Diversity of mire massif types in the boreal zone of European Russia

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Abstract. In Russia, mire massif type is the principal structural unit for descriptions of the diversity of regional mire ecosystems of various ranks, vegetation mapping, and decision-making on the use of mires. The classification of mire massifs is based on various criteria and indicators. The botanical-geographical classification of mire massifs of the boreal zone of European Russia is four-tiered, and includes 22 types gathered in groups, subgroups and three classes. For most of the types their characteristic associations and diagnostic species are stated.

1. Introduction

The three major structural levels distinguished for mire ecosystems are mire sites (habitats), mire massifs and mire systems. The central object for the study and classification of mire ecosystems in Russian mire science is mire massifs, which develop in isolated depressions or on watersheds. Studies on mire massif classification have a more than a century-long history. There are several classification approaches, the main ones being the trophic, botanical-geographical, geomorphological and hydrological [1-3]. In each of these classifications the units of different ranks are determined not only by the principal traits on which they are based, but also by additional indicators.

The most thoroughly elaborated and widely used in many spheres of science and practice are botanical-geographical classifications of mire massifs, especially in various kinds of vegetation mapping [3-6]. The sets and distribution patterns of plant communities and their combinations (composite habitats) in massifs are one of the basic criteria for such classifications. Their geographic affiliation is also taken into account and reflected in the names of types. The botanical-geographical classification of mire massifs developed for European Russia by T. Yurkovskaya [3] is made up of 28 types, grouped into 5 classes with groups and subgroups distinguished within them. The boreal (taiga) zone of this region has only 20 types belonging to 4 classes, including the forest mires class. Mire massif types in this classification are rather broad, and in the vegetation map of Europe they are even more general [2]. The above classifications were designed to meet the purposes of small-scale mapping (1: 1000 000 and smaller) of mire or vegetation types for very extensive regions. This always means that quite a broad set of mire types are generalized within one composite type, even though they vary widely in the composition and structure of the plant cover and in ecological characteristics. Massifs smaller than 100 (or even 1000) hectares are thus overlooked. When describing (assessing) the diversity of the plant cover and mire ecosystems of smaller areas, such as individual protected areas, there is no need to classify all the mire massif types identified here into known generalized (broad) regional types. The more important task is to state their detailed typology, features of the plant

cover structure, and nature conservation value. Identification of new, narrower massif types is necessary when assessing the specifics of mire ecosystem diversity at the regional level, as demonstrated in a number of publications [7, 8].

2. Material and Methods

This endeavor was based on materials from long-term field surveys of mire ecosystems performed by the Laboratory of Mire Ecosystems, Institute of Biology KarRC RAS in Karelia and some adjacent regions in the European north of Russia [9, 10]. The typology of mire massifs was developed relying on the basic classification principles set out in a number of papers [3-6]. It is for the first time in a mire classification that the syntaxa (associations) the most characteristic of the massif's central part, as well as some diagnostic species discriminating them from similar types are provided for a majority of massif types.

3. Results and Discussion

A more detailed botanical-geographical classification of mire massif types has been developed for the north of European Russia within its boreal zone (table 1). It is four-tiered, and includes 22 types grouped into three classes, with groups and subgroups of types distinguished within them. Classification by T. Yurkovskaya [3] was taken as the backbone, with additions and amendments made at the level of subgroups and types of mire massifs. Also, variants were distinguished within some types. Names of massif types are taken over from Yurkovskaya's classification if their scope is also retained. Digital codes are introduced for all classification levels, permitting quick reference to the massif's status and easy modification and expansion of the classification.

