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Bryophytes in Estonian mires

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Abstract. A list of 212 bryophyte species occurring in Estonian mires was compiled using published sources, databases, and specimens from Estonian herbaria. The highest number of species, 153, occur in fens, 98 species have been found in transitional mires, and 77 in bogs. Of the mire species 10 are protected by law and 42 are redlisted in Estonia. The present list is a basis for further scientific investigations and nature protection planning.

Key words: bryophytes, mires, threatened species, protected species.

INTRODUCTION

Almost a quarter of Estonia's terrestrial area is covered by peatlands. Peatland is an area with or without vegetation with a naturally accumulated peat layer at the surface (Joosten and Clark, 2002). Mire is a peatland with a peat layer of at least 30 cm depth, which is in a continuous process of development (Paal and Leibak, 2011). Only about 5.5% of the Estonian territory is covered by different types of mires (open or with a scattered low tree layer), and 17% is covered by paludified (peat layer less than 30 cm) and peatland forests (peat layer more than 30 cm) and degraded peatlands (Paal and Leibak, 2011). Draining for agriculture and other uses as well as peat excavation have diminished the past mire areas significantly. The area of mires in Estonia declined approximately by 36% in the recent 60 years; the most drastic change is seen in floodplain fens, whose area diminished 28 times (Paal and Leibak, 2011). The situation in the whole of Europe is even worse, 62% of its former mire area is lost (Raeymaekers, 2000). Many mire types are already very rare in Europe and the remaining areas are in urgent need to be preserved (Habitat Directive, 1992). Land use and climate change are the major threats to the existence of mires and mire plants causing extinction or diminishing the distribution of many mire bryophyte species.

Knowledge on the species diversity in different communities and their demands for the community properties are indispensable for improving management planning and nature protection. We have a list of Estonian hemerophobic forest bryophyte species (Trass et al., 1999), also lists of indicator species for Estonian woodland

key habitats of different forest communities (RT, 2010), but there is no up-to-date list of Estonian mire bryophytes, although bryophytes are the main components in mires and in peat. A preliminary list of bryophytes of Estonian peatlands was published 42 years ago (Kannukene and Kask, 1982). Since then several papers including data about mire bryophytes have been published, and numerous mire bryophyte specimens have been accumulated in Estonian herbaria (TU, TAA, TAM, TALL). A database of Estonian biodiversity (eElurikkus), established in 2008 and continuously complemented, includes information on records of different recent case studies of mires. During the last 20 years several mire inventories have been carried out on the whole territory of Estonia and data sheets with species lists and community-level evaluations have been compiled.

The aim of this study is to present an updated list of mire bryophytes and their community preferences, and to highlight threatened mire species in Estonia.

MATERIAL AND METHODS

For compiling an updated list of Estonian mire bryophytes we checked the former list, published sources listed in Nurkse (2011), herbarium specimens from TU, TAA, and TAM, the database of Estonian biodiversity with 8742 records (eElurikkus), and data sheets for more than 8676 mires deposited in the Estonian Fund of Nature. The nomenclature of species was updated according to Hill et al. (2006) and Söderström et al. (2007). The species were grouped into main mire types used in Estonia (Laasimer and Masing, 1995): fen, transitional mire, and bog. Fen is a minerotrophic mire, fed mainly by groundwater, and divided into poor and rich fens; bog is ombotrophic, fed by precipitation; transitional mire is mixotrophic, fed on hummocks by precipitation and in depressions by groundwater. The list is restricted with open communities and wet forest types are excluded.

