis,* ***Stipa sareptana;*** *Xanthoparmelia camschadalis*

Constant species: ***Agropyron cristatum, Artemisia frigida,*** *Festuca valesiaca, Koeleria cristata,* ***Kochia prostrata***

Desert-steppe is open low-productive vegetation currently occurring in the basins of the southern Siberian mountain systems. It is dominated by steppe grasses (e.g. *Festuca valesiaca, Psathyrostachys juncea* and *Stipa sareptana*) combined with dwarf shrubs and semi-shrubs, especially various species of *Artemisia* such as *A. frigida*, *A. nitrosa*, *A. schrenkiana* and *A. semiarida*, and *Amaranthaceae* species, e.g. *Kochia prostrata*.

**22. Semi-desert**

(17 vegetation plots)

Diagnostic species: ***Anabasis salsa,*** *Anabasis truncata, Artemisia gracilescens,* ***Artemisia species,*** *Caragana balchaschensis,* ***Ceratocarpus arenarius,*** *Ceratocarpus utriculosus, Drabopsis species,* ***Ferula species,*** *Iris glaucescens, Kochia prostrata,* ***Krascheninnikovia ceratoides,*** *Lappula spinocarpos, Leptaleum filifolium,* ***Megacarpaea megalocarpa, Nanophyton erinaceum, Rheum tataricum,*** *Salix arbuscula,* ***Salsola species,*** *Scorzonera species,* ***Stipa richteriana,*** *Stipa*

*sareptana, Tetracme quadricornis, Tetracme species, Thalictrum isopyroides, Tulipa biflora, Tulipa species; Asperula affinis,* ***Aspicilia desertorum, Aspicilia lacunosa, Aspicilia vagans, Collema species,*** *Endocarpon pusillum, Endocarpon species,* ***Psora decipiens, Ramalina species***

Constant species: ***Artemisia species, Ferula species, Nanophyton erinaceum,*** *Rheum tataricum,* ***Salsola species, Stipa richteriana;*** *Aspicilia lacunosa, Aspicilia vagans*

Dominant species: *Artemisia species, Salsola species, Stipa richteriana*

Semi-deserts currently occur especially in central Kazakhstan and Mongolia. They are transitional between dry steppes or desert-steppes and true deserts. Steppe grasses (especially tussock species of the genera *Festuca* and *Stipa*) are mixed with dwarf shrubs typical of the true steppe. This vegetation is sparse and has low productivity.

**23. Desert**

(26 vegetation plots)

Diagnostic species: *Aira species, Allium iliense, Allium sabulosum,* ***Alyssum turkestanicum, Anabasis salsa,*** *Anabasis truncata, Anisantha tectorum,* ***Arnebia decumbens, Artemisia gracilescens,*** *Artemisia pauciflora,* ***Artemisia species, Artemisia turanica,*** *Atriplex species, Carex physocarpa,* ***Carex physodes, Ceratocarpus utriculosus,*** *Ceratocephala falcata, Ceratocephala testiculata, Climacoptera lanata,* ***Diptychocarpus strictus,*** *Drabopsis nuda, Ephedra intermedia,* ***Eremopoa species, Eremopyrum species,*** *Erysimum czernjajevii, Euphorbia blepharophylla, Filago species,* ***Gagea species, Girgensohnia oppositiflora,*** *Holosteum umbellatum, Hypecoum species, Chorispora species, Chorispora tenella, Jurinea species, Kochia iranica, Kochia species, Krascheninnikovia ceratoides,* ***Lappula species,*** *Lappula spinocarpos,* ***Lepidium perfoliatum, Leptaleum filifolium, Meniocus linifolius, Nanophyton erinaceum,*** *Neotorularia brevipes,* ***Petrosimonia sibirica, Poa bulbosa,*** *Potentilla astragalifolia,* ***Rheum tataricum,*** *Rhinopetalum karelinii, Rhinopetalum species, Rochelia retorta,* ***Salsola orientalis, Salsola species,*** *Scorzonera species, Stipa caspia,* ***Streptoloma desertorum,*** *Strigosella africana, Strigosella species,* ***Tetracme quadricornis,*** *Trigonella arcuata,* ***Tulipa species, Veronica species,*** *Ziziphora species, Ziziphora tenuior; Asperula affinis,* ***Aspicilia desertorum,*** *Aspicilia lacunosa,* ***Collema species,*** *Psora decipiens*

Constant species: *Artemisia species,* ***Ceratocarpus utriculosus,*** *Eremopoa species,* ***Leptaleum filifolium,*** *Meniocus linifolius, Poa bulbosa, Salsola species, Tetracme quadricornis*

Dominant species: *Salsola species*

Deserts currently occur especially in southern Kazakhstan and Mongolia. They have a very sparse vegetation cover characterized by dwarf shrubs, some of them succulent (e.g. the genera *Anabasis*, *Artemisia* and *Salsola*), and spring geophytes and therophytes.