New or modified types and their variants are named after the dominant communities in the central parts of the massifs or after their trophic status, as well as regional affiliations. For the Sphagnum bogs class (1), for instance, subgroups of massifs with compound and homogenous plant cover structure were distinguished, and a subgroup of bogs with *Sphagnum angustifolium* and *S. magellanicum* was singled out (table 1). New types of massifs were identified within several groups: for dystrophic suboceanic Sphagnum bogs (1.1.1) these are the Lapland (1.1.1.2) and North-East European (1.1.1.3) types. A finer division was suggested for Sphagnum poor fens (1.4.1), which are differentiated into 4 types, two of them with variants. There is also a new typology for aapa mires (class 2). The mesotrophic and eutrophic variants, which are distinct in their flora and the spectrum of plant communities, were distinguished within the Karelian (2.1.1.2) and Onega-Pechora (2.1.2.2) types. The class of herb and herb-brown moss mires (boreal subgroup 3.1.1) now comprises 4 types (Yurkovskaya's classification had only one). Mire massifs with a sparse tree stand (canopy closure 0.2-0.3) and abundant moss cover, which is the main producer component of the communities, were included in the classification.

Forest mires (wetland forests and swamps) with a canopy closure of 0.4 or more are not considered here. They constitute a separate class [3], and their typology is based on different indicators [11]. There are occasional palsa mires in the utter north of the forest zone, but their typology needs to be further developed together with other types of mires of the tundra zone.

The syntaxa (associations) that are the most typical for the massif's central part and define their overall appearance are provided for a majority of types and their variants (table 2). Associations were determined by the ecological topology method relying on dominant or diagnostic species for the main layers of the community [12, 13] Also, diagnostic species enabling clear discrimination of some massif types were identified (table 2). They are mostly species found at the margins of their distribution range due to climatic or biogeographic factors, such as some subatlantic (*Calluna vulgaris, Trichophorum cespitosum, Carex livida, Sphagnum cuspidatum, S. rubellum*), hypoarctic (*Carex rotundata, Sphagnum lindbergii*), East European and Siberian (*Chamaedaphne calyculata, Carex omskiana, Betula humilis*) species.

Table 1. Classification of mire massif types of taiga zone the European Part of Russia.

CLASS and group of mire massifs (after: [3], with additions)	Subgroup of mire massifs (after: [3], with additions)	Mire massif types and their variants (after: [3]* and in own interpretation)
1	2	3
1. BOREAL SPHAGNUM BOGS 1.1 European suboceanic Sphagnum raised bogs (distrophic)	1.1.1 Liverwort-lichen-Sphagnum ridge-hollow raised bogs with secondary pools	1.1.1.1. Calluna-lichen-Sphagnum- liverwort ridge-hollow raised bogs of the White Sea coastal region* 1.1.1.2 Lapland Empetrum-lichen-Sphagnum-liverwort ridge-hollow raised bogs 1.1.1.2a inland 1.1.1.2b Barents Sea coastal 1.1.1.3. North-East European Empetrum-lichen-Sphagnum-liverwort ridge-hollow raised bogs
1.2 North-West European Sphagnum raised bogs	1.2.1 Sphagnum ridge-hollow raised bogs with *Calluna vulgaris* and *Sphagnum fuscum*	1.2.1.1 Karelian dwarf shrub-cloudberry-Sphagnum ridge-hollow raised bogs 1.2.1.1a North-Karelian* 1.2.1.1b Middle-Karelian* 1.2.1.2 West-Russian dwarf shrub-Sphagnum ridge-hollow raised bogs*
	1.2.2 Homogenous Sphagnum bogs with *Sphagnum angustifolium, S. fuscum, S. magellanicum*	1.2.2.1 North-West European pine-cottongrass-Sphagnum bogs* I.2.2.2 North-West European cottongrass-Sphagnum bogs
I.3 North-East European Sphagnum raised bogs	1.3.1 Sphagnum ridge-hollow raised bogs with *Chamaedaphne calycylata* and *Sphagnum fuscum*	1.3.1.1. Chamaedaphne-cloudberry-Sphagnum ridge-hollow raised bogs of the Onega-Pechora Region*
	1.3.2 Homogenous Sphagnum bogs with *Sphagnum angustifolium, S. fuscum, S. magellanicum*	1.3.2.1. North-East European pine-cottongrass-Sphagnum bogs* 1.3.2.2. North-East European cottongrass-Sphagnum bogs
1.4 North-East European oligotrophic Sphagnum mires (poor fens)	I.4.1 Homogenous grass-Sphagnum poor fens	1.4.1.1 Low sedge-dwarf shrub-Sphagnum (*Sphagnum papillosum, S. balticum, S. majus*) poor fens 1.4.1.1a Trichophorum-dwarf shrub-Sphagnum poor fens 1.4.1.1b Scheuchzeria-cottongrass- Sphagnum poor fens 1.4.1.2 Tall sedge-Sphagnum (*S. fallax, S. angustifolium, S. lindbergii*) poor fens

