Folia Cryptog. Estonica, Fasc. 44: 125–130 (2008)

Species richness and distribution ranges of European *Sphagnum*

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Abstract: There are 51 *Sphagnum* species in Europe. *Sphagnum* species richness shows a gradient of decrease from the boreal region towards the north and the south, as well as from west to east to some degree. There is a strong correlation between number of species and number of range restricted species. The most species rich countries (Norway and Sweden) also have most range restricted species. Most species occur in boreal, oceanic and/or alpine areas. Several areas, primarily several countries on the Balkans and Slovakia are identified as probably underexplored for *Sphagnum* species.

Kokkuvõte: Perekonna *Sphagnum* liigirikkus ja levik Euroopas.

Euroopas on 51 turbasambla (*Sphagnum*) liiki. Turbasammalde liigirikkus väheneb boreaalpiirkonnast põhja ja lõuna poole, samuti mõnevõrra läänest ida poole. Liikide koguarvu ja piiratud levikuga liikide arvu vahel on tugev korrelatsioon. Kõige liigirikkamates riikides (Norra ja Rootsi) on ka kõige enam piiratud levikuga liike. Enamus liike esineb boreaalsetes, okeaanilistes ja/või alpiinsetes piirkondades. Paljud kohad, eeskätt mitmed Balkanimaad ja Slovakkia, on turbasammalde poolest väheuuritud.

INTRODUCTION

The importance of recognizing areas that are *Sphagnum* species rich is that the species are ecologically important and dominating large areas, especially mire ecosystems. In addition, as main constituents of peat, they have a direct economic value and are thus subject to human exploitation and depletion.

Sphagnum is a fairly well known genus in Europe, but includes species that show large morphological plasticity and number of taxa recognized has been fluctuating over time. Even today there remains some controversy with the delimitation of some taxa. Flatberg (1994) recognizes, e.g., 5 species in the *S. fallax* complex while Daniels & Eddy (1990) recognize only one and Hill *et al.* (2006) recognize three.

In order to evaluate conservation needs it is necessary to identify species rich areas and areas rich in rare species. However, a species may be rare for several reasons. Rabinowitz (1981), e.g. use three variables that a species can be rare along: habitat requirements, population size and distribution range, and all can be combined. Ideally the rarity of a species should be analyzed along all variables. An attempt in this direction is made for liverworts (Söderström, Séneca & Santos, 2007). However, some of the variables are difficult to score for a large number of species, especially the population sizes for less well known species. This variable was also excluded in Söderström, Séneca & Santos (2007). The variable best known is usually distribution, though many areas are still insufficiently explored bryologically.

This study tries to identify which areas of Europe and Macaronesia are most *Sphagnