Tuexenia 39: 139–160. Göttingen 2019.
doi: 10.14471/2019.39.003, available online at www.tuexenia.de

Syntaxonomy of forest vegetation of the central zone of the Lake Baikal eastern coast

Syntaxonomie der Waldvegetation im zentralen Bereich des Ostufers des Baikalsees

Elena Brianskaia[1,*], Klaus Schmieder[2], Reinhard Boecker[2], Ayur Gyninova[1] & Larisa Balsanova[1]

[1]*Institute of General and Experimental Biology of Siberian Branch of Russian Academy of Sciences, Sakhyanovoy str. 6, 670047 Ulan-Ude, Russia;*
[2]*Hohenheim University, Institute of Landscape and Plant Ecology (320), August-von-Hartmann str. 3, 70599 Stuttgart, Germany*
**Corresponding author, e-mail: blenysik@mail.ru*

Abstract

The object of this study are the forest ecosystems in the central zone at the eastern coast of Lake Baikal. In total, 98 relevés were collected according to the Braun-Blanquet approach. To identify forest vegetation types based on floristic composition a relatively new method, supervised k-means clustering was performed. By comparing the original vegetation data from the studied area with data from the adjacent territories, such as Svyatoy Nos Peninsula and the Barguzinskiy mountain range, the final prodromus of forest vegetation types was obtained. Six associations and two communities are attributed to the class of boreal coniferous forests *Vaccinio-Piceetea* Br.-Bl. in Br.-Bl. et al. 1939. The forest vegetation demonstrates prominent changes along the altitudinal gradient, which corresponds to the specific humid Baikal type of altitudinal zonation. Higher altitudes are occupied by the sub-belt of the dark coniferous forest belonging to ass. *Calamagrostio obtusatae-Abietetum sibiricae* Danihelka et al. in Anenkhonov et Chytrý 1998. At the medium altitudes mixed coniferous-deciduous forests of ass. *Calamagrostio obtusatae-Laricetum sibiricae* Chytrý et al. in Anenkhonov et Chytrý 1998 are represented. Near the shoreline of Lake Baikal, the sub-belt of the siberian pine coniferous forest *Maianthemo bifolii-Pinetum sibiricae* Danihelka et al. in Anenkhonov et Chytrý 1998 occurs. The association *Calamagrostio epigei-Pinetum sylvestris* Anenkhonov et Chytrý 1998 is considered as a post-fire succession community. The supervised k-means clustering method can be highly recommended for phytosociological classification of vegetation due to reliability of the results.

Keywords: Braun-Blanquet approach, Eastern Siberia, forest plant communities, JUICE, relevés, supervised k-means clustering

Erweiterte deutsche Zusammenfassung am Ende des Artikels

1. Introduction

During the past decades, along with global computerization, more formalized statistical approaches have been increasingly applied for obtaining an objective phytosociological classification of studied vegetation (HILL 1979, TICHÝ & HOLT 2006, OKSANEN et al. 2007).

Manuscript received 12 June 2018, accepted 18 January 2019
Co-ordinating Editor: Norbert Hölzel

Currently, the most widely applied approaches for phytosociological data analysis are unsupervised classifications. One of them is TWINSPAN, which partitions data along the main compositional gradients (HILL 1979, ROLEČEK et al. 2009). Commonly, obtained results are followed by a routine interpretation, such as comparing the obtained clusters with the literature, the identification and naming of new clusters, and the classification of them according to phytosociological hierarchy. However, the main disadvantage of such an unsupervised approach are changes, which may appear after rerunning the classification with newly added relevés into a dataset (BRUELHEIDE & CHYTRÝ 2000). Normally, phytosociologists explore large areas for a long period of time, which leads to an annual addition of new relevés into their datasets. Due to these entangling changes, supervised approaches are becoming increasingly popular among phytosociologists (AL-HARBI & RAYWARD-SMITH 2006, FINLEY & JOACHIMS 2008, VAN TONGEREN et al. 2008, ČERNÁ & CHYTRÝ 2009, TICHÝ et al. 2014). The rapidly increasing attractiveness of supervised techniques has to do with the specific classification process, which assigns new unidentified vegetation data to a priori classified vegetation units (ČERNÁ & CHYTRÝ 2009, CÁCERES et al. 2010, TICHÝ et al. 2014, GAVILÁN et al. 2017).

By this study, we give an example for the application of such supervised technique, namely k-means clustering, for forests near Lake Baikal in the central zone of the eastern coast. Phytosociological studies of forests in the Baikal region are given in a considerable number of scientific publications (KRASILNIKOV 1937, POVARITSYN 1937, TYULINA 1954, 1976, EPOVA 1960, BUZYKIN 1969, MOLOZNIKOV 1974, 1986, PESHKOVA 1985, CHYTRÝ et al. 1993, 1995, DANIHELKA & CHYTRÝ 1995, ANENKHONOV & CHYTRÝ 1998, ERMAKOV 2001, VALACHOVIČ et al. 2002, ANENKHONOV 2015). However, despite the big amount of data about Baikal Siberian vegetation, there is a lack of published information related to the territory of our interest. The central zone of Lake Baikal on the eastern coast represents the gap in the present phytosociological knowledge and no detailed information about the forest vegetation composition and distribution has been published so far. Consequently, this paper aims (1) to study the composition of forest vegetation in the central zone of Lake Baikal eastern coast from phytosociological perspective, and (2) to see whether the floristic composition and distribution of woody plant communities is similar to adjacent well-studied areas on the eastern coast. In order to achieve the aim, we applied the supervised k-means clustering method by comparing the vegetation data from our own study (~430 km^2) with the data from the adjacent territories, such as Svyatoy Nos Peninsula (~600 km^2; ANENKHONOV & CHYTRÝ 1998) and the Barguzinskiy mountain range (22 km transect in Bolshaja Cheremshana Valley; 13 km transect in Gremyachaya Valley; CHYTRÝ et al. 1995, DANIHELKA & CHYTRÝ 1995, VALACHOVIČ et al. 2002).

2. Study area

2.1 Location

The territory under study is located in south-eastern Siberia, in the central zone of Lake Baikal eastern coast (Fig. 1). Administratively, the territory belongs to Pribaikal'skiy and Barguzinskiy districts (Republic of Buryatia, Russia) and lies between villages of Goryachinsk (52° 59′ 03″ N; 108° 17′ 48″ E) and Maksimikha (53° 15′ 51″ N; 108° 44′ 22″ E).

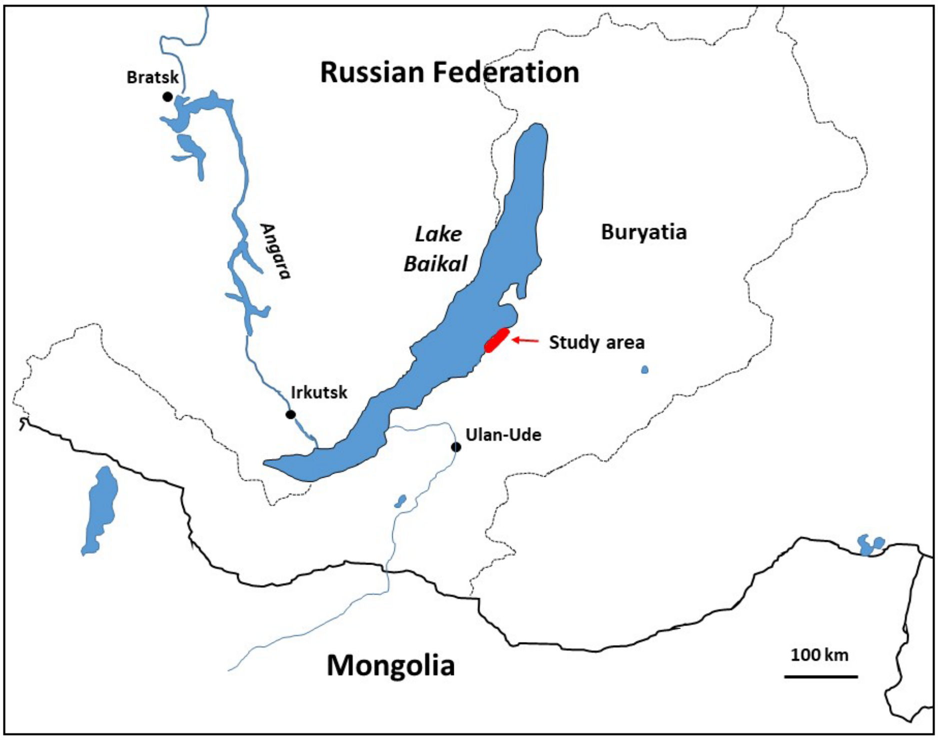

Fig. 1. Location of the study area on the eastern shore of Lake Baikal.

Abb. 1. Lage des Untersuchungsgebietes am Ostufer des Baikalsees.

2.2 Climate

Eastern Siberia is predominantly characterized by continental climate features. The climate of Baikal area is determined by the distance from the oceans, the elevation above sea level, and the complex landscape structure (PRONIN & UBUGUNOV 2013). In comparison with the areas at the same latitudes, Eastern Siberia differs by the coldest winter, the warmest summer, and the lowest amount of precipitation (ALISOV 1956). However, Lake Baikal mitigates continentality, in terms of smoothening temperature amplitudes and increasing humidity. (TYULINA 1976). According to climatic zonation of Baikal coastal areas, the studied area belongs to the Central climatic zone, which is characterized by moderately cold summer (mean July +13 °C) and relatively warm winter (mean January -18.7 °C); the duration of a frostless period is 70–80 days; the precipitation increases from 547 mm at the coast to 700–800 mm – in the mountains (LADEISHCHIKOV 1982). In winter, the amount of precipitation influences the thickness of snowpack which diminishes the depth soil freezing with increasing altitude. As a result, dark-coniferous forests find suitable conditions at altitudes of 900–1200 m a.s.l. These combinations of temperature and precipitation features form the specific humid Baikal type of vegetation zonation (TYULINA 1976). The studied territory has an island distribution of permafrost (10–15% of the area, from 1m to 50 m deep) within the Baikal geokryological zone (ERSHOV 1989).