The occurrence frequency (Table 1) of obligatory mire species was estimated on the basis of species frequency in Estonia (http://www.botany.ut.ee/bruoloogia/), records in the literature and herbaria, and field experience of the authors. The following notation is used: C – common, more than 20 localities in Estonia; R – rare, less than 20 localities in Estonia. Facultative mire species (F), which grow preferably in other communities (incl. wet forests), are presented in the table without frequency estimation in mires (Table 1). Species protection value is based on the Red Data Book of Estonia (2008) and the list of protected species of Estonia. The species in the Estonian Red List are divided into categories according to the IUCN criteria (IUCN, 2003). The list of protected bryophyte species in Estonia includes altogether 46 species in three categories; the first and second category have been confirmed by the Estonian Government, the third by the Ministry of the Environment (RT, 2004a, 2004b). Categories I and II cover rare and/or at risk of extinction species. All localities of the category I species and half of the localities of the category II species should be protected. Category III covers species that are declining; 10% of their localities should be protected (Loodus-kaitseseadus, 2004).

Table 1. List of bryophytes in fens, transitional mires (Trans), and bogs in Estonia (compiled in 2013). Nomenclature follows Hill et al. (2006) and Söderström et al. (2007). Abbreviations: RL – Red List category (RE = regionally extinct, EN = endangered, VU = vulnerable, NT = near threatened); LPS – List of Protected Species of Estonia category. Occurrence: C – common; R – rare; F – facultative; * – odd finds, atypical for the mire type

Species	Habitat			Category	
	Fen	Trans	Bog	RL	LPS
LIVERWORTS					
Aneura pinguis	C				
Barbilophozia attenuata			F		
Barbilophozia hatcheri	F				
Barbilophozia kunzeana	R	R		NT	
Blepharostoma trichophyllum	F		F		
Calypogeia integristipula	F	F	F		
Calypogeia muelleriana	F				
Calypogeia neesiana	R	R	R		
Calypogeia sphagnicola	R	R	C		
Cephalozia bicuspidata	F				
Cephalozia connivens	R	R	C		
Cephalozia loitlesbergeri			R		
Cephalozia lunulifolia			C		
Cephalozia pleniceps	R		R		
Cephaloziella divaricata			F		
Cephaloziella elachista			R	VU	
Cephaloziella hampeana	F		F		
Cephaloziella rubella	F	F	F		
Cephaloziella spinigera			R	VU	
Chiloscyphus pallescens		R			
Chiloscyphus polyanthos	C	C	R		
Cladopodiella fluitans		R	C		
Fossombronia foveolata	R			VU	
Geocalyx graveolens	F		F	NT	
Gymnocolea inflata	R		C		
Harpanthus flotovianus	R			VU	
Kurzia pauciflora			C		
Lepidozia reptans	F	F	F		
Lophocolea bidentata	R				
Lophozia bantriensis	R	R		NT	
Lophozia incisa	R		F		
Lophozia laxa			R	VU	
Lophozia longiflora			F		
Lophozia rutheana	C	R		NT	
Marchantia polymorpha	C		R		
Moerkia hibernica	R	R			
Mylia anomala		R	C		
Odontoschisma denudatum		F	F		
Pellia endiviifolia	R				
Pellia epiphylla	R				
Plagiochila asplenioides	F				
Plagiochila porelloides	*				

Continued overleaf

Table 1. *Continued*

Species	Habitat			Category	
	Fen	Trans	Bog	RL	LPS
Preissia quadrata	C	R	*		
Riccardia chamaedryfolia	R	R	R		
Riccardia incurvata	R		R	VU	
Riccardia latifrons	R	R	R		
Riccardia multifida	R		F		
Riccardia palmata	F				
Riccia fluitans	F				
Ricciocarpus natans	F				
Scapania irrigua	R		*		
Scapania paludicola	C	R			
Scapania undulata	F			VU	
Trichocolea tomentella	F				
MOSSES					
Amblyodon dealbatus	R			EN	
Amblystegium riparium	F				
Amblystegium saxatile	*			VU	
Amblystegium serpens	R				
Amblystegium varium	F				
Aplodon wormskioldii			R	VU	
Atrichum angustatum			*	VU	
Atrichum undulatum			*		
Aulacomnium palustre	C	C	C		
Brachythecium mildeanum	R	R			
Brachythecium rivulare	R				
Brachythecium rutabulum	F		F		
Brachythecium salebrosum	F	F			
Brachythecium turgidum	R			NT	II
Breidleria pratensis	C		F		
Bryoerythrophyllum recurvirostrum		*	*		
Bryum marratii			*	VU	II
Bryum moravicum	F				
Bryum neodamense	R		F	NT	III
Bryum pallens			*		
Bryum pseudotriquetrum	C				
Bryum weigelii		R		RE	
Calliergon cordifolium	C	R			
Calliergon giganteum	C				
Calliergon richardsonii	R	R		NT	
Calliergon stramineum	R	C	R		
Calliergonella cuspidata	C	R			
Calliergonella lindbergii	R	R	F		
Campyliadelphus elodes	R				
Campylium chrysophyllum	C				
Campylium stellatum	C	C			
Campylophyllum sommerfeltii	F				
Campylopus fragilis	R				
Catoscopium nigritum	R			NT	II
Ceratodon purpureus	F	F	F		