	I.4.2 Grass-Sphagnum compound poor fens	1.4.2.1 Low sedge-dwarf shrub-Sphagnum (*Sphagnum papillosum, S. balticum, S. majus*)-liverwort poor fens with hummock-flark microrelief 1.4.2.2 Dwarf shrub-grass-Sphagnum (*Sphagnum fuscum, S. jensenii, S. majus, S. lindbergii*) string-flark poor fens
	1.4.3. Wood-herb-Sphagnum poor fens	1.4.3.1. Pine-dwarf shrub-sedge-Sphagnum poor fens 1.4.3.2. Birch-pine-herb-Sphagnum poor fens
2. GRASS-SPHAGNUM-BROWN MOSS FENS (AAPA MIRES) 2.1. North European aapa mires	2.1.1.North-West European aapa mires (Fennoscandian aapa mires)	2.1.1.1. Lapland aapa mires with dwarf shrub-cloudberry-Sphagnum strings and herbs flarks* 2.1.1.2. Karelian aapa mires with *Betula nana-Molinia caerulea*-Sphagnum strings and herbs and herb-brown moss flarks* 2.1.1.2a mesotrophic 2.1.1.2b eutrophic
	2.1.2. North-East European aapa mires	2.1.2.1. Forest tundra aapa mires with dwarf shrub-cloudberry-Sphagnum strings and herb-moss flarks* 2.1.2.2. Aapa mires of the Onega-Pechora Region with dwarf shrub-Trichophorum-Sphagnum strings and herbs and herb-moss flarks* 2.1.2.2a mesotrophic 2.1.2.2b eutrophic
3. HERB AND HERB-BROWN MOSS FENS 3.1.East European herb and herb-brown moss fens	3.1.1. Boreal herb and herb-brown moss fens	3.1.1.1. Herb and shrub-herb floodplain and lacustrine shore mesoeutrophic (ME) and eutrophic (E) fens 3.1.1.1a Sedge fens 3.1.1.1b Herb and shrub-herb fens 3.1.1.2. Sedge-brown moss fens without spring water recharge 3.1.1.3. Herb-moss fens with spring water recharge

This classification permits a more accurate determination of the affiliation of many syntaxa, as well as harvestable, rare and red-listed species to certain massif types. Thus, the most productive populations of *Menyanthes trifoliata, Comarum palustre* occur in floodplain and lacustrine shore herb and shrub-herb massifs (3.1.1.1). High cranberry yields are likely to be found in grass-moss poor fens (1.4.1) and cottongrass-Sphagnum raised bogs (1.2.2.2 & 1.3.2.2). A majority of vascular plant and moss species red-listed in Russia and boreal regions of its European part inhabit in spring-fed eutrophic (3.1.1.3) and aapa mires (2.1).

This classification will be further augmented, details on the distribution of individual types in the region will be added, and comparisons will be drawn to classifications of massif types for North European countries in order to produce a common classification for the entire Northern Europe.

Table 2. Characteristic syntaxa and diagnostic species of some types of massifs and their variants.