**References**


Cherepanov, S. K. 1995. Vascular Plants of Russia and Adjacent Countries (within the Former USSR). – Mir i sem'ya-95, Sankt Petersburg (in Russian).

Chytrý, M. et al. 2002. Determination of diagnostic species with statistical fidelity measures. – J. Veg. Sci. 13: 79–90.

Ermakov, N. et al. 2000a. Classification of continental hemiboreal forests of North Asia. – Braun-Blanquetia 28: 1–131.

Ermakov, N. et al. 2000b. The class *Mulgedio-Aconitetea* in Siberia. – Phytocoenologia 30: 145–192.

Golub, V. B. et al. 2001. Survey of communities of the class *Salicornietea fruticosae*. – Rastitel'nost' Rossii 2: 87–98.

Golub, V. B. et al. 2005. Soobshchestva klassa *Festuco-Puccinellietea* Soó ex Vicherek 1973 na territorii Evrazii (Communities of the class *Festuco-Puccinellietea* Soó ex Vicherek 1973 on the territory of Eurasia). – Rastitel'nost' Rossii 7: 59–75 (in Russian).

Janská, V. et al. 2017. Palaeodistribution modelling of European vegetation types at the Last Glacial Maximum using modern analogues from Siberia: Prospects and limitations. – Quaternary Sci. Rev 159: 103–115.

Korolyuk, A.Yu. 2002. Rastitel'nost' (Vegetation). – In: Khmelev V. A. (ed.), Stepi Tsentral'noj Azii (Steppes of Central Asia). – Sib. Otd. Ross. Akad. Nauk., Novosibirsk, pp. 45–94 (in Russian).

Korolyuk, A.Yu. 2014. Plant communities of the class *Festuco-Brometea* in the West Siberian Plain. – Rastitel'nost' Rossii 25: 45–70 (in Russian).

Lapshina, E. 2010. Rastitel'nost' Bolot yugo–vostoka Zapadnoi Sibiri (Vegetation of mires of the south-east of Western Siberia). – Izdatel'stvo NGU, Novosibirsk (in Russian).

Lashchinsky, N.N. and Korolyuk, A.Yu. 2015. Sintaksonomiya temnokhvoinykh zonal'nykh lesov yuzhnoi taigi Zapadno-Sibirskoi ravniny i gumidnykh nizkogorii Altae-Sayanskoi gornoi oblasti (Syntaxonomy of zonal dark-coniferous forests of southern taiga of the West Siberian Plain and of humid low-mountains of the Altai-Sayan mountain region). – Rastitel'nost' Rossii 26: 85–107 (in Russian).

Shumilova, L.V. 1962. Botanicheskaya Geografiya Sibiri (Botanical geography of Siberia). – Izdateľstvo Tomskogo universiteta (in Russian).

Tichý, L. 2002. JUICE, software for vegetation classification. – J. Veg. Sci. 13: 451–453.

Walker, D. A. et al. 2005. The Circumpolar Arctic vegetation map. – J. Veg. Sci. 16: 267–282.

Walter, H. 1974. Die Vegetation Osteuropas, Nord- und Zentralasiens. – Gustav Fischer Verlag.

## Appendix 2

**Table A1.** Localities of the frozen fauna finds. Most carcasses were found in Siberia; those from Alaska and the Yukon Territory are indicated by an asterisk*. If available, geographic coordinates were taken from the original publications. † indicates approximate coordinates based on published maps or locality descriptions. For references see below.