2.3 Landform

Morphologically, the studied area is divided in two parts. The first one is the western part located in the vicinity of Goryachinsk village. This area comprises the western relatively gentle slope of low altitudinal mountain Chernaya Griva predominantly covered by forest. The plain landform is complicated by peaty valleys of the Cheremshanka and Talovka rivers. The second part of the area includes the Katkovskaya mountain range. The range is low and medium altitudinal with maximal elevation of 1306 m. It has relatively flat and gently dome-shaped summits, which were flattered in the course of long-term denudation. The slopes exposed to open Baikal are slightly steep; however, they do not form rocky ledges. There are no valleys that cut the mountain of Katkovskaya range; however, it has a net of creeks flowing into the intermountain basins. The parent material of the Katkovskaya range is early Paleozoic intrusions of Vitimkanskiy complex composed by fine and medium-grained leucocratic and biotitic granites and granosyenites (PRONIN & UBUGUNOV 2013).

2.4 Soils

Weathering products of granites and granosyenites are the main material of Baikal Siberian soils (TSYBZHITOV & UBUGUNOVA 1992). Granite bedrock is characterized by low content of Mg^{2+}, acidic pH, high drainage properties and considerable accumulation of ferrous oxide and aluminum compounds (SOKOLOV 1978).

Baikal Siberian forest soils have altitudinal distribution pattern (TSYBZHITOV & UBUGUNOVA 1992). Within the studied area, at the higher altitudes active exogenous and endogenous processes take place, which prevent the formation of full-profile soils and contribute to the formation of weakly-developed stony profiles from the coarse weathering materials of parent rock (KOPOSOV 1983, GLADKOV 1985). Such soils are usually rich in nutrients, well-drained and occupied by Siberian fir forests. At the medium altitudes, typical brown soils are developed under mixed coniferous forests. Rich loamy brown soils of Baikal Siberia contribute to the abundance of tall grasses, e.g. *Calamagrostis obtusata*. At the lowest altitudes oligotrophic sandy podzolic soils are formed. Such soils are the result of poor accumulation of organic matter in the topsoil due to the high abundance of fruticose lichens and groundcover dwarf shrubs. Within Baikal Siberia, *Pinus sylvestris* is confined to such sandy oligotrophic soils (PESHKOVA 1985).

3. Materials and Methods

3.1 Data Collection

98 relevés were collected during summer seasons of 2013, 2015 and 2016. Vegetation plots were selected by the author (E. Brianskaia) based on field observation. We covered the studied territory by the even net of routes. Itinerary was planned in a manner to cover a wide variety of habitats. In the mountain range transects were done along the altitudinal gradient to track the vegetation changes at the different altitudes. Relevés were described on quadrat plots of 900 m^2 (WESTHOFF & VAN DER MAAREL 1973, CHYTRÝ & OTÝPKOVÁ 2003). We recorded all species of vascular plants, ground-dwelling bryophytes and macro-lichens, and used seven-degree cover abundance scale – r: < 1%, +: 1–4%, 1: 5–9%, 2: 10–24%, 3: 25–49%, 4: 50–74%, 5: 75–100% (WESTHOFF & VAN DER MAAREL 1973).

3.2 Supervised k-means clustering

3.2.1 Software

The classification was performed in JUICE program (http://www.sci.muni.cz/botany/juice/) by means of the built-in R script (R-studio version 2.14.0; https://cran.r-project.org), which is available as **.txt* file in JUICE (TICHÝ 2002, ZELENÝ & TICHÝ 2009).

3.2.2 Data Preparation

Commonly, supervised clustering methods require the fixed number of clusters which have been segmented by different data attributes (AL-HARBI & RAYWARD-SMITH 2006, FINLEY & JOACHIMS 2008, TICHÝ et al. 2014). For supervised k-means clustering method we used one unidentified group 0, which is represented by 98 relevés from the current study and 65 a priori groups (phytosociological associations), including 589 relevés from Svyatoy Nos Peninsula (ANENKHONOV & CHYTRÝ 1998) and Barguzinskiy mountain range (CHYTRÝ et al. 1995, DANIHELKA & CHYTRÝ 1995, VALACHOVIČ et al. 2002), which were provided by Prof. Dr. Milan Chytrý from his personal archive.

All the relevés were stored in TURBOVEG program (Russian checklist; HENNEKENS & SCHAMINÉE 2001) and transported as a standard *.xml file to JUICE program (TICHÝ 2002). In JUICE for supervised k-means clustering, all values in short header higher than 0 are accepted as a priori groups and a group with 0 value is subjected to the classification (TICHÝ 2002). So that, in order to count, define and label a priori clusters we used the eight color pallet tool in JUICE. The process was a routine coloring of each a priori group and sequential labeling of them by a number in the short header. Hence, we obtained 65 a priori groups. 98 plots from classified group 0 were colored in red for better distinction within the whole dataset after running the classification.

3.2.3 Algorithm

In the current study the input data for supervised k-means clustering represent *65 a priori* and one unidentified groups. The algorithm starts by placing the *k* centroids randomly in hyperspace (TICHÝ et al. 2014). Three plots of each of *65 a priori* groups were defined as centroids. The clustering starts when each unidentified plot from the current study finds its nearest centroid based on the Euclidean distance (Hellinger transformation in JUICE) and assigns to it. Thus, 98 relevés of the current study assign to the most similar plots of *65 a priori* clusters. The algorithm continues until the centroid has come to the mean of all plots assigned to it and no plots have changed their cluster assignment (LAVRENKO 2014).

3.2.4 Data Extraction

All classified 98 red-colored relevés were extracted from the dataset and interpreted by their assignment to a matching association from Svyatoy Nos Peninsula and Barguzinskiy mountain range. The obtained results of k-means clustering were the basis for building the final synopsis of the forest vegetation of the central zone of Lake Baikal eastern coast according to the Braun-Blanquet approach (WESTHOFF & VAN DER MAAREL 1973).

3.3 Identification of Diagnostic Species

In our classification, we used the term diagnostic species as a definition of the most faithful species of specific phytosociological units, which exceed a certain fidelity threshold. Diagnostic species of an association were identified by means of phi-coefficient, which is defined as "a statistical measure of association between two categories, which can be used as a two-sided measure of fidelity" (CHYTRÝ et al. 2002). Application of phi-coefficient has advantages over other fidelity measures. First of all, this coefficient calculates only presence/absence data; consequently, species cover or abundance values do not affect the results. Secondly, phi-coefficient is independent of the dataset size and the size of phytosociological clusters within the dataset (CHYTRÝ et al. 2002). Typically, a fidelity threshold is determined arbitrary by experts. A literature review revealed that the most frequent and applied fidelity threshold values for diagnostic species of association unit falls within 0.15 to 0.25 and depends on the dataset size. In our study, we aim to obtain the list of the most faithful robust diagnostic species. Hence, we set 0.25 as a threshold value for the diagnostic species of an association unit. In the "Results" chapter for each classified association the list of diagnostic species is provided with layer information in square brackets and bold typed are those, which exceed fidelity threshold > 50%.

3.4 Sharpness

Sharpness index was measured for associations in JUICE program. Sharpness represents the proportion or quality of diagnostic species relative to the average species number of a vegetation cluster (CHYTRÝ & TICHÝ 2003). The range of sharpness lies within 0 and ∞. An association can be defined sharp if it possesses a large number of diagnostic species with a high fidelity capacity (phi-coefficient) to the average number of species in a specific phytosociological unit.

4. Results

The results of supervised k-means clustering reveal the assignment of 98 unidentified plots to six forest associations of Baikal Siberia. Based on the constructed syntaxonomy of Svyatoy Nos Peninsula and Barguzinskiy mountain range vegetation, the synopsis of the central zone of Lake Baikal eastern coast is built.

Synopsis

Vaccinio-Piceetea Br.-Bl. in Br.-Bl. et al. 1939
- *Pinetalia sylvestris* Oberd. 1957
  - *Hieracio umbellati-Pinion sylvestris* Anenkhonov et Chytrý 1998
    - *Calamagrostio epigei-Pinetum sylvestris* Anenkhonov et Chytrý 1998
- *Ledo palustris-Laricetalia cajanderi* Ermakov in Ermakov et Alsynbaev 2004
  - *Pino sibiricae-Laricion sibiricae* Guinochet ex Dostalek et al. 1988
    - *Calamagrostio obtusatae-Abietetum sibiricae* Danihelka et al. in Anenkhonov et Chytrý 1998
      - *Pinus pumila-Abies sibirica* community
      - *Brachypodium pinnatum-Abies sibirica* community
    - *Calamagrostio obtusatae-Laricetum sibiricae* Chytrý et al. in Anenkhonov et Chytrý 1998
    - *Maianthemo bifolii-Pinetum sibiricae* Danihelka et al. in Anenkhonov et Chytrý 1998
- *Piceo obovatae-Pinetalia sibiricae* Ermakov 2013
  - *Aconito rubicundi-Abietion sibiricae* Anenkhonov et Chytrý 1998
    - *Cardamino macrophyllae-Abietetum sibiricae* Chytrý et al. in Anenkhonov et Chytrý 1998
    - *Matteuccio struthiopteridis-Abietetum sibiricae* Anenkhonov et al. in Anenkhonov et Chytrý 1998

4.1 Overview of plant communities

1. *Calamagrostio epigei-Pinetum sylvestris* Anenkhonov et Chytrý 1998 (Table 1, Cluster 1, Fig. 2a–b)

Diagnostic species: *Pinus sylvestris* [1]; ***Rhododendron dauricum*** [5]; *Antennaria dioica* [6], ***Arctostaphylos uva-ursi*** [6], ***Astragalus membranaceus*** [6], *A. propinquus* [6], *Pulsatilla turczaninovii* [6]; *Cladonia amaurocraea* [9], ***C. arbuscula*** [9], *C. deformis* [9], ***C. stellaris*** [9].

All relevés were collected near Goryachinsk village, on the plain part of the area (470–520 m). Communities of *Calamagrostio epigei-Pinetum sylvestris* represent oligotrophic xerophytic mostly monodominant stands of scots pine (*P. sylvestris*) on sandy soil. The physiognomy of *P. sylvestris* is an important indicator of oligotrophic substrate conditions. Commonly, trees of *P. sylvestris* are rather low (up to 10 m), young-aged and cover up to 80% of the total area.