Mire types	Syntaxa	Species
1.1.1.1	*Calluna vulgaris – Cladonia spp.* (ridges), *Scheuchzeria palustris –Sphagnum lindbergii, Trichophorum cespitosum – Hepaticae* (hollows)	*Calluna vulgaris, Carex rariflora, Sphagnum tenellum, S. capillifolium*
1.1.1.2	*Empetrum hermaphroditum – Cladonia* spp. (ridges), *Eriophorum vaginatum - Sphagnum lindbergii, E. vaginatum-Hepaticae* (hollows)	*Eriophorum russeolum, Carex rotundata*
1.1.1.3	*Empetrum hermaphroditum – Cladonia* spp. (ridges), *Eriophorum vaginatum - Sphagnum lindbergii, E. vaginatum-Hepaticae* (hollows)	absence of *Calluna vulgaris, Rhynchospora alba, Sphagnum tenellum*
1.2.1.1	*Chamaedaphne calyculata – Sphagnum fuscum* (ridges), *Scheuchzeria palustris –Sphagnum majus , Eriophorum vaginatum –S. balticum* (hollows)	*Calluna vulgaris, Trichophorum cespitosum, Sphagnum tenellum*
1.2.1.2	*Chamaedaphne calyculata – Sphagnum fuscum* (ridges), *Eriophorum vaginatum –S. balticum, Scheuchzeria palustris –Sphagnum cuspidatum* (hollows)	*Sphagnum cuspidatum, S. rubellum*
1.2.2.1	*Pinus sylvestris – Ledum palustre – Sphagnum angustifolium*	*Calluna vulgaris*
1.2.2.2	*Chamaedaphne calyculata – Eriophorum vaginatum - S. angustifolium*	*Carex pauciflora, Sphagnum papillosum*
1.3.1.1	*Chamaedaphne calyculata – Sphagnum fuscum* (ridges), *Scheuchzeria palustris –Sphagnum majus* (hollows)	absence of *Calluna vulgaris, Rhynchospora alba, Sphagnum tenellum*
1.3.2.1	*Pinus sylvestris – Ledum palustre – Sphagnum angustifolium*	absence of *Calluna vulgaris*
1.3.2.2	*Chamaedaphne calyculata – Eriophorum vaginatum - S. angustifolium*	absence of *Calluna vulgaris*
1.4.1.1	*Andromeda polifolia - Trichophorum cespitosum+ Carex pauciflora -– Sphagnum papillosum+S. balticum*	
1.4.1.1a	*Andromeda polifolia - Trichophorum cespitosum – Sphagnum papillosum+S. balticum*	*Sphagnum compactum, S. pulchrum*
1.4.1.1b	*Scheuchzeria palustris+Carex rostrata – Sphagnum majus*	*Sphagnum jensenii*
1.4.1.2	*Carex lasiocarpa – Sphagnum fallax, C. rostrara - S. angustifolium*	*Sphagnum subsecundum*
1.4.2.1	*Andromeda polifolia - Trichophorum cespitosum+ Carex pauciflora – Sphagnum papillosum+S. balticum* (carpets), *Carex limosa - Sphagnum majus +Hepaticae* (hollows)	*Drosera anglica, Rhynchospora alba*
1.4.2.2	*Chamaedaphne calyculata – Sphagnum fuscum* (ridges), *Carex limosa +Menyanthes trifoliata – Sphagnum jensenii* (flarks)	
1.4.3.1	*Pinus sylvestris – Chamaedaphne calyculata – Carex lasiocarpa -Sphagnum angustifolium*	
1.4.3.2	*Betula pubescens+ Pinus sylvestris – Carex lasiocarpa+Menyanthes trifoliata - Sphagnum angustifolium*	*Salix myrtilloides, Calliergon cordifolium*

2.1.1.1	*Empetrum hermaphroditum+Rubus chamaemorus – Sphagnum fuscum* (strings), *Trichophorum cespitosum – Campylium stellatum* (carpets), *Carex limosa+Menyanthes trifoliata* (flarks)	*Carex rariflora, C. rotundata Eriophorum russeolum Loeskypnum badium*
2.1.1.2	*Carex lasiocarpa –Sphagnum fuscum* (hummocks), *Molinia caerulea- S. papillosum, Carex lasiocarpa –Sphagnum warnstorfii* (strings), *Carex limosa –Menyanthes trifoliata, Carex livida – Scorpidium scorpioides* (flarks)	
2.1.1.2a	*Carex lasiocarpa –Sphagnum papillosum, Molinia caerulea- S. papillosum* (strings), *Carex limosa – Menyanthes trifoliata* (flarks)	*Calluna vulgaris, Trichophorum cespitosum, Nymphaea candida, Selaginella selaginoides*
2.1.1.2b	*Carex lasiocarpa –Sphagnum warnstorfii, Molinia caerulea- S. warnstorfii,* (strings), *Carex livida – Scorpidium scorpioides, Carex limosa – S. scorpioides* (flarks)	*Juniperus communis Carex dioica, C. livida, Potentilla erecta, Sphagnum subfulvum, Scorpidium trifarium*
2.1.2.1	*Empetrum hermaphroditum+Rubus chamaemorus – Sphagnum fuscum* (strings), *Carex rariflora – Sphagnum lindbergii, Carex rotundata – Warnstorfia exannulata* (flarks)	absence of *Calluna vulgaris, Carex lasiocarpa, Scheuchzeria palustris*
2.1.2.2	*Carex lasiocarpa –Sphagnum magellanicum, Trichophorum cespitosum –S. papillosum, Trichophorum alpinum –S. warnstorfii* (strings), *Carex limosa – Menyanthes trifoliata, Carex limosa –Sphagnum jensenii* (flarks)	absence of *Calluna vulgaris, Molinia caerulea, Sphagnum subfulvum*
2.1.2.2a	*Carex lasiocarpa –Sphagnum magellanicum, Trichophorum cespitosum –S. papillosum* (strings), *Carex limosa – Menyanthes trifoliata, Carex limosa –Sphagnum jensenii* (flarks)	*Eriophorum russeolum*
2.1.2.2b	*Trichophorum alpinum –S. warnstorfii, Betula nana - Carex lasiocarpa –S. warnstorfii* (strings), *Carex limosa – Scorpidium scorpioides* (flarks)	*Betula humilis, Carex omskiana*
3.1.1.1a	*Carex diandra – Comarum palustre, C. lasiocarpa - Comarum palustre, C. aquatilis, C. cespitosa, C. omskiana*	*Carex chordorrhiza, C. buxbaumii, C. panicea, Cicuta virosa, Lathyrus palustris, Calliergon giganteum*
3.1.1.1b	*Salix lapponum – Carex rostrata, Equisetum fluviatile - Comarum palustre, Phragmites australis*	*Salix pentandra, S. cinerea, S. phylicifolia, Thyselium palustre, Hamatocaulis vernicosus*
3.1.1.2	*Carex lasiocarpa – Scorpidium scorpioides, C. limosa –S. scorpioides, C. lasiocarpa - Warnstorfia exannulata*	*Carex chordorrhiza, C. panicea, C. livida, Menyanthes trifoliata, Juncus stygius, Hammarbya paludosa, Sphagnum contortum, S. teres, S. obtusum*

3.1.1.3	*Carex lasiocarpa –Bistorta major –Sphagnum warnstorfii, Molinia caerulea –Campylium stellatum, Trichophorum alpinum – Scorpidium cossonii*	*Salix myrsinites, S. rosmarinifolia, Saxifraga hirculus, Stellaria crassifolia, Epipactis palustris, Paludella squarrosa, Bryum pseudotriquetrum*
3.1.1.4	*Betula pubescens+Picea abies – Pharagmites australis – Sphagnum warnstorfii, Alnus glutinosa –Carex elongata, Pinus sylvestris –Equisetum palustre+Bistorta major – Sphagnum warnstorfii*	*Carex appropinquata, Listera ovata, Cypripedium calceolus, Helodium blandowii*

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