| ID | Nickname or [short name] | Locality | Reference No. in the Appendix | Coordinates |
|---|---|---|---|---|
| 1 | Rauchua Bison | W Chukotka, the mouth of the Rauchua River near Bilibino | 6 | 69°30'N, 166°49'E |
| 2 | Yukagir Bison | N Yakutia, northern bank of Chukchalakh Lake, Yana-Indigirka Lowland | 2 | 72°17'N, 140°54'E |
| 3 | Yuribei Mammoth | Gydan Peninsula, middle Yuribei River | 17 | 70°18'N, 76°00'E |
| 4 | Alaskan Late Glacial mammoth* | Alaska, Cape Blossom in Kotzebue Sound, Baldwin Peninsula | 3 | 66°53'N, 162°35'W † |
| 5 | [Reindeer] | Taimyr Peninsula, NW shore of Lake Taimyr | 13 | 74°31'N, 100°30'E |
| 6 | Finish Creek Valley Mammoth | NE Yakutia | 18 | 68°43'N, 161°35'E |
| 7 | Mongochen Mammoth | Gydan Peninsula, Mongocha-Yakha drainage basin | 10 | 72°10'N, 79°35'E |
| 8 | Yukagir Mammoth | N Yakutia, Muksunuokha River | 14 | 71°52'N, 140°34'E |
| 9 | Churapcha Rhinoceros | Central Yakutia, Churapcha settlement on the Lena-Amga interfluve | 11 | 62°00'N, 132°25'E |
| 10 | Fishhook Mammoth | Taimyr Peninsula, the estuary of the Upper Taimyra River, Western Lake Taimyr | 12 | 74°09'N, 99°35'E |
| 11 | Chekurovka Mammoth | N Yakutia, a tributary of Lena River near Chekurovka | 16 | 71°00'N, 127°40'E |
| 12 | Yukon/Last Chance Creek Horse* | Yukon, Last Chance Creek near Dawson City | 5 | 63°58'N, 139°07'W † |
| 13 | Mylakhchin Bison | NE Yakutia, middle Indigirka River | 17 | 68°30'N, 146°40'E |
| 14 | Khalbugai Rhinoceros | N Yakutia, Khalbugai Creek, tributary of Bytantaj River, middle Yana River basin | 15 | 67°45'N, 134°41'E † |
| 15 | Blue babe (bison)* | Alaska, Pearl Creek, a tributary of the Chatanika River | 4 | 65°59'N, 147°19'W |
| 16 | Kolyma Rhinoceros | NE Yakutia, Malaya Filippova River, Lower Kolyma River basin | 1 | 68°46'N, 161°38'E |
| 17 | Selerikan Horse | NE Yakutia, Balkhan Creek, Upper Indigirka River basin | 17 | 64°40'N, 147°45'E |
| 18 | Kirgilyakh/ Dima Mammoth | NE Yakutia, Kirgilyakh Creek, upper part of Kolyma River basin | 4 | 62°40'N, 147°59'E |
| 19 | Shandrin Mammoth | NE Yakutia, a right tributary of the lower Indigirka River | 17 | 70°30'N, 151°00'E |
| 20 | Mammoth dung F-552 | N Yakutia, Terekhtyakh River, Lower Indigirka River basin | 7 | 68°32'N, 146°11'E |
| 21 | Yuribey/ Lyuba Baby Mammoth | Yamal Peninsula, a bank of the Yuribei River | 9 | 68°38'N, 71°40'E |
| 22 | Vilyuy Rhinoceros | Central Yakutia, Vilyuy River, near the town of Vilyuysk | 17 | 63°44'N, 121°37'E † |
| 23 | Berezovka Mammoth | NE Yakutia, Berezovka River, Kolyma River basin | 17 | 67°10'N, 155°30'E |
| 24 | Chondon Rhinoceros | N Yakutia, middle Chondon River | 6 | 70°12'N, 137°00'E |
| 25 | Mammoth dung F-3447 | W Chukotka, Maly Anyui River | 7 | 68°18'N, 161°44'E |
| 26 | [Bison] | NE Yakutia | 18 | 68°44'N, 161°38'E |
| 27 | Drevniy Creek Mammoth | NE Yakutia | 18 | 68°35'N, 161°45'E |

**References: 1:** Boeskorov et al. (2011), **2:** Boeskorov et al. (2014), **3:** van Geel et al. (2011), **4:** Guthrie (1990), **5:** Harington (2002), **6:** Kirillova et al. (2013), **7:** Kirillova et al. (2016a), **8:** Kirillova et al. (2016b), **9:** Kosintsev et al. (2010), **10:** Kosintsev et al. (2012), **11:** Lazarev (1977), **12:** Mol et al. (2001), **13:** Mol et al. (2003), **14:** Mol et al. (2006), **15:** Tolmachoff (1929), **16:** Tomskaya (2000), **17:** Ukraintseva (1993), **18:** Willerslev et al. (2014)

**References**


**1:** Boeskorov, G. G. et al. 2011. Woolly rhino discovery in the lower Kolyma River. – Quarternary Sci. Rev. 30: 2262–2272.

**2:** Boeskorov, G. G. et al. 2014. Preliminary analyses of the frozen mummies of mammoth (*Mammuthus primigenius*), bison (*Bison priscus*) and horse (*Equus* sp.) from the Yana-Indigirka Lowland, Yakutia, Russia. – Integr. Zool. 9: 471–480.

**3:** van Geel, B. et al. 2011. Mycological evidence of coprophagy from the feces of an Alaskan Late Glacial mammoth. – Quaternary Sci. Rev. 30: 2289–2303.

**4:** Guthrie, R. D. 1990. Frozen Fauna of the Mammoth Steppe: The Story of Blue Babe. – The University of Chicago Press.

**5:** Harington, C. R. 2002. Yukon horse. – Beringian Research Notes 14: 1–4.

**6:** Kirillova, I. V. et al. 2013. The first finding of a frozen Holocene bison (*Bison priscus* Bojanus, 1827) carcass in Chukotka. – Dokl. Biol. Sci. 452: 296–299.

**7:** Kirillova, I. V. et al. 2016a. The diet and environment of mammoths in North-East Russia reconstructed from the contents of their feces. – Quatern. Int. 406: 147–161.

**8:** Kirillova, I. V. et al. 2016b. The first finding of a rhinoceros of the genus Stephanorhinus in Arctic Asia. – Dokl. Biol. Sci. 471: 300–303.

**9:** Kosintsev, P. A. et al. 2010. The intestinal contents of a baby woolly mammoth (*Mammuthus primigenius* Blumenbach, 1799) from the Yuribey River (Yamal Peninsula). – Dokl. Biol. Sci. 432: 209–211.

**10:** Kosintsev, P. A. et al. 2012. Living environments and diet of the Mongochen mammoth, Gydan Peninsula, Russia. – Quatern. Int. 276–277: 253–268.

**11:** Lazarev, P. A. 1977. History of the find of the Selerikan horse carcass and of its study. – In: Skarlato, O. A. (ed.), Fauna i flora antropogena Severo-Vostoka Sibiri (Anthropogene Fauna and Flora of the Siberian Northeast). – Nauka, Leningrad, pp. 281–285 (in Russian).

**12:** Mol, D. et al. 2001. The Fishhook Mammoth: rediscovery of a woolly mammoth carcass by the CERPOLEX/Mammuthus Team, Taimyr Peninsula, Siberia. – In: Cavarretta, G. et al. (eds.), Proceedings of the 1st International Congress La Terra degli Elefanti/The World of Elephants, Rome, October 16–20, 2001. – Istituto Salesiano Pio XI., Rome, pp. 310–313.

**13:** Mol, D. et al. 2003. Discoveries of woolly mammoth, *Mammuthus primigenius* (Proboscidea: Elephantidae) and some other Pleistocene mammals on the Taimyr Peninsula. – Russ. J. Theriol. 2: 77–95.

**14:** Mol, D. et al. 2006. The Yukagir Mammoth: brief history, 14C dates, individual age, gender, size, physical and environmental conditions and storage. – Sci. Annals, Geol. School, AUTH, Special Vol. 98: 299–314.

**15:** Tolmachoff, I. P. 1929. The carcasses of the mammoth and rhinoceros found in the frozen ground of Siberia. – Trans. Am. Philos. Soc. 23: i-74b.

**16:** Tomskaya, A. I. 2000. Kormovaya baza mamonta v pozdnem pleistotsene Yakutii (The nutritive base of mammoth in the Late Pleistocene of Yakutia). – Muzei Mamonta, Yakutsk (in Russian).

**17:** Ukraintseva, V. V. 1993. Vegetation Cover and Environment of the "Mammoth Epoch" in Siberia. – Mammoth Site of Hot Springs.

**18:** Willerslev, E. et al. 2014. Fifty thousand years of Arctic vegetation and megafaunal diet. – Nature 506: 47–51.

**Table A2**. A list of well-preserved frozen carcasses of the Pleistocene and early-Holocene megaherbivores from which plant pollen/spores, macrofossils or DNA found in the gastrointestinal tract were published. Note that some of the finds refer to coprolites. Fauna specimens are arranged by their radiocarbon age (for details see Table 1). Most carcasses were found in Siberia; those from Alaska and Yukon are indicated by an asterisk (see Table A1 for details on localities).

| ID | Species | Nickname or [short name] | Pollen-spores | Macrofossils | DNA | (O) oral cavity (G) gastrointestinal (C) coprolite | References |
|---|---|---|---|---|---|---|---|
| 1 | *Bison priscus* | Rauchua Bison | x | x | | G | 19 |
| 2 | *Bison priscus* | Yukagir Bison | x | x | x | G | 19 |
| 3 | *Mammuthus primigenius* | Yuribei Mammoth | x | x | | G | 11 |
| 4 | *Mammuthus primigenius** | Alaskan Late Glacial mammoth | x | x | x | C | 12 |
| 5 | *Rangifer tarandus* | [Reindeer] | x | x | | G | 18 |
| 6 | *Mammuthus primigenius* | Finish Creek Valley Mammoth | | | x | C | 18 |
| 7 | *Mammuthus primigenius* | Mongochen Mammoth | x | x | x | G | 13, 4, 19 |
| 8 | *Mammuthus primigenius* | Yukagir Mammoth | x | x | x | G (C) | 11 |
| 9 | *Coelodonta antiquitatis* | Churapcha Rhinoceros | x | | x | G | 18 |
| 10 | *Mammuthus primigenius* | Fishhook Mammoth | x | x | | G | 18 |
| 11 | *Mammuthus primigenius* | Chekurovka Mammoth | x | | | G | 18 |
| 12 | *Equus lambei** | Yukon/Last Chance Creek Horse | | x | x | G | 1, 19 |
| 13 | *Bison priscus* | Mylakhchin Bison | x | x | | G | 7 |
| 14 | *Coelodonta antiquitatis* | Khalbugai Rhinoceros | x | | | O | 2 |
| 15 | *Bison priscus** | Blue Babe | | x | | G | 18 |
| 16 | *Coelodonta antiquitatis* | Kolyma Rhinoceros | x | | x | G | 8, 19 |
| 17 | *Equus lenensis* | Selerikan Horse | x | x | | G | 17 |
| 18 | *Mammuthus primigenius* | Kirgilyakh Mammoth (Dima) | x | x | | G | 16 |
| 19 | *Mammuthus primigenius* | Shandrin Mammoth | x | x | | G | 15, 19 |
| 20 | *Mammuthus primigenius* | Mammoth dung F-552 | x | x | | C | 3 |
| 21 | *Mammuthus primigenius* | Yuribey Baby Mammoth (Lyuba) | x | x | x | G | 14, 19 |
| 22 | *Coelodonta antiquitatis* | Vilyuy Rhinoceros | | x | | G | 19 |
| 23 | *Mammuthus primigenius* | Berezovka Mammoth | x | x | | G | 16 |
| 24 | *Stephanorhinus kirchbergensis* | Chondon Rhinoceros | | x | | O | 5 |
| 25 | *Mammuthus primigenius* | Mammoth dung F-3447 | x | x | | C | 18 |
| 26 | *Bison priscus* | [Bison] | | | x | C | 6 |
| 27 | *Mammuthus primigenius* | Drevniy Creek Mammoth | | | x | C | 9, 10 |

**References: 1:** Boeskorov et al. (2011), **2:** Garut et al. (1970), **3:** van Geel et al. (2008), **4:** van Geel et al. (2011a), **5:** van Geel et al. (2011b), **6:** van Geel et al. (2014), **7:** Guthrie (1990), **8:** Harington (2002),**9:** Kirillova et al. (2013), **10:** Kirillova et al. (2015),**11:** Kirillova et al. (2016a), **12:** Kirillova et al. (2016b), **13:** Kosintsev et al. (2010), **14:** Kosintsev et al. (2012), **15:** Lazarev & Tirskaya (1975), **16:** Mol et al. (2003), **17:** Tomskaya (2000), **18:** Ukraintseva (2013), **19:** Willerslev et al. (2014)