In some areas, additionally *Pinus sibirica*, *Betula pendula* and *Larix sibirica* grow with low frequency and coverage. In the shrub layer, *R. dauricum* is the most abundant, occurring in each relevé with a coverage up to 60%. *Alnus alnobetula* subsp. *fruticosa* and *Ledum palustre* are less frequent and abundant. The herb layer is characterized by frequent evergreen ericaceous meso-xerophilous dwarf shrubs such as *A. uva-ursi*, *Vaccinium vitis-idaea*, and xerophylous herbs such as *A. membranaceus*, *A. propinquus*, *A. dioica*, *Allium splendens*, and *P. turczaninovii*. The ground layer is formed by lichens and mosses: fruticose lichens which might be considered as pioneer species of post-fire succession, namely *C. stellaris* (coverage up to 80%), *C. arbuscula* (up to 60%), *C. amaurocraea* (up to 40%), *C. deformis* (< 20%); mosses include typical mesophytic taiga species such as *Dicranum polysetum* (< 10%) and *Pleurozium schreberi* (< 5%). In the ecotone areas, *Rhytidium rugosum* and *Polytrichum commune* occasionally occur.

2. *Calamagrostio obtusatae-Abietetum sibiricae* Danihelka et al. in Anenkhonov et Chytrý 1998 (Table 1, Cluster 3, Fig. 2c–d)

Diagnostic species: *Abies sibirica* [1], *Populus tremula* [1]; ***Bergenia crassifolia*** [6], *Brachypodium pinnatum* [6], *Calamagrostis obtusata* [6], *Gymnocarpium dryopteris* [6], *Lilium martagon* [6], *Linnaea borealis* [6], *Maianthemum bifolium* [6], *Pinus pumila* [6], *Polypodium sibiricum* [6]; ***Hylocomium splendens*** [9].

The communities of this association are mesophytic dark-coniferous taiga forests with the dominance of *A. sibirica* and *Pinus sibirica* (20–30 m) in the tree layer; in some areas, they are mixed with *P. tremula* and *Betula pendula*. All of these communities are found in the upper part of the mountain range – 600(700)–1100 m a.s.l. They occupy steep and gentle (15–17°) slopes and grow on well-drained poorly developed rocky soils. The species composition of this association is highly similar to the *Calamagrostio obtusatae-Laricetum sibiricae*. However, the most distinctive feature of these forests is a dense canopy, in which tree coverage reaches about 70%. The shrub layer is poorly represented. Tall shrubs, *Alnus alnobetula* subsp. *fruticosa*, *Sorbus sibirica* and *Lonicera pallasii*, occur sparsely and form isolated patches. In the herb layer, *B. crassifolia, C. obtusata* and *L. borealis* are dominant.

Table 1. Synoptic table of the forest communities of the central zone of the Lake Baikal eastern coast. *1, 3 – tree layer; 4, 5 – shrub layer; 6 – ground layer; 9 – moss/lichen layer.

Tabelle 1. Synoptische Tabelle der Waldgesellschaften der zentralen Zone der Ostküste des Baikalsees. *1, 3 – Baumschicht; 4, 5 – Strauchschicht; 6 – Krautschicht; 9 – Moos-/Flechtenschicht.

Cluster			1	2	3	4	5	6
Number of relevés			11	43	25	12	3	4
	layer*	freq.						
Ass. *Calamagrostio epigei-Pinetum sylvestris*								
Arctostaphylos uva-ursi	6	10	76.1	---	---	---	---	---
Cladonia stellaris	9	14	72.0	---	---	7.0	---	---
Cladonia arbuscula	9	4	56.8	---	---	---	---	---
Astragalus membranaceus	6	4	56.8	---	---	---	---	---
Cladonia amaurocraea	9	5	49.2	---	---	1.5	---	---
Astragalus propinquus	6	3	36.3	---	---	---	---	---
Pulsatilla turczaninovii	6	11	29.6	12.1	---	---	---	---
Cladonia deformis	9	1	27.7	---	---	---	---	---
Antennaria dioica	6	1	27.7	---	---	---	---	---
Ass. *Calamagrostio obtusatae-Laricetum sibiricae*								
Rosa acicularis	6	39	---	42.2	7.8	---	9.2	---
Poa nemoralis	6	16	---	40.5	8.7	---	---	---
Alnus alnobetula ssp. *fruticosa*	4	41	---	40.1	---	---	4.2	---
Rhytidium rugosum	9	29	2.1	33.5	13.9	---	---	---
Milium effusum	6	21	---	31.0	18.7	---	---	---
Ptilium crista-castrensis	9	24	---	30.6	8.2	14.7	---	---
Pyrola incarnata	6	26	---	29.2	12.8	---	19.1	---
Chamaenerion angustifolium	6	4	---	28.1	---	---	---	---
Polytrichum juniperinum	9	9	---	27.8	9.0	---	---	---
Ass. *Calamagrostio obtusatae-Abietetum sibiricae*								
Calamagrostis obtusata	6	21	---	29.1	31.7	---	---	---
Bergenia crassifolia	6	36	---	12.0	63.6	---	---	---
Hylocomium splendens	9	18	---	---	61.0	---	---	---
Linnaea borealis	6	34	---	22.8	46.0	---	---	---
Polypodium sibiricum	6	3	---	---	31.9	---	---	---
Brachypodium pinnatum	6	4	---	---	28.2	---	---	---
Gymnocarpium dryopteris	6	11	---	16.1	27.8	---	---	---
Pinus pumila	6	2	---	---	26.0	---	---	---
Ass. *Maianthemo bifolii-Pinetum sibiricae*								
Empetrum nigrum	6	14	---	---	---	83.7	---	---
Ledum palustre	6	24	---	---	---	81.8	---	---
Polytrichum commune	9	24	---	2.0	---	58.4	---	---
Vaccinium uliginosum	6	7	---	---	---	56.9	---	---
Ass. *Cardamino macrophyllae-Abietetum sibiricae*								
Cardamine macrophylla	6	5	---	---	---	---	77.5	25.8
Aconitum rubicundum	6	12	---	---	---	---	77.4	---
Bromopsis austrosibirica	6	5	---	---	---	---	74.1	---
Veratrum lobelianum	6	8	---	---	---	---	65.6	---
Agrostis stolonifera	6	2	---	---	---	---	79.1	---
Carex vesicaria	6	5	---	---	---	---	77.5	25.8
Equisetum arvense	6	6	---	---	---	---	50.6	32.2

Cluster			1	2	3	4	5	6
Number of relevés			11	43	25	12	3	4
	layer*	freq.						
Poa supina	6	3	---	---	---	---	63.9	12.1
Urtica dioica	6	3	---	---	---	---	63.9	12.1
Ass. *Matteuccio struthiopteridis-Abietetum sibiricae*								
Matteuccia struthiopteris	6	4	---	---	---	---	---	100.0
Poa raduliformis	6	4	---	---	---	---	---	100.0
Cirsium helenioides	6	4	---	---	---	---	---	100.0
Poa pratensis	6	5	---	---	---	---	---	97.7
Athyrium filix-femina	6	5	---	---	---	---	---	97.7
Salix rhamnifolia	4	3	---	---	---	---	---	84.5
Persicaria hydropiper	6	3	---	---	---	---	---	84.5
Urtica sondenii	6	3	---	---	---	---	---	84.5
Sambucus sibirica	5	3	---	---	---	---	---	84.5
Cacalia hastata	6	5	---	---	---	---	12.0	83.7
Ribes nigrum	6	9	---	---	---	---	8.5	77.4
Equisetum fluviatile	6	2	---	---	---	---	---	67.4
Poa palustris	6	2	---	---	---	---	---	67.4
Carex rhynchophysa	6	4	---	---	---	---	17.8	66.2
Calamagrostis langsdorffii	6	2	---	---	---	---	---	43.9
Class *Vaccinio-Piceetea*								
Pinus sylvestris	1	80	29.8	23.1	---	21.7	---	---
Larix sibirica	1	63	---	28.6	11.5	32.4	---	---
Abies sibirica	1	54	---	---	42.1	---	42.1	---
Pinus sibirica	1	64	---	16.6	15.0	43.6	---	---
Populus tremula	1	64	---	35.3	27.8	---	---	23.4
Betula pendula	1	64	---	28.4	---	35.5	13.1	---
Rhododendron dauricum	5	48	57.1	29.3	---	18.7	---	---
Sorbus sibirica	4	31	---	4.3	17.0	---	35.2	---
Maianthemum bifolium	6	46	---	29.8	31.7	13.4	---	---
Vaccinium vitis-idaea	6	68	6.7	37.0	8.0	32.5	---	---
Pleurozium schreberi	9	64	---	34.9	19.2	29.1	---	---
Dicranum polysetum	9	56	16.9	7.8	13.7	42.1	---	---
Other species								
Galium boreale	6	25	---	20.7	22	---	18.8	---
Lathyrus humilis	6	22	---	18.4	3.5	---	19.3	---
Rubus saxatilis	6	18	---	15.2	13.2	---	25.3	---
Lilium martagon	6	16	---	25.5	26.8	---	---	---
Vicia cracca	6	13	---	6.1	---	---	62.0	---
Paris quadrifolia	6	13	---	2.9	16.7	---	29.6	---
Carex pediformi	6	12	---	12.1	22.6	2.2	---	---
Rubus arcticus	6	12	---	16.9	---	---	---	23.1
Vicia unijuga	6	11	---	8.9	2.6	---	34.0	---
Diphasiastrum complanatum	6	10	3.1	11.5	---	16.1	---	---
Thalictrum baikalense	6	10	---	---	---	---	52.5	5.8
Atragene sibirica	6	9	---	3.3	3.8	---	36.4	---
Trientalis europaea	6	9	---	---	---	16.9	28.2	---
Sanguisorba officinalis	6	8	9.9	20.4	---	---	---	---
Thalictrum minus	6	8	---	0.3	4.5	---	37.7	---