Table 1. *Continued*

Species	Habitat			Category	
	Fen	Trans	Bog	RL	LPS
Cinclidium stygium	C	R			
Cirriphyllum pilliferum	F				
Climacium dendroides	C	R	F		
Cratoneurum filicinum	R				
Ctenidium molluscum	R				
Dicranella cerviculata			F		
Dicranum bonjeanii	R				
Dicranum leioneuron			C	NT	
Dicranum majus	*				
Dicranum polysetum	R	R	C		
Dicranum scoparium	F	F	F		
Dicranum undulatum	R	R	C		
Drepanocladus aduncus	R				
Drepanocladus polygamus	R				
Drepanocladus sendtneri	R				
Drepanocladus sordidus	R				
Eurhynchium angustirete	*	*			
Fissidens adianthoides	C				
Fissidens dubius	F				
Fissidens osmundoides	R				
Fissidens taxifolius	F				
Fontinalis antipyretica	R	R			
Funaria hygrometrica	*				
Hamatocaulis lapponicus		R		DD	
Hamatocaulis vernicosus	C	R		NT	III
Helodium blandowii	C	R			
Hylocomium splendens	F	F	R		
Hymenostylium recurvirostrum	*				
Hypnum pallescens	*	*			
Kindbergia praelonga	*				
Leptobryum pyriforme			F		
Leucobryum glaucum	F	F			III
Loeskypnum badium	R			RE	
Meesia longiseta		R		RE	
Meesia triquetra	C	R		NT	
Meesia uliginosa			R	EN	
Mnium hornum	F	F			
Myurella julacea	*				
Paludella squarrosa	C	R		NT	
Palustriella commutata	R				
Philonotis caespitosa	R			NT	
Philonotis calcarea	R				
Philonotis fontana	R	R			
Plagiomnium affine	F	F			
Plagiomnium cuspitatum	F				
Plagiomnium elatum	C	R			
Plagiomnium ellipticum	R				
Plagiomnium medium	R				

Continued overleaf

Table 1. *Continued*

Species	Habitat			Category	
	Fen	Trans	Bog	RL	LPS
Plagiomnium undulatum	R				
Plagiothecium denticulatum		F			
Plagiothecium laetum	F	F	F		
Pleurozium schreberi	R	R	C		
Pohlia camptotrachela			*		
Pohlia cruda	*				
Pohlia nutans	F		C		
Pohlia sphagnicola	F	R	C		
Polytrichastrum formosum	F	F			
Polytrichastrum longisetum	F				
Polytrichum commune	R	C			
Polytrichum juniperinum	F				
Polytrichum strictum	*	C	C		
Pseudobryum cinclidioides	R				
Pseudocalliergon lycopodioides	C	R			
Pseudocalliergon trifarium	R	R		NT	
Pseudocalliergon turgescens	R				
Ptilium crista-castrensis	*	*			
Rhizomnium pseudopunctatum	R				
Rhizomnium punctatum	C				
Rhodobryum roseum	F	F			
Rhytidiadelphus squarrosus	*				
Rhytidiadelphus triquetrus	F	F	F		
Sanionia uncinata	R	R			
Scorpidium cossonii	C	R			
Scorpidium revolvens	R				
Scorpidium scorpioides	C	R			
Sphagnum angustifolium		C	C		
Sphagnum auriculatum		R		DD	
Sphagnum austinii			R		
Sphagnum balticum		R	C		
Sphagnum capillifolium	C	C	C		
Sphagnum centrale	R	C			
Sphagnum compactum		R	C		
Sphagnum contortum	R	C			
Sphagnum cuspidatum		R	C		
Sphagnum fallax	R	C	R		
Sphagnum fimbriatum	R	R			
Sphagnum flexuosum	R	R	R		
Sphagnum fuscum	*	R	C		
Sphagnum girgensohnii	R	C			
Sphagnum inundatum	R	R		VU	III
Sphagnum jensenii		R	R	DD	
Sphagnum lindbergii			R	NT	III
Sphagnum magellanicum	R	C	C		
Sphagnum majus		R	C		
Sphagnum molle	R			VU	
Sphagnum obtusum	R	R	R		
Sphagnum palustre	C	C			

Table 1. *Continued*

Species	Habitat			Category	
	Fen	Trans	Bog	RL	LPS
Sphagnum papillosum	R	C	C		
Sphagnum platyphyllum	R	R			
Sphagnum pulchrum		R	R		
Sphagnum riparium		R			
Sphagnum rubellum		R	C		
Sphagnum russowii		R	F		
Sphagnum squarrosum	C	R			
Sphagnum subfulvum		R		EN	
Sphagnum subnitens	C	R			
Sphagnum subsecundum	R	C			
Sphagnum tenellum			C		
Sphagnum teres	C	C			
Sphagnum warnstorfii	C	C			
Sphagnum wulfianum	F			NT	III
Splachnum ampullaceum	R		R		
Splachnum rubrum	R	R	R	EN	
Splachnum sphaericum			R	RE	
Splachnum vasculosum			R	RE	
Thuidium assimile	F	F			
Thuidium delicatulum	F				
Thuidium recognitum	F	F			
Thuidium tamariscinum	F				
Tomenthypnum nitens	C	R			
Warnstorfia exannulata	R				
Warnstorfia fluitans	R	R	F		
Warnstorfia tundrae	R			VU	III

RESULTS

The present list of Estonian mire bryophytes includes 212 species, among them 54 liverworts and 158 mosses (Table 1), and covers 37% of the whole Estonian bryoflora. Six species listed in 1982 as mire species are not listed in the updated list. *Dicranum muehlenbeckii* was eliminated from the list of Estonian bryophytes due to misidentifications (Vellak et al., 2009). *Cephalozia catenulata* and *Scapania curta* were excluded from the list because we did not find any present or former localities situated in mires. *Bryum bimum* is now recognized as a variety and was united with *B. pseudotriquetrum* (Hill et al., 2006). Former species *Lophozia guttulata* and *L. porphyroleuca* are synonyms of *L. longiflora* now (Söderström et al., 2007). Seven species – *Cephalozia elachista*, *Harpantus flotovianus*, *Lophozia laxa*, *Campylopus fragilis*, *Hamatocaulis lapponicus*, *Pohlia sphagnicola*, and *Sphagnum pulchrum* – were added to the list because they have been registered in Estonia as new species after the previous list was published (Kannukene et al., 1997; Vellak et al., 2006, 2011; Leis and Kannukene, 2007). Additional 58 species were included in the list according to the data found in the literature, herbaria, and databases.

From the total number of species that have been recorded in mires, about 71% (148 species) were evaluated as obligatory species for mires, among them 34 liverworts and 114 mosses. Nineteen species of liverworts and 46 of mosses were evaluated as facultative species for all mire types. Eighteen species were evaluated as odd for all mire types (Table 1). An example of such species is *Bryum marratii*, which grows typically on wet seashores, but was an exceptional find in a bog. The richest in species are fens and the poorest are bogs (Table 2). The total number of species found in only one mire type is the highest for fens and the lowest for transitional mires (Fig. 1). Although the highest number of facultative mire species was also counted for fens, the proportion of these species is the highest in bogs (Fig. 2). According to the chi-square test of the species numbers distribution (Table 2), the three mire communities are significantly different: $\chi^2 = 16.5$; $df = 8$; $p < 0.035$.

Ten species in the present list are protected by law in Estonia. Four of these belong to the second and six to the third category of the protected species (Table 1). This forms 22% of the total number of protected species in Estonia.

Altogether 42 species from Estonian mire bryophytes are registered in the Estonian Red List of Threatened Species (Red Data Book of Estonia, 2008), making up 19% of the whole Estonian redlisted bryoflora. Five of them were

Table 2. Number and percentage of bryophyte species in different mire types of Estonia

	Fen		Transitional mire		Bog	
	No.	%	No.	%	No.	%
Total	153	100	98	100	77	100
Redlisted	23	15.0	16	16.3	15	19.5
Common	33	21.6	18	18.4	26	33.8
Rare	76	49.7	62	63.2	26	33.8
Facultative	44	28.7	18	18.4	25	32.4

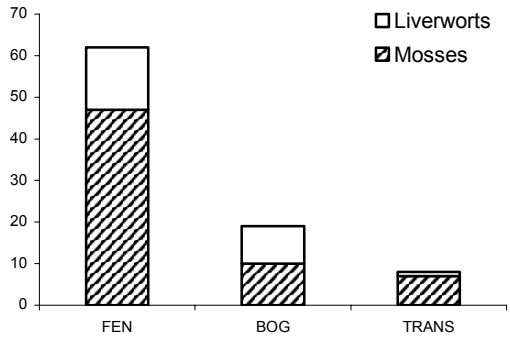

Fig. 1. Number of type-specific bryophyte species found in fens, transitional mires, and bogs.

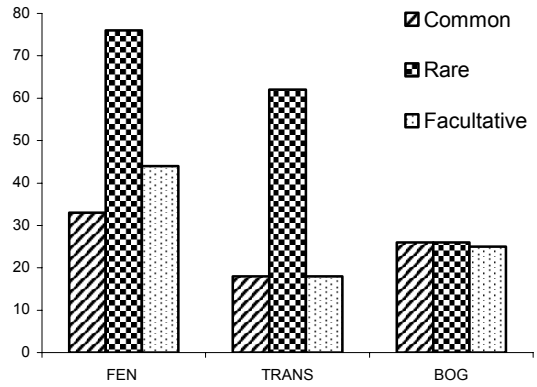

Fig. 2. Number of common, rare, and facultative bryophyte species in Estonian three mire types.

Table 3. Redlisted mire bryophytes according to the IUCN categories in Estonia. RE – regionally extinct, EN – endangered, VU – vulnerable, NT – near threatened, DD – data deficient

RD category	RE	EN	VU	NT	DD
Liverworts	0	0	7	4	0
Mosses	5	4	7	12	3
Sphagnum	0	2	2	2	2
Other mosses	5	2	5	10	1

classified as regionally extinct, three as data deficient, and 34 as threatened (Table 3). The proportion of redlisted species in the three mire types is almost equal, but the number of redlisted species is the highest in fens (Table 2).

From the Estonian bryoflora 11 species and the genus *Sphagnum* belong to the Annexes II and V of the EU Habitats Directive (Habitat Directive, 1992), four of these and 36 *Sphagnum* species are recorded in the present list of mire species.

DISCUSSION

The current list of Estonian mire species includes altogether 212 species, covering more than one third of the whole Estonian bryoflora. The great number of species added to the former list (65) can be explained by thorough inventories of Estonian mires in 1997 and 2009–2010 and also by many recent inventories of protected areas. The number of obligatory mire species in Estonia is 148, which is a bit higher than the number of mire species recorded from Finland, but the proportion of liverworts and mosses is rather similar (Heikkilä and Heikkilä, 2002). Although the distinction between facultative and obligatory species in some cases relies on

the personal experience of the authors, the list as a whole represents adequately the present species pool of Estonian mires. Therefore it can serve as a source for calculating the community completeness (Pärtel et al., 2013) in local mire communities and as a tool for the evaluation of the state and protection necessity of the sites.

The area of fens in Estonia is ca 45 000 ha, of transitional mires ca 38 000 ha, and of bogs ca 152 000 ha (Paal and Leibak, 2011). Although the area of fens is the smallest in Estonia, this mire type is the richest in species. Fens (in this study both poor and rich fens) are characterized by a wide pH gradient, while in species-poor bogs the water pH is always very low. The wide pH gradient allows species with different demands for mire water reaction to grow in fens. Rather few obligatory mire species, altogether 11, are found in all mire types. This shows that different mire types have specific ecological characteristics that provide habitats for bryophytes with different ecological demands. Species found in several mire types are characterized by higher tolerance for fluctuations in environmental parameters or by preference for specific substrata (decaying wood, stones, etc.) that may be present in every mire type (Dierβen, 2001).

This list includes 46 facultative mire species that grow preferably in other habitats. These species usually grow in drier habitat patches of mires, such as trunk bases of single trees, large woody debris, or hummocks. The proportion of facultative as well as common species is the lowest in transitional mires (Fig. 2). The possible explanation for this is that the area of transitional mires is smaller compared to fens and bogs in Estonia (Paal and Leibak, 2011).

The proportion of mire species among protected bryophytes is rather high in Estonia. The state monitoring of protected species was established in 1994 (Kukk, 2000). The aim of species monitoring is to observe and collect data on changes in the state of species and their populations. The results of monitoring are used in complementing the action plans for species protection. The first mire species taken under monitoring in 1996 was *Sphagnum lindbergii*. In 2013 altogether five protected species growing in mires were included in the state monitoring programme. Two of them (*Catoscopium nigritum* and *Hamatocaulis vernicosus*) inhabit fens and one species (*Sphagnum lindbergii*) grows only in bogs. Two species (*Leucobryum glaucum* and *Sphagnum wulfianum*) are facultative for open mires; they prefer to grow in wet forests, occurring rarely in fen or mire margins. Every species is monitored at three sites in the same years with the monitoring interval of five years. According to the recent evaluations, all the above-mentioned species were in a good condition. Although these species appear to be in a favourable position in their habitats, we do not know the habitat conditions for the other protected mire bryophyte species. Moreover, the state of quite a large number of redlisted mire species in their localities is not known either.

The majority of redlisted mire bryophytes grow in fens and transitional mires. The area of these mire types has declined drastically in the last 60 years. The most effective way to protect bryophyte species is to protect their habitats. At present 554.5 km^2 of fens and transitional mires and 1159.4 km^2 of bogs are situated within protected areas (Paal and Leibak, 2011), but many fen and transitional mire

areas of high conservation value are still not protected. They should be taken under protection in the nearest future because the economic pressure is increasing and the influence of drainage, peat excavation, and air pollution is already now harmful to the vegetation of many peatland areas (Ingerpuu et al., 2001; Paal et al., 2010).

Several of the regionally extinct and endangered mire species are more or less with northern distribution and thus the reason for their disappearance or further threat could be also climate warming. Fortunately, new localities for two species (*Loeskypnum badium* and *Bryum weigelii*) marked as regionally extinct in 2008 were found in recent years, and thus they should be re-evaluated in the Estonian red list. Also a new locality was found for the endangered *Sphagnum subfulvum* in 2012 (Ingerpuu and Vellak, 2012).

We can conclude that Estonian mires are still rich in bryophyte species, but many of them are endangered by human management practices, especially in fens and transitional mires. Only five mire species are under state monitoring, but the number of redlisted obligatory mire species in Estonia is 36. The task in the nearest future is to get an overview of the state of these species in their localities and to take measures to restore or maintain their habitats in a favourable condition.

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