**References**


**1:** Boeskorov, G. G. et al. 2011. Woolly rhino discovery in the lower Kolyma River. – Quarternary Sci. Rev. 30: 2262–2272.
**2:** Garutt, V. E. et al. 1970. New data on the food of woolly rhinoceros in Siberia. – In: Tolmachev, A. N. (ed.), The Arctic Ocean and its Coast in the Pleistocene. – Gidrometeoizdat, Leningrad, pp. 113–125 (in Russian).
**3:** van Geel, B. et al. 2008. The ecological implications of a Yakutian mammoth's last meal. – Quaternary Res. 69: 361–376.
**4:** van Geel, B. et al.2011a. Palaeo-environmental and dietary analysis of intestinal contents of a mammoth calf (Yamal Peninsula, northwest Siberia). – Quaternary Sci. Rev. 30: 3935–3946.
**5:** van Geel, B. et al. 2011b. Mycological evidence of coprophagy from the feces of an Alaskan Late Glacial mammoth. – Quaternary Sci. Rev. 30: 2289–2303.
**6:** van Geel, B. et al. 2014. Multiproxy diet analysis of the last meal of an early Holocene Yakutian bison. – J. Quaternary Sci. 29: 261–268.
**7:** Guthrie, R. D. 1990. Frozen Fauna of the Mammoth Steppe: The Story of Blue Babe. – The University of Chicago Press.
**8:** Harington, C. R. 2002. Yukon horse. – Beringian Research Notes 14: 1–4.
**9:** Kirillova, I. V. et al. 2013. The first finding of a frozen Holocene bison (*Bison priscus* Bojanus, 1827) carcass in Chukotka. – Dokl. Biol. Sci. 452: 296–299.
**10:** Kirillova, I. V.et al. 2015. An ancient bison from the mouth of the Rauchua River (Chukotka, Russia). – Quaternary Res., 84: 232–245.
**11:** Kirillova, I. V. et al. 2016a. The diet and environment of mammoths in North-East Russia reconstructed from the contents of their feces. – Quatern. Int. 406: 147–161.
**12:** Kirillova, I. V. et al. 2016b. The first finding of a rhinoceros of the genus Stephanorhinus in Arctic Asia. – Dokl. Biol. Sci. 471: 300–303.
**13:** Kosintsev, P. A. et al. 2010. The intestinal contents of a baby woolly mammoth (*Mammuthus primigenius* Blumenbach, 1799) from the Yuribey River (Yamal Peninsula). – Dokl. Biol. Sci. 432: 209–211.
**14:** Kosintsev, P. A. et al. 2012. Living environments and diet of the Mongochen mammoth, Gydan Peninsula, Russia. – Quatern. Int. 276–277: 253–268.
**15:** Lazarev, P. A and Tirskaya, N. F. 1975. The remains of woolly rhino from Churapcha settlement (Central Yakutia) and spore-pollen spectrum of its deposits. – In: Tomskaya, A. I. (ed.), Palinologicheskie materially dlya stratigraphii sedimentacionnykh otlozheniy Yakutii. – Yakutsk Sci. Center Press, pp. 66–72 (in Russian).
**16:** Mol, D. et al. 2003. Discoveries of woolly mammoth, *Mammuthus primigenius* (Proboscidea: Elephantidae) and some other Pleistocene mammals on the Taimyr Peninsula. – Russ. J. Theriol. 2: 77–95.
**17:** Tomskaya, A. I. 2000. Kormovaya baza mamonta v pozdnem pleistotsene Yakutii (The nutritive base of mammoth in the Late Pleistocene of Yakutia). – Muzei Mamonta, Yakutsk (in Russian).
**18:** Ukraintseva, V. V. 2013. Mammoths and the Environment. – Cambridge University Press.
**19:** Willerslev, E. et al. 2014. Fifty thousand years of Arctic vegetation and megafaunal diet. – Nature 506: 47–51.

**Table A3.** Most frequent palaeobotanical taxa recorded in the frozen fauna using pollen + spore analysis. Frequency refers to the number of carcasses in which the taxon was found.

| Taxon | Species | Genus | Family | Frequency |
|---|---|---|---|---|
| *Artemisia* | . | *Artemisia* | Asteraceae | 20 |
| *Poaceae* | . | . | Poaceae | 20 |
| *Cyperaceae* | . | . | Cyperaceae | 18 |
| *Salix* | . | *Salix* | Salicaceae | 17 |
| *Caryophyllaceae* | . | . | Caryophyllaceae | 17 |
| *Ranunculaceae* | . | . | Ranunculaceae | 14 |
| *Rosaceae* | . | . | Rosaceae | 12 |
| *Asteraceae* | . | . | Asteraceae | 12 |
| *Brassicaceae* | . | . | Brassicaceae | 11 |
| *Chenopodiaceae/Amaranthaceae* | . | . | Amaranthaceae | 11 |
| *Apiaceae* | . | . | Apiaceae | 11 |
| *Betula* | . | *Betula* | Betulaceae | 11 |
| *Sphagnum* | . | *Sphagnum* | Sphagnaceae | 10 |
| *Larix* | . | *Larix* | Pinaceae | 9 |
| *Betula nana* | *Betula nana* | *Betula* | Betulaceae | 9 |
| *Ericaceae* | . | . | Ericaceae | 8 |
| *Alnus* | . | *Alnus* | Betulaceae | 8 |
| *Potentilla* | . | *Potentilla* | Rosaceae | 8 |
| *Valeriana capitata* | *Valeriana capitata* | *Valeriana* | Caprifoliaceae | 8 |
| *Polygonaceae* | . | . | Polygonaceae | 8 |
| *Fabaceae* | . | . | Fabaceae | 8 |
| *Picea* | . | *Picea* | Pinaceae | 8 |
| *Duschekia fruticosa* | *Duschekia fruticosa* | *Duschekia* | Betulaceae | 8 |
| *Polemonium* | . | *Polemonium* | Polemoniaceae | 7 |
| *Sanguisorba officinalis* | *Sanguisorba officinalis* | *Sanguisorba* | Rosaceae | 7 |
| *Equisetum* | . | *Equisetum* | Equisetaceae | 7 |
| *Ranunculus* | . | *Ranunculus* | Ranunculaceae | 7 |
| *Selaginella rupestris* | *Selaginella rupestris* | *Selaginella* | Selaginellaceae | 7 |
| *Polypodiaceae* | . | . | Polypodiaceae | 7 |
| *Pinus* | . | *Pinus* | Pinaceae | 6 |
| *Alnus hirsuta* | *Alnus hirsuta* | *Alnus* | Betulaceae | 6 |
| *Saxifraga* | . | *Saxifraga* | Saxifragaceae | 6 |
| *Papaver* | . | *Papaver* | Papaveraceae | 6 |
| *Pinus sibirica* | *Pinus sibirica* | *Pinus* | Pinaceae | 6 |