Cluster			1	2	3	4	5	6
Number of relevés			11	43	25	12	3	4
	layer*	freq.						
Vicia venosa	6	8	---	---	---	---	35.3	---
Thalictrum foetidum	6	7	---	13.9	20.4	---	---	---
Viola uniflora	6	6	---	9.7	22.6	---	---	---
Aconitum barbatum	6	6	---	9.7	22.6	---	---	---
Paris verticillata	6	6	---	---	5.9	---	40.5	---
Equisetum sylvaticum	6	6	---	13.7	0.9	11.3	---	---
Juniperus sibirica	4	6	10.6	0.8	17.0	---	---	---
Rubus matsumuranus	6	5	---	---	---	---	44.4	---
Dryopteris carthusiana	6	4	---	---	7.5	---	43.6	---
Climacium dendroides	9	12	---	2.1	---	46.4	---	---
Ceratodon purpureus	9	7	---	24.2	---	10.9	---	---
Campylium chrysophyllum	9	4	---	---	0.4	29.9	---	---
Lonicera pallasii	6	14	---	---	8.8	---	14.8	33.4
Spiraea media	6	8	---	9	14.6	7.0	---	---
Salix caprea	3	8	---	17.7	18.5	---	---	---
Spiraea salicifolia	6	4	---	0.5	---	---	47.5	---

Within this association, two unranked communities were distinguished based on five relevés. The first one is *Pinus pumila-Abies sibirica* community, which occurs at the highest location of the mountain range, at 1113 m a.s.l. At this altitude *P. pumila* occurs with the same species composition as in *Calamagrostio obtusatae-Abietetum sibiricae*. In addition, deforested areas were observed within communities of *Calamagrostio obtusatae-Abietetum sibiricae*. In these areas, we notice undergrowth of *B. pendula* and *A. sibirica* replacing the cut coniferous trees. Former deforested areas are distinguished as the secondary *Brachypodium pinnatum-Abies sibirica* community. They have a young forest physiognomy; the undergrowth of *A. sibirica* is mixed with small-leaved deciduous species, *B. pendula* and *P. tremula*. The open ground areas are conspicuous and affected by the direct insolation. Consequently, soil becomes drier, and relatively xerophytic species invade, such as *Brachypodium pinnatum*, *Spiraea media*, *Thalictrum minus*, *T. foetidum*, *Galium boreale* and *Vicia venosa*.

3. ***Calamagrostio obtusatae-Laricetum sibiricae*** **Chytrý et al. in Anenkhonov et Chytrý 1998 (Table 1, Cluster 2, Fig. 2e–f)**

Diagnostic species: *Betula pendula* [1], *Larix sibirica* [1], *Populus tremula* [1]; *Alnus alnobetula* subsp. *fruticose* [4]; *Rhododendron dauricum* [5]; *Calamagrostis obtusata* [6], *Chamaenerion angustifolium* [6], *Lilium martagon* [6], *Maianthemum bifolium* [6], *Milium effusum* [6], *Poa nemoralis* [6], *Pyrola incarnata* [6], *Rosa acicularis* [6], *Vaccinium vitis-idaea* [6]; *Pleurozium schreberi* [9], *Polytrichum juniperinum* [9], *Ptilium crista-castrensis* [9], *Rhytidium rugosum* [9].

As mentioned above, the communities of this association are similar to the preceding association. Despite the dominance of light-coniferous trees such as *L. sibirica* and *P. sylvestris*, the tree species of dark-coniferous taiga as well as constant companions of Baikal forests such as *B. pendula* and *P. tremula*, are also sufficiently dominant. These communities occupy the lower part and gentle slopes (10–15°) of the mountain range on deep well-drained soils. In the plain areas, communities of this association grow on wetter soil, which leads to higher abundance of *Ledum palustre* in the shrub layer.

The average height of the tree layer is 20–25 m with a coverage of 20–50%. Due to the moderate canopy density, the understory covers up to 20–50%. Commonly, the understory is two-layered. The first layer is composed of *R. dauricum*, *R. acicularis*, *L. palustre* with a height of 40–100 cm. In the second layer *A. alnobetula* subsp. *fruticosa*, and *Sorbus sibirica* with a height over 150–200 cm are present. Another distinctive feature is the frequent occurrence of the moss species, *P. crista-castrensis,* mixed with *R. rugosum*, *D. polysetum*, and widespread *P. schreberi*. These species cover up to 20–40%. In the herb layer, typical taiga species, such as *Vaccinium vitis-idaea*, *Maianthemum bifolium*, *Pyrola incarnata*, *L. borealis*, *C. obtusata* play an important role and cover up 50–80% of the ground. Also, two nemoral species, *Milium effusum* and *Poa nemoralis*, occurred.

4. *Maianthemo bifolii-Pinetum sibiricae* Danihelka et al. in Anenkhonov et Chytrý 1998 (Table 1, Cluster 4, Fig. 2g–h)

Diagnostic species: Betula pendula [1], *Larix sibirica* [1], *Pinus sibirica* [1]; *Betula nana* [6], *Caltha palustris* [6], ***Empetrum nigrum*** [6], ***Ledum palustre*** [6], *Oxycoccus microcarpus* [6], *Ranunculus propinquus* [6], ***Vaccinium uliginosum*** [6], *V. vitis-idaea* [6]; *Campylium chrysophyllum* [9], *Climacium dendroides* [9], *Dicranum polysetum* [9], *Pleurozium schreberi* [9], ***Polytrichum commune*** [9].

This association is the most unique phytosociological unit, occurring only along the coast of Lake Baikal. Due to the confinement to sand deposits near the lake shoreline, the communities are influenced by strong cool winds from the Lake Baikal water body. In some areas, due to the permanent wind activity the crowns are deformed in most of the trees. These communities occupy the plain part of the studied territory and, in some areas, they occur adjacent to wetland communities.

The tree layer contains individuals of very different height, ranging from 3 to 20 m. The dominant tree species is *P. sibirica*, which is considered as most resistant to cool and strong winds from the water body of Lake Baikal. *P. sibirica* is accompanied in the tree layer by *P. sylvestris*, *L. sibirica*, and *Betula pendula*. The tree layer reaches a cover of 20–30%. The upper shrub layer (60–150 cm) is formed by *R. dauricum* and – especially in the undergrowth – by *P. sibirica*. The middle layer (50–60 cm) is formed by *L. palustre*, *V. uliginosum*, and by *E. nigrum*, *V. vitis-idaea* in the lower layer (10–20 cm). Shrub species dominate throughout all the communities with the coverage of 40–90%. In the herb layer, *Maianthemum bifolium* plays an important role. In the moss layer, *P. schreberi*, *D. polysetum*, *P. commune* occur with 10–40% coverage. One of the moss species, *C. dendroides*, grows on the pine tree roots with 10% coverage.

5. *Matteuccio struthiopteridis-Abietetum sibiricae* Anenkhonov et al. in Anenkhonov et Chytrý 1998 (Table 1, Cluster 6, Fig. 2i–j)

Diagnostic species: ***Salix rhamnifolia*** [4]; ***Sambucus sibirica*** [5]; ***Matteuccia struthiopteris*** [6], ***Athyrium filix-femina*** [6], ***Cacalia hastata*** [6], *Calamagrostis langsdorffii* [6], *Cardamine macrophylla* [6], ***Carex rhynchophysa*** [6], ***Cirsium helenioides*** [6], *Equisetum arvense* [6], *E. fluviatile* [6], *Lonicera pallasii* [6], ***Persicaria hydropiper*** [6], ***Poa palustris*** [6], ***P. pratensis*** [6], ***P. raduliformis*** [6], ***Ribes nigrum*** [6], ***Urtica sondenii*** [6].


a)
b)
c)
d)
e)
f)
g)
h)

Fig. 2. Stands of the following forest communities: **a)** and **b)** *Calamagrostio epigei-Pinetum sylvestris* in the vicinity of Goryachinsk village, **c)** and **d)** *Calamagrostio obtusatae-Abietetum sibiricae* in the Katkovskaya mountain range, **e)** and **f)** *Calamagrostio obtusatae-Laricetum sibiricae* in the Katkovskaya mountain range, **g)** and **h)** *Maianthemo bifolii-Pinetum sibiricae* on the coast of Lake Baikal in the vicinity of Goryachinsk village, **i)** and **j)** *Matteuccio struthiopteridis-Abietetum sibiricae* in the Katkovskaya mountain range (Photos: E. Brianskaia, July 2015 except g) and h) August 2017).

Abb. 2. Bestände der folgenden Waldgesellschaften: **a)** und **b)** *Calamagrostio epigei-Pinetum sylvestris* in der Nähe des Dorfes Goryachinsk, **c)** und **d)** *Calamagrostio obtusatae-Abietetum sibiricae* im Katkovskaya-Höhenzug, **e)** und **f)** *Calamagrostio obtusatae-Laricetum sibiricae* m Katkovskaya-Höhenzug, **g)** und **h)** *Maianthemo bifolii-Pinetum sibiricae* an der Küste des Baikalsees in der Nähe des Dorfes Goryachinsk, **i)** und **j)** *Matteuccio struthiopteridis-Abietetum sibiricae* im Katkovskaya-Höhenzug (Juli 2015) (Fotos: E. Brianskaia, Juli 2015 außer g) und h) August 2017).

These communities occupy rich-nutrient and sufficiently moist sub-acid soils, along the gentle and steep slopes of the mountain creeks. These factors result in the dominance of mesohygrophytic ferns, especially, *M. struthiopteris* and *A. filix-femina*. Hygrophytic shrubs are typical of for this community. They are represented by *R. nigrum*, *S. sibirica*, and *S. rhamnifolia* (30–35%).

Due to the prevalence of tall herb species, it is difficult to trace the difference in height between herbs and shrubs. Generally, they have the same height, which is about 100–150 cm. The trees grow along creeks, at the distance from them (3–7 m). *Abies sibirica* and *Populus tremula* are dominant in the tree layer with a coverage of 20–30% and a height of 20–25 m. We registered these communities at altitudes of 540–650 m.

6. *Cardamino macrophyllae-Abietetum sibiricae* Chytrý, Anenkhonov et Valachovič 1998 (Table 1, Cluster 5)

Diagnostic species: *Abies sibirica* [1]; *Sorbus sibirica* [4]; ***Aconitum rubicundum*** [6], ***Agrostis stolonifera*** [6], *Amoria repens* [6], *Atragene sibirica* [6], ***Bromopsis austrosibirica*** [6], ***Cardamine macrophylla*** [6], *C. pratensis* [6], ***Carex vesicaria*** [6], *Chelidonium majus* [6], ***Chrysosplenium alternifolium*** [6], *Dryopteris carthusiana* [6], ***Equisetum arvense*** [6], ***E. pratense*** [6], ***Impatiens noli-tangere*** [6], *Paris quadrifolia* [6], *P. verticillata* [6], ***Poa supina*** [6], ***Pteridium aquilinum*** [6], *Rubus matsumuranus* [6], *R. saxatilis* [6], ***Saussurea amurensis*** [6], *Spiraea salicifolia* [6], ***Stellaria palustris*** [6], ***Thalictrum baikalense*** [6], *T. minus* [6], *Trientalis europaea* [6], ***Urtica dioica*** [6], ***Veratrum lobelianum*** [6], ***Vicia cracca*** [6], *V. unijuga* [6], *V. venosa* [6]; ***Aulacomnium palustre*** [9], ***Paludella squarrosa*** [9].

According to the habitat ecological conditions, the communities of this association are similar to *Matteuccio struthiopteridis-Abietetum sibiricae*. They also occupy areas along the creeks, however, in the relatively plain parts of the mountain range, which are exposed to temporary flooding and drawdown. A decreasing role of ferns and the leading position of *C. macrophylla* are characteristic of this community. In the tree layer *A. sibirica* plays a dominant role; together with *Pinus sylvestris* and *Betula pendula* it reaches a cover of 40–50% and a height of 20–25 m. Typical species of wet habitats, such as *Alnus alnobetula* subsp. *fruticosa*, *Ribes nigrum*, *Lonicera palasii* compose the understory with a height of 100–200 cm and a coverage of 20–40%. The herb coverage is high, reaching 90%, and the most abundant species are *A. rubicundum*, *C. macrophylla*, *V. lobelianum*, *C. vesicaria*.

4.2 Sharpness

Forests communities of the studied area with the most distinct habitat features have the highest sharpness value (Table 2).

The analysis of correlation between average positive fidelity (phi-coefficient) and sharpness value revealed that associations with higher average fidelity of species have a higher sharpness. The most sharply differentiated associations are represented by the most hygrophytic forests of *Matteuccio struthiopteridis-Abietetum sibiricae* and *Cardamino macrophyllae-Abietetum sibiricae* (see Table 2). Communities of both associations are demanding in terms of air and soil moisture, so that the most special species combinations occur within these communities. The oligotrophic habitat conditions and the post-fire successional status of the communities of the *Calamagrostio epigei-Pinetum sylvestris* lead to the selection of pioneer fruticose lichens species, which have high diagnostic value and result in a moderately high sharpness value (Table 2). Mesophytic communities related to the alliance *Pino sibiricae-Laricion sibiricae* have the lowest sharpness value. This is obviously due to the similarity of habitat conditions, and consequently, relatively similar floristic composition. Associations such as *Calamagrostio obtusatae-Laricetum sibiricae*, *Calamagrostio obtusatae-Abietetum sibiricae* and *Maianthemo bifolii-Pinetum sibiricae* exhibit a sufficient number of diagnostic species, however with low average positive fidelity. Hence, communities which occupy more extreme habitats tend to have more diagnostic species with high fidelity value, which consequently leads to the higher sharpness.

Table 2. Sharpness and species fidelity for the vegetation associations. *Names of associations are abbreviated to the first three letters of the name-giving taxa.

Tabelle 2. Schärfe und Arttreue der Vegetations-Assoziationen. *Namen der Assoziationen sind auf die ersten drei Buchstaben der namensgebenden Taxa abgekürzt.

Association*	Number of species with phi-coefficient < 25%	Average species number in association	Average positive fidelity	Sharpness
Cal epi-Pin syl	11	9.09	37.73	57.23
Cal obt-Abi sib	12	17.00	20.26	26.58
Cal obt-Lar sib	18	18.86	17.30	30.85
Mai bif-Pin sib	17	15.00	30.47	48.91
Mat str-Abi sib	19	17.00	59.71	79.85
Car mac-Abi sib	36	23.00	45.12	80.99

5. Discussion

Our study provides the first detailed results on the phytosociological structure of forests in the central zone of Lake Baikal Eastern coast. The applied supervised k-means clustering revealed comprehensible and reasonable assignment of unidentified relevés among identified ones. Thus, we highly recommend its application in the case of the available comparable vegetation data. Since all unidentified relevés were assigned to previously described associations, no new syntaxa have been arisen, so that it is possible to consider that the relevant associations have a larger scale distribution within the eastern coast of Lake Baikal mountain taiga. For example, the three most wide spread forest associations, namely *Maianthemo bifolii-Pinetum sibiricae*, *Calamagrostio obtusatae-Laricetum sibiricae*, and *Calamagrostio obtusatae-Abietetum sibiricae* showed similar altitudinal and ecological confinement within the mountain system on the eastern coast of the Lake Baikal, despite the relative distance of comparable vegetation (Svyatoy Nos Peninsula and Barguzinskiy mountain range are located in 150–200 km away from the studied area in the north-eastern direction).

The construction of the final synopsis of the forest vegetation was based on the prodromus of ANENKHONOV (2015). All forest communities of the studied area are classified as belonging to the *Vaccinio-Piceetea* class, which comprises boreal coniferous taiga forests on acid soils of Eurasia (ERMAKOV 2012). Within the territory of the Republic of Buryatia, this class represents the dominant biome of zonal boreal taiga forest.

The order *Pinetalia sylvestris* comprises light oligotrophic pine forest and represents the most xerophytic type of forest within the *Vaccinio-Piceetea*. There are different opinions about the origin of oligotrophic pine forests. For example, in the study of boreal forests of central Yakutia, N.B. Ermakov defined them as azonal psammophilous forests with the dominance of *Pinus sylvestris*, which grow on sandy deposits of watersheds; he classified them into *Cladonio-Vaccinetalia* Kielland-Lund 1967 (ERMAKOV et al. 2002). Likewise, Anenkhonov determined them as azonal mesophytic and xerophytic light-coniferous forests of watersheds, and classified them into *Pinetalia sylvestris* (ANENKHONOV 2015). Both names were considered synonymous (ERMAKOV 2012); however, in this study we adhere to the first accepted name, *Pinetalia sylvestris*.

Some scientists emphasized that light-coniferous forests may be stable climax communities in the boreal zone due to their abundance and dominance over other forest types (SEMENOVA-TYAN-SHANSKAYA 1956, DYRENKOV 1984). However, the most prevalent opinion is that monodominant forests with *P. sylvestris* and fruticose lichens appear as fire-induced successional stage (AHTI 1977, SMIRNOVA 2004, SMIRNOVA & ALEINIKOV 2012). During the field work, we noticed a significant amount of burnt pine trees in each plot (see Fig. 3a–b). Another distinct feature is a relatively young age of the *P. sylvestris* stands. A special investigation of tree age was not performed in the study; however, the performed visual field measurements (counting of coniferous trees branch verticals) showed that scots pine forest is composed by relatively young trees. Hence, we hypothesize that this type of forest can be considered as a fire-induced successional community.

To prove our hypothesis we refer to the study of AHTI (1977) of Finnish northern boreal forests in which he concluded that all pine-lichen forests represent different stages of fire-induced succession. Successional stages can be recognized according to the dominant fruticose lichen species. According to Ahti's scheme, there are at least three recognizable stages of successional process. Firstly, various combinations of *Cladonia* species are a distinct feature of the early stage. Secondly, *Cladonia arbuscula*, *C. mitis* and *C. rangiferina* dominate during the middle phase. In the final stage, *C. stellaris* replaces other *Cladonia* species

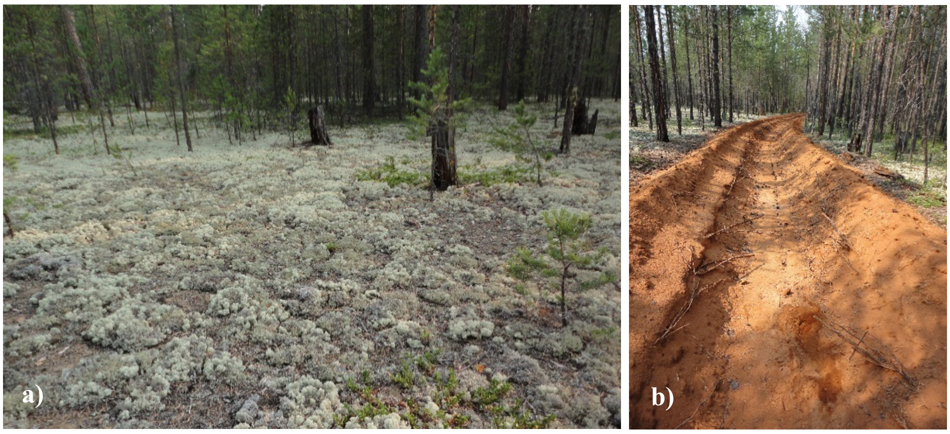

Fig. 3. a) Burnt tree stumps, and **b)** fire-preventing gutter in the vicinity of Goryachinsk village (Photos: E. Brianskaia, July 2015).

Abb. 3. a) Verkohlte Baumstümpfe und **b)** feuerhemmende Rinne in der Nähe des Dorfes Goryachinsk (Fotos: E. Brianskaia, Juli 2015).

and becomes the dominant lichen (AHTI 1977, ESSEEN 1983, ESSEEN et al. 1997). Species richness also depends on a succession phase, for example, it is higher in early and middle stages, while richness decreases at the final stage (CONNELL 1978, BRÅKENHIELM & PERSSON 1980, OKSANEN & AHTI 1982, SCHOONMAKER & MCKEE 1988). In her study of East-European forests, SMIRNOVA (2004) pointed out the importance of soil type for the succession process: she concluded that *P. sylvestris*, appears exclusively or predominantly on nutrient-poor sandy substrate in the post-fire succession of nemoral and boreal forests. Based on literature and our own findings we consider forest communities of *Pinetalia sylvestris* as a temporary fire-prone vegetation formation in our study area. Most communities of *Pinetalia sylvestris* have reached the final stage due to the dominance of *C. stellaris* and low species richness (the average number of species is 9.09 in 11 classified relevés).

The second *Pinetalia sylvestris* community, *Calamagrostio epigei-Pinetum sylvestris*, was described for the first time in Svyatoy Nos Peninsula (ANENKHONOV & CHYTRÝ 1998). The authors mentioned that this association represents an exceptionally xerophytic community type within the alliance *Hieracio umbellati-Pinion sylvestris*. Moreover, the prominent diagnostic role belongs to fruticose lichens of the *Cladonia* genus and evergreen dwarf-shrubs such as *Arctostaphylos uva-ursi* and *Vaccinium vitis-idaea*, which are also typical of the European alliances *Dicrano-Pinion sylvestris* (Libbert 1933) Matuszkiewicz 1962 and *Cladonio stellaris-Pinion sylvestris* K.-Lund ex Ermakov et Morozova 2011. However, the permanent occurrence and the high cover values of East-Asian species such as *Rhododendron dauricum* make it impossible to classify these communities within the European phytosociological units. Hence, following to ANENKHONOV & CHYTRÝ (1998), we assign *Calamagrostio epigei-Pinetum sylvestris* to *Hieracio umbellati-Pinion sylvestris*.

The second order *Ledo palustris-Laricetalia cajanderi* represents the most cryophilic forests within the *Vaccinio-Piceetea* class. This order comprises boreal northern and middle taiga coniferous (predominantly larch) forests of Northern Eurasia (ERMAKOV & ALSYNBAEV 2004). Communities of this order occupy territories of permafrost in the continental and ultra-continental climate. Within Siberia, they were also described from the Western

Sayan Mountain range (Ermakov & Alsynbaev 2004), West Siberian Plain (Ermakov & Makhatkov 2011), central Yakutia (Krestov et al. 2009) and Svyatoy Nos Peninsula at Lake Baikal (Anenkhonov & Chytrý 1998). In the Katkovskaya mountain range, forests of this order are mesophytic. In ultra-continental climatic conditions, for example, in Yakutia, the only dominant in the tree layer is *Larix cajanderi*, and due to the harsh climatic conditions some moderately thermophilous species of boreal forests are absent, such as *Sorbus sibirica*, *Maianthemum bifolium*, *Gymnocarpium dryopteris*, *G. jessoense*. The forests of the studied area grow under the mitigating influence of Lake Baikal water body as well as western Atlantic air masses, both resulting in lower continentality and more humid and warm climatic conditions (Tyulina 1976). Hence, the communities of this order within the Baikal Region are represented by more thermophilous mixed coniferous-deciduous forests, which are classified into the East-Siberian alliance *Pino sibiricae-Laricion sibiricae*. All associations of this alliance are among the most relevant forest types under the regional climatic conditions (humid cyclonic sector) of Baikal Siberia and typically occupy the middle altitudinal forest belt (Ermakov 2014, Anenkhonov 2015).

The dark-coniferous forests of the association *Calamagrostio obtusatae-Abietetum sibiricae* are typical of the upper forest sub-belt within the Baikal Siberian mountain systems. Previously, they were described in the Barguzinskiy range (Tyulina 1976, Chytrý et al. 1995, Danihelka & Chytrý 1995), the Khamar-Daban mountain range (Epova 1957), and the Western Sayan Mountains (Chytrý et al. 2008). Epova considered all fir forests containing nemoral species (e.g. *Milium effusum*, *Paris quadrifolia*) as relict communities of the Tertiary period, when mixed coniferous-deciduous (nemoral) forests were widespread throughout Baikal Siberia (Epova 1957, Peshkova 1985). However, in a recent study, 27 nemoral broad-leaved forest species, which have not been registered in our area were considered as Tertiary relicts (Chepinoga at al. 2017). Consequently, the studied fir forests can-not be referred to the Tertiary relicts. In her study of the Barguzinskiy mountain range, Tyulina (1976) distinguished two types of dark-coniferous forests according to tree dominance of either *Pinus sibirica-Bergenia crassifolia* or *Abies sibirica-Bergenia crassifolia* combinations. She concluded that the substrate features play an important role in their distribution (Tyulina 1976). *Abies sibirica-Bergenia crassifolia* forests prefer stony soils, which is also supported by our study. Soils of *Abies-Bergenia* forests exhibit rather shallow (27 cm) soil depth and many boulder; however, soil is well supplied with moisture due to water inflow.

At lower altitudes, a second forest sub-belt is formed by communities of mixed coniferous-deciduous forests, mostly belonging to the *Calamagrostio obtusatae-Laricetum sibiricae*. Communities of this association were described in publications of Tyulina (1976), Chytrý et al. (1995), Danihelka & Chytrý (1995), Anenkhonov & Chytrý (1998), Valachovič et al. (2002) in the Barguzinskiy range, Kuminova (1960) in the Altai region. Generally, forests with combinations of light-coniferous species are the most typical of the forests of Eastern Siberia (Anenkhonov 2015).

In the plain part of the study area, communities of the association *Maianthemo bifolii-Pinetum sibiricae* occurred. For the first time these communities were described from the Barguzinskiy Ridge by Tyulina (1976) using the dominant approach to classify vegetation. She introduced the term "pseudogoltsy altitudinal belt", implying the coastal woodland communities developed under the strong cooling influence of winds from the Lake Baikal water body. According to the Braun-Blanquet approach, these communities were validly described from the Svyatoy Nos Peninsula (Anenkhonov & Chytrý 1998).

The order *Piceo obovatae-Pinetalia sibiricae* unites the most hygrophytic forest types in the *Vaccinio-Piceetea* class. Communities of this order are dominated by dark-coniferous species and confined to riverine alluvial soils. In the Russian prodromus, all these forest types were integrated into the *Piceetalia excelsae* Pawłowski et al. 1928, which unites the Eurasian boreal dark-coniferous taiga communities (ERMAKOV 2012). However, Ermakov proposed to separate these Siberian dark-coniferous forests from their European counterparts (ERMAKOV 2006, 2012, 2013, ERMAKOV & MAKHATKOV 2011). The main reason for the separation has been a too broad interpretation of the order *Piceetalia excelsae* due to merging European, Siberian and Far Eastern dark-coniferous forests into the same order. In addition, Ermakov pointed out that the Siberian dark-coniferous taiga is different from the European and Far Eastern analogues, with the robust combination of diagnostic species, such as *Abies sibirica*, *Pinus sibirica*, *Picea obovata*, *S. sibirica*, *Calamagrostis obtusata*, *Stellaria bungeana*, *Cerastium pauciflorum* (ERMAKOV 2013). Ermakov's concept was followed by ERMAKOV & LAPSHINA (2013), and ANENKHONOV (2015).

The alliance *Aconito rubicundi-Abietion sibiricae* is classified within *Piceo obovatae-Pinetalia sibiricae* Ermakov 2013. For the first time, this alliance was described in the Svyatoy Nos Peninsula as a unit that represents azonal forests of the river valleys with tall grasses (ANENKHONOV & CHYTRÝ 1998). Communities of this alliance were reported from several areas in Siberia and Cisurals (VALACHOVIČ et al. 2002, ERMAKOV & MAKHATKOV 2011, ERMAKOV 2014). Ecologically, these communities occupy the territories of prominent cyclonic climate with moderately continental humid conditions (ERMAKOV 2013). The territory under study provides suitable habitats for this type of forests due to the well-formed net of creeks in the intermountain basins. The main diagnostic species in the tree layer is *A. sibirica*, which coexists with *Populus tremula* and *Betula pendula* in some plots.

Within the alliance *Aconito rubicundi-Abietion sibiricae*, two associations of *Matteuccio struthiopteridis-Abietetum sibiricae* and *Cardamino macrophyllae-Abietetum sibiricae* are distinguished. Communities of both associations form narrow strips along the mountain creeks, similar to other dark-coniferous taiga stands with tall herbs and shrubs. However, when comparing the habitat preferences, it became clear that plants of *Cardamino macrophyllae-Abietetum sibiricae* are more resistant to the temporary lack of moisture in contrast to plants of the *Matteuccio struthiopteridis-Abietetum sibiricae* (TSYGANOV 1983). Another distinct feature is a diverse composition of the tree layer in the *Cardamino macrophyllae-Abietetum sibiricae*, with *P. sylvestris* and *B. pendula* playing a more significant role in addition to the still dominant *A. sibirica*.

Erweiterte deutsche Zusammenfassung

Einleitung – Einhergehend mit der weltweiten Computerisierung wurden in den letzten Jahrzehnten zunehmend formale statistische Ansätze zur objektiven Klassifizierung von Pflanzengesellschaften der untersuchten Vegetation angewandt (HILL 1979, TICHÝ & HOLT 2006, OKSANEN et al. 2007). Aktuell ist der meist angewandte Ansatz zur phytosoziologischen Datananalyse die nicht überwachte Klassifikation, insbesondere die TWINSPAN Methode (HILL 1979, ROLEČEK et al. 2009). Jedoch gilt als Hauptnachteil dieses Ansatzes, dass sich die Klassifikationsergebnisse ändern können, wenn einem Datensatz weitere Vegetationsaufnahmen hinzugefügt werden (BRUELHEIDE & CHYTRÝ 2000). Daher werden überwachte Klassifikationsansätze unter Pflanzensoziologen zunehmend beliebter (AL-HARBI & RAYWARD-SMITH 2006, FINLEY & JOACHIMS 2008, VAN TONGEREN et al. 2008, ČERNÁ & CHYTRÝ 2009, TICHÝ et al. 2014). In der vorliegenden Arbeit werden überwachte Klassifikationstechniken wie k-means Clusteranalyse auf Pflanzengesellschasften der Wälder der zentralen Bereiche des Ostufers am Baikalsee beispielhaft angewandt. Obwohl sehr viele Daten zur Vegetation der Baikal-Sibirischen

Region vorliegen, sind kaum Daten zur untersuchten Region verfügbar. Vor diesem Hintergrund ist das Ziel der vorliegenden Studie die Erforschung der phytosoziologischen Zusammensetzung und der räumlichen Verbreitung der Waldvegetation im zentralen Bereich des Ostufers des Baikalsees und deren Vergleich mit gut erforschten Nachbargebieten am Ostufer des Sees.

Methoden – In den Sommermonaten 2013, 2015 und 2016 wurden insgesamt 98 Vegetationsaufnahmen im zentralen Bereich der Ostküste des Baikalsees aufgenommen. Zur Klassifikation der Waldgesellschaften wurde die überwachte k-means Clusteranalyse angewandt. Dabei wurde eine nicht klassifizierte Gruppe 0 von 98 Vegetationsaufnahmen der vorliegenden Studie mit 65 a priori Gruppen (Pflanzensoziologischen Assoziationen) aus 589 Vegetationsaufnahmen der Svyatoy Nos Halbinsel (ANENKHONOV & CHYTRÝ 1998) und des Barguzinskiy Gebirges (DANIHELKA & CHYTRÝ 1995, CHYTRÝ et al. 1995, VALACHOVIČ et al. 2002) verglichen und zugeordnet.

Ergebnisse – Durch Vergleich der 98 originalen Vegetationsaufnahmen des Untersuchungsgebietes (UG) mit Daten angrenzender Gebiete wie der Svyatoy Nos Halbinsel und des Barguzinskiy Gebirges (589 Vegetationsaufnahmen) wurde eine finale Synopsis der Waldvegetation erreicht. Sechs Assoziationen und zwei Gesellschaften wurden der Klasse der Borealen Nadelwädler *Vaccinio-Piceetea* Br.-Bl. in Br.-Bl. et al. 1939 zugeordnet.

Diskussion – Die vorliegende Studie beinhaltet erste Forschungsergebnisse zur pflanzensoziologischen Zusammensetzung der Wälder der zentralen Bereiche des Ostufers am Baikalsee. Die angewandte überwachte k-means Clusteranalyse ergab nachvollziehbare und begründete Zuordnungen von nicht klassifizierten Aufnahmen innerhalb einer Gruppe von bereits klassifizierten Aufnahmen. Aufgrund dessen empfehlen wir die Anwendung dieser Methode, wenn vergleichbare Vegetationsdaten vorhanden sind. Da alle nicht klassifizierten Vegetationsaufnahmen bereits vorher beschriebenen Assoziationen der Nachbarregionen zugeordnet werden konnten, ergaben sich keine neuen Syntaxa. Dies lässt den Schluss zu, dass die beschriebenen Assoziationen eine weitere Verbreitung in der Bergtaiga am Ostufer des Baikalsees besitzen. Die am weitesten verbreiteten Wald-Assoziationen, namentlich *Maianthemo bifolii-Pinetum sibiricae*, *Calamagrostio obtusatae-Laricetum sibiricae* und *Calamagrostio obtusatae-Abietetum sibiricae*, zeigen eine ähnliche Höhenverbreitung und Standortsansprüche wie in den Gebieten der Vergleichsaufnahmen, obwohl diese doch in einiger Entfernung zum UG liegen (Svyatoy Nos Halbinsel und Barguzinskiy Gebirge liegen 150–200 km nordöstlich des UG).

Acknowledgement

The study was financially supported by Erasmus-Mundus Iamonet-Ru project and executed at Hohenheim University, Institute of Landscape and Plant Ecology (320). Preparation of this article was carried out using the framework of project *AAAA-A*17-117011810036-3, supported by the Russian Federal Budget. Special thanks are due to Prof. Dr. Milan Chytrý for the supervision during the stay at Masaryk State University, Department of Botany and Zoology, and for sharing the dataset from the north-eastern coast of Lake Baikal, to Dr. Oleg A. Anenkhonov for critical comments and editing the manuscript, to Dr. Dolgor Ya. Tubanova for consulting on mosses and initial identification of moss species. Dr. Tat'yana D. Pykhalova kindly advised processing of some vascular plant specimens.

Author contribution statement

Elena Brianskaia conceived the idea of the research; defined the aim and questions of the study; planned itinerary of field work; performed field data collection; identified plant species; analyzed vegetation data; interpreted results; wrote the final manuscript. Klaus Schmieder and Reinhard Boecker supervised the research; verified and corrected questions of the research; planned routes for the field trips; determined methods for data collection and vegetation classification; helped in analyzing and interpretation of the results. Ayur Gyninova and Larisa Balsanova organized the field trip to the research area in order to study soils in different forest vegetation communities. They helped to write the "Soils" subchapter of the manuscript. Critical feedbacks from all authors contributed to the final version of the manuscript.

References

AHTI, T. (1977): Lichens of the boreal coniferous zone. – In: SEAW, M.R.D. (Ed.): Lichen ecology: 145–181. Academic Press, London.

AL-HARBI, S.H. & RAYWARD-SMITH, V.J. (2006): Adapting k-means for supervised clustering. – Appl. Intell. 24: 219–226.

ALISOV, B.P. (1956): Klimaty SSSR (Climates of USSR) [in Russian]. – Moskovskiy Gosudarstvennyy Universitet, Moskva: 127 pp.

ANENKHONOV, O.A. (2015): Lesnaya rastitel'nost' Zapadnogo Zabaykal'ya i veroyatnye napravleniya ee klimatogennoy dinamiki (Forest vegetation of the Western Transbaikalia and probable directions of its climatogenic dynamics) [in Russian]. – Ulan-Ude: 475 pp.

ANENKHONOV, O.A. & CHYTRÝ, M. (1998): Syntaxonomy of vegetation of the Svyatoy Nos Peninsula, Lake Baikal 2. Forests and krummholz in comparison with other regions of Northern Buryatia. – Folia Geobot. 33: 31–75.

BRÅKENHIELM, S. & PERSSON, H. (1980): Vegetation dynamics in developing scots pine stands in central Sweden. – Ecol. Bull.: 139–152.

BRUELHEIDE, H. & CHYTRÝ, M. (2000): Towards unification of national vegetation classifications: A comparison of two methods for analysis of large data sets. – J. Veg. Sci. 11: 295–306.

BUZYKIN, A.I. (1969): Lesa Buryatskoy ASSR (Forests of the Buryat ASSR). – In: Lesa SSSR (Forests of USSR) [in Russian]: 350–388. Nauka, Moskva.

CÁCERES, M.D., FONT, X. & OLIVA, F. (2010): The management of vegetation classifications with fuzzy clustering. – J. Veg. Sci. 21: 1138–1151.

ČERNÁ, L. & CHYTRÝ, M. (2009): Supervised classification of plant communities with artificial neural networks. – J. Veg. Sci. 16: 407–414.

CHEPINOGA, V.V., PROTOPOPOVA, M.V. & PAVLICHENKO, V.V. (2017): Detection of the most probable Pleistocene microrefugia on the northern macroslope of the Khamar-Daban Ridge (Southern Prebaikalia). – Contemp. Probl. Ecol. 10: 38–82.

CHYTRÝ, M., ANENCHONOV, O.A. & DANIHELKA, J. (1995): Plant communities of the Bol'šoj Čivyrkuj River Valley, Barguzinskij Range, East Siberia. – Phytocoenologia: 399–434.

CHYTRÝ, M., DANIHELKA, J., KUBEŠOVÁ, S. … PIŠÚT, I. (2008): Diversity of forest vegetation across a strong gradient of climatic continentality: Western Sayan Mountains, southern Siberia. – Plant Ecol. 196: 61–83.

CHYTRÝ, M. & OTÝPKOVÁ, Z. (2003): Plot sizes used for phytosociological sampling of European vegetation. – J. Veg. Sci. 14: 563–570.

CHYTRÝ, M., PEŠOUT, P. & ANENCHONOV, O.A. (1993): Syntaxonomy of vegetation of Svjatoj Nos Peninsula, Lake Baikal 1. Non forest communities. – Folia Geobot. Phytotaxon. 28: 337–383.

CHYTRÝ, M. & TICHÝ, L. (2003): Diagnostic, constant and dominant species of vegetation classes and alliances of the Czech Republic: a statistical revision. – Masaryk University, Brno: 231 pp.

CHYTRÝ, M., TICHÝ, L., HOLT, J., BOTTA-DUKÁT, Z. & BRUELHEIDE, H. (2002): Determination of diagnostic species with statistical fidelity measures. – J. Veg. Sci. 13: 79–90.

CONNELL, J.H. (1978): Diversity in tropical rain forests and coral reefs. – Science 199: 1302–1310.

DANIHELKA, J. & CHYTRÝ, M. (1995): Some plant communities in the Bolšaja Čeremšana valley, Barguzinskij range. – Sib. Nat. 1: 165–202.

DYRENKOV, S.A. (1984): Structura i dinamika elovoy taygi (Structure and dynamics of spruce taiga) [in Russian]. – Nauka, Leningrad: 174.

EPOVA, N.A. (1957): K istorii rastitel'nosti Khamar-Dabana (To the history of the Khamar-Daban vegetation) [in Russian]. – Nauchnye chteniya pamyati M.G. Popova: 45–66.

EPOVA, N.A. (1960): K kharakteristike pihtovoy taygi Khamar-Dabana (Characteristics of fir forests of the Khamar-Daban mountain range) [in Russian]. – NII SO RAN: 141–163.