**Table A3.** Continuation.

| Taxon | Species | Genus | Family | Frequency |
|---|---|---|---|---|
| *Pinus pumila* | *Pinus pumila* | *Pinus* | Pinaceae | 6 |
| *Valeriana* | . | *Valeriana* | Caprifoliaceae | 5 |
| *Liliaceace* | . | . | Liliaceace | 5 |
| *Stellaria* | . | *Stellaria* | Caryophyllaceae | 5 |
| *Polemonium boreale* | *Polemonium boreale* | *Polemonium* | Polemoniaceae | 5 |
| *Rumex acetosa* | *Rumex acetosa* | *Rumex* | Polygonaceae | 5 |
| *Cichorioideae* | . | . | Asteraceae | 5 |
| *Lycopodium* | . | *Lycopodium* | Lycopodiaceae | 5 |
| *Plantago* | . | *Plantago* | Plantaginaceae | 5 |
| *Carex* | . | *Carex* | Cyperaceae | 5 |
| *Bistorta vivipara* | *Bistorta vivipara* | *Bistorta* | Polygonaceae | 5 |
| *Betula humilis* | *Betula humilis* | *Betula* | Betulaceae | 5 |
| *Pinus sylvestris* | *Pinus sylvestris* | *Pinus* | Pinaceae | 5 |

**Table A4.** Most frequent palaeobotanical taxa recorded in the frozen fauna using macrofossil analysis. Frequency refers to the number of carcasses in which the taxon was found.

| Taxon | Species | Genus | Family | Frequency |
|---|---|---|---|---|
| *Poaceae* | . | . | Poaceae | 18 |
| *Carex* | . | *Carex* | Cyperaceae | 15 |
| *Salix* | . | *Salix* | Salicaceae | 15 |
| *Cyperaceae* | . | . | Cyperaceae | 12 |
| *Betula* | . | *Betula* | Betulaceae | 8 |
| *Poa* | . | *Poa* | Poaceae | 8 |
| *Alnus* | . | *Alnus* | Betulaceae | 7 |
| *Caryophyllaceae* | . | . | Caryophyllaceae | 7 |
| *Polytrichum* | . | *Polytrichum* | Polytrichaceae | 7 |
| *Betula nana* | *Betula nana* | *Betula* | Betulaceae | 6 |
| *Festuca* | *Festuca* | *Festuca* | Poaceae | 6 |
| *Larix* | . | *Larix* | Pinaceae | 6 |
| *Sphagnum* | . | *Sphagnum* | Sphagnaceae | 6 |
| *Comarum palustre* | *Comarum palustre* | *Comarum* | Rosaceae | 5 |
| *Brassicaceae* | . | . | Brassicaceae | 5 |
| *Duschekia fruticosa* | *Duschekia fruticosa* | *Duschekia* | Betulaceae | 5 |
| *Ericaceae* | . | . | Ericaceae | 5 |
| *Eriophorum* | . | *Eriophorum* | Cyperaceae | 5 |
| *Potentilla* | . | *Potentilla* | Rosaceae | 5 |

**Table A5.** Validation of the new method of the similarity-based sample assignment to vegetation type. We tested if the current vegetation plot of a given vegetation type will be most similar to this original vegetation type or another one. The values in the matrix are counts of plots originally assigned to a vegetation type (rows) that were most similar to the tested vegetation types (columns) or vegetation type groups (colours). Numbers on the diagonal indicate plots correctly assigned to the same vegetation type.