ERMAKOV, N. (2006): Analiz sostava tsenoflor kontinental'nykh gemiboreal'nykh lesov Severnoy Azii (Analysis of floristic composition of hemiboreal forests of northern Asia) [in Russian]. – Turczaninowia 9: 5–92.
ERMAKOV, N. (2013): Sintaxony temnokhvoyno-taezhnykh lesov s khrebta Kuznetskiy Alatau (Uzhnaya Sibir') (Syntaxa of dark-coniferous forests from Kuznetsky Alatau mountain ridge (Southern Siberia)) [in Russian]. – Bulleteni Novosibirskogo Gosudarstvennogo Universiteta 1: 83–91.
ERMAKOV, N. (2014): Associatsii gorno-taezhnoy rastitel'nosti basseyna reki Bol'shoy On (Zapadniy Sayan) (Associations of boreal vegetation in the Bolshoy On river basin (Western Sayan)) [in Russian]. – Rastitel'nyi mir Aziatskoy Rossii 2: 56–64.
ERMAKOV, N.B. (2001): Gemiborealnyye lesa kontinentalnoy Severnoy Azii (Klassifikatsiya. Ordinatsiya. Analiz tsenoflor) (Hemiboreal forests of the continental northern Asia (Classification. Ordination. Ananlysis of coenoflora)) [in Russian]. – Novosibirsk: 551 pp.
ERMAKOV, N.B. (2012): Prodromus vysshikh edinits rastitel'nosti Rossii (Prodromus of high-rank vegetation units of Russia). – In: MIRKIN, B.M. & NAUMOVA, L.G. (2012): Sovremennoe sostoyanie osnovnykh kontseptsyi nauki o rastitel'nosti (The present condition of the main concepts of vegetation science) [in Russian]. – Gilem, Ufa: 377–483.
ERMAKOV, N. & ALSYNBAEV, K. (2004): Modelirovanie prostranstvennoy organizatsii lesnogo pokrova uzhnoy chasti Zapadnogo Sayana (Modeling of the spatial distribution of forests in the southern part of the Western Sayan) [in Russian]. – Sibirskiy ecologicheskiy zhurnal 11: 687–702.
ERMAKOV, N., CHEROSOV, M. & GOGOLEVA, P. (2002): Classification of ultracontinental boreal forests in central Yakutia. – Folia Geobot. 37: 419–440.
ERMAKOV, N. & MAKHATKOV, I. (2011): Classification and ordination of north boreal light-coniferous forests of the West Siberian Plain. – Plant Biosyst. 145: 199–207.
ERMAKOV, N.B. & LAPSHINA, E.D. (2013): Sintaxony temnokhvoynykh lesov iz uzhnoy taigi Zapadno-Sibirskoy ravniny (Syntaxa of dark-coniferous forests from the southern boreal subzone of the West Siberian Plain) [in Russian]. – Bulleteni Novosibirskogo Gosudarstvennogo Universiteta 1: 75–82.
ERSHOV, E.D. (Ed.) (1989): Geokrynologiya SSSR. Gornye strany uga SSSR (Geogryology of USSR. The mountain areas of the south of USSR) [in Russian]. – Nedra, Moskva: 359 pp.
ESSEEN, P.A. (1983): Ecology of lichens in boreal coniferous forests with reference to spatial and temporal patterns. – Doctoral Dissertation, Umeå University: 147 pp.
ESSEEN, P.A., EHNSTRÖM, B., ERICSON, L. & SJÖBERG, K. (1997): Boreal Forests. – Ecol. Bull.: 16–47.
FINLEY, T. & JOACHIMS, T. (2008): Supervised k-Means Clustering. – Cornell Computing and Information Science Technical Report: 10 pp.
GAVILÁN, R.G., VILCHES, B., FONT, X. & JIMÉNEZ-ALFARO, B. (2017): A review of high-mountain acidophilous vegetation in the Iberian Peninsula. – Appl. Veg. Sci. 20: 513–526.
GLADKOV, A.A. (1985): Osobennosti pochvoobrazovaniya v Barguzinskoy kotlovine (Peculiarities of soil formation in the Barguzinkaya basin) [in Russian]. – Pochvovedenie: 20–28.
HENNEKENS S.M. & SCHAMINÉE J.H.J. (2001): TURBOVEG, a comprehensive data base management system for vegetation data. – J. Veg. Sci. 12: 589–591.
HILL, M.O. (1979): TWINSPAN: a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. – Cornell University, Section of Ecology and Systematics, Ithaca, N.Y.
KOPOSOV, G.F. (1983): Genesis pochv gor Pribaikal'ya (The genesis of the Baikal mountains) [in Russian]. – Nauka, Novosibirsk: 253 pp.
KRASILNIKOV, P.K. (1937): Pochvy i rastitelnost Goremykinskogo selsoveta Severobaykalskogo rayona (Soils and vegetation of the Goremykinskiy sel'sovet of the Severobaikal'skiy district) [in Russian]. –In: Buryat-Mongolia: 133–174. AS USSR, Moskva-Leningrad.
KRESTOV, P.V., ERMAKOV, N.B., OSIPOV, S.V. & NAKAMURA, Y. (2009): Classification and Phytogeography of Larch Forests of Northeast Asia. – Folia Geobot. 44: 323–363.
KUMINOVA, A.V. (1960): Rastitel'nyy pokrov Altaya (The vegetation of Altay) [in Russian]. – Sibiriskoe Otdelenie Rossiyskoy Akademii Nauk SSSR, Novosibirsk: 456 pp.
LADEISCHIKOV, N.P. (1982): Osobennosti klimata krupnykh ozer (na primere Baikala) (Aspects of the climate of large lakes (case study of Lake Baikal)) [in Russian]. – Nauka, Moskva: 136 pp.
LAVRENKO, V. (2014): K-means clustering: how it works. – URL: https://www.youtube.com/watch?v=_aWzGGNrcic [accessed 2018-03-03].

MOLOZNIKOV, V.N. (1974): Chivyrkuyskoye semiostrovye i poluostrov Svyatoy Nos (sostoyaniye ekosistem i voprosy okhrany ikh zhivotnykh komponentov) (Chivyrkuyskoye Peninsula and Svyatoy Nos Peninsula (the ecosystem conditions and protection aspects of their wildlife)) [in Russian]. – In: Priroda Baykala (Nature of Baikal): 254–267. Leningrad.

MOLOZNIKOV, V.N. (1986): Rastitelnyye soobshchestva Pribaykalia (Plant communities of the Baikal region) [in Russian]. – Nauka, Novosibirsk: 254–267 pp.

OKSANEN, J. & AHTI, T. (1982): Lichen-rich pine forest vegetation in Finland. – Ann. Bot. Fenn. 19: 275–301.

OKSANEN, J., KINDT, R., LEGENDRE, R., O'HARA, R.B., HENRY, M. & STEVENS, M.H.H. (2007): Vegan: Community Ecology Package. – URL: http://CRAN.R–project.org/package=vegan.

PESHKOVA, G.A. (1985): Rastitel'nost Sibiri – Predbaikal'e I Zabaikal'e (The vegetation of Siberia - Baikal and Transbaikal areas) [in Russian]. – Nauka, Novosibirsk: 144 pp.

POVARITSYN, V.A. (1937): Pochvy i rastitelnost basseyna reki Verkhney Angary (Soils and vegetation of Verkhnyaya Angara river) [in Russian]. – In: Buryat-Mongolia: 7–132. Moskva-Leningrad.

PRONIN, N.M. & UBUGUNOV, L.L. (Eds.) (2013): Ozero Kotokel'skoe: prirodnye usloviya, biota, ecologiya (Lake Kotokel'skoe: natural conditions, biota, ecology) [in Russian]. – Ulan-Ude: 340 pp.

ROLEČEK, J., TICHÝ, L., ZELENÝ, D. & MILAN, C. (2009): Modified TWINSPAN classification in which the hierarchy respects cluster heterogeneity. – J. Veg. Sci. 20: 596–602.

SCHOOMAKER, P. & MCKEE, A. (1988): Species composition and diversity during secondary succession of coniferous forests in the western cascade mountains of Oregon. – For. Sci. 34: 960–979.

SEMENOVA-TYAN-SHANSKAYA, A.M. (1956): Sosnovye lesa (Pine forests) [in Russian]. – Rastitel'not' SSSR, Academiya nauk SSSR: 217–248.

SMIRNOVA, O.V. (2004): Vostochnoevropeyskie lesa: istoriya v Golotsene i sovremennost' (East European forests: history in Holocene and modern age) [in Russian]. – Nauka, Moskva: 479 pp.

SMIRNOVA, O.V. & ALEINIKOV, A.A. (2012): Suktsesionnye sistemy boreal'nykh lesov Evropeiskoy Rossii (Successional systems of boreal forests in European part of Russia) [in Russian]. – Bulleteni Samarskogo Nauchnogo Centra Rossiyskoy Akademii Nauk 5: 1367–130.

SOKOLOV, I.A. (1978): O vertikal'noy zonal'nosti gornykh pochv Zabaikal'ya (About vertical zonation of the mountain soils in Transbaikal) [in Russian]. – Pochvovedenie: 113–123.

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

TICHÝ L., CHYTRÝ M. & BOTTA-DUKÁT Z. (2014): Semi-supervised classification of vegetation: preserving the good old units and searching for new ones. – J. Veg. Sci. 25: 1504–1512.

TICHÝ, L. & HOLT, J. (2006): JUICE program for management, analysis and classification of ecological data. Program manual. – Czech Republic: 98 pp. – URL: http://www.sci.muni.cz/botany/juice/jc06_man.htm [accessed 2018-04-05].

TSYBZHITOV, T.K. & UBUGUNOVA, V.I. (1992): Genesis I geographiya taezhnykh pochv basseyna ozera Baikal (The genesis and geography of taiga soils of the Lake Baikal pool) [in Russian]. – Buryatskoe knizhnoe izdatel'stvo, Ulan-Ude: 240 pp.

TSYGANOV, D.N. (1983): Phytoindikaciya ecologicheskih rezhimov v podzone khvoino-shirokolistvennykh lesov (Phytoindication of ecological regimes in the zone of coniferous-deciduous forests) [in Russian]. – Nauka, Moskva: 195 pp.

TYULINA, L.N. (1954): Listvennichnyye lesa severo-vostochnogo poberezhia Baykala i zapadnogo sklona Barguzinskogo khrebta (Larch forests of the north-eastern Baikal and the western slope of Barguzinskiy mountain range) [in Russian]. – Geobotanika 3: 150–209.

TYULINA, L.N. (1976): Vlazhnyi Pribaikal'skii tip poyasnosti (The humid Baikal type of zonality) [in Russian]. – Nauka, Novosibirsk: 289 pp.

VALACHOVIČ, M., ANENCHONOV O. & HODÁLOVÁ I. (2002): Vegetation along an altitudinal gradient in Gremyachay Valley (Barguzinskii Range, Eastern Siberia). – Biologia, Sect. Bot. 57: 83–100.

VAN TONGEREN, O., GREMMEN, N. & HENNEKENS, S. (2008): Assignment of relevés to pre-defined classes by supervised clustering of plant communities using a new composite index. – J. Veg. Sci. 19: 525–536.

WESTHOFF, V. & VAN DER MAAREL, E. (1973): The Braun-Blanquet approach. – In: WHITTAKER R.H. (Ed.): Ordination and classification of plant communities: 617–737. The Hague, Junk.

ZELENÝ, D. & TICHÝ, L. (2009): Linking JUICE and R: New developments in visualization of unconstrained ordination analysis. – 18th Workshop of European Vegetation Survey in Rome.