| | | | **Tested vegetation types: number of plots which were most similarto the given vegetation type** | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | | |
| | | Number of plots (original assignment) | Blackish taiga | Hemiboreal forest | Taiga | Alluvial forest and scrub | Fen and swamp woodland | Bog | Open fen | Arctic or alpine deciduous scrub | Arctic or alpine heathland | Tundra grassland | *Betula nana* s.l. scrub | Tall forbs | Saline grassland | Marsh | Wet meadow | Mesic meadow | Dry meadow | Steppe scrub | Meadow-steppe | Dry steppe | Desert steppe | Semi-desert | Desert | **Plots classified correctly to the original type [%]** | **Plots classified correctly to the original group [%]** |
| **Original expert classification of plots** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | Blackish taiga | 75 | 59 | 12 | 1 | 3 | | | | | | | | | | | | | | | | | | | | 78.7 | 78.7 |
| 2 | Hemiboreal forest | 278 | 8 | 229 | 12 | 3 | | | | | | 3 | | | | | | 1 | 1 | 7 | 11 | 3 | | | | 82.4 | 86.1 |
| 3 | Taiga | 204 | 5 | 65 | 111 | | 4 | 2 | | | 10 | 1 | 6 | | | | | | | | | | | | | 54.4 | |
| 4 | Alluvial forest and scrub | 41 | 3 | 14 | 1 | 18 | 2 | | | | | | | | 1 | | | | 2 | | | | | | | 43.9 | |
| 5 | Fen and swamp woodland | 51 | 2 | 11 | 13 | 9 | 2 | 10 | 1 | | 1 | | | | | | 2 | | | | | | | | | 3.9 | |
| 6 | Bog | 65 | | 1 | 7 | | | 35 | 1 | 1 | 16 | | 4 | | | | | | | | | | | | | 53.8 | 56.0 |
| 7 | Open fen | 117 | | | 1 | 3 | 7 | 8 | 58 | 11 | 17 | 2 | 4 | | | 2 | 4 | | | | | | | | | 49.6 | |
| 8 | Arctic or alpine decid. scrub | 42 | 1 | 1 | 1 | 1 | | | 2 | 20 | 6 | 2 | 5 | 1 | | | 2 | | | | | | | | | 47.6 | 79.2 |
| 9 | Arctic or alpine heathland | 93 | | 1 | 2 | | 1 | 2 | 1 | | 76 | 2 | 8 | | | | | | | | | | | | | 81.7 | |
| 10 | Tundra grassland | 114 | | 2 | 3 | | | | 5 | 2 | 28 | 57 | 7 | 1 | | | 5 | | | | 3 | 1 | | | | 50.0 | |
| 11 | *Betula nana* s.l. scrub | 54 | | 5 | 7 | | | | | 2 | 8 | 7 | 25 | | | | | | | | | | | | | 46.3 | |
| 12 | Tall forbs | 38 | 6 | 6 | 3 | 5 | | | | | | 3 | | 10 | | | 4 | | | | 1 | | | | | 26.3 | |
| 13 | Saline grassland | 212 | | 1 | | 1 | 1 | | | | | 3 | | | 110 | | 13 | 7 | 53 | | 5 | 7 | | | 11 | 51.9 | 51.9 |
| 14 | Marsh | 217 | | 1 | | 19 | 22 | | 1 | | | | | | 2 | 132 | 40 | | | | | | | | | 60.8 | 60.8 |
| 15 | Wet meadow | 223 | 1 | 20 | | 12 | 3 | | 2 | 5 | 1 | 7 | | | 2 | 5 | 152 | 3 | 5 | | 5 | | | | | 68.2 | 64.9 |
| 16 | Mesic meadow | 76 | | 5 | | | | | | | | 3 | | | 1 | | 9 | 30 | 18 | | 9 | 1 | | | | 39.5 | |
| 17 | Dry meadow | 88 | | 2 | | | | | | | 1 | | | | | | 5 | 3 | 56 | | 21 | | | | | 63.6 | 92.4 |
| 18 | Steppe scrub | 75 | | 11 | | | | | | | | 1 | | | | | | | | 6 | 30 | 27 | | | | 8.0 | |
| 19 | Meadow-steppe | 267 | | 20 | | | | | | | | 5 | 1 | | | | 1 | 3 | 24 | 1 | 176 | 36 | | | | 65.9 | |
| 20 | Dry steppe | 416 | | 4 | | 7 | | | | | | 2 | | | | | | | 26 | 3 | 85 | 287 | 2 | | | 69.0 | |
| 21 | Desert steppe | 50 | | | | | | | | | | | | | 1 | | | | | | 1 | 42 | 5 | | 1 | 10.0 | |
| 22 | Semi-desert | 17 | | 1 | | 1 | | | | | | | | | | | | | | 2 | 2 | 8 | 1 | | 2 | 0.0 | 32.6 |
| 23 | Desert | 26 | | | | | | | | | | | | | | | | | | | 6 | 9 | | | 11 | 42.3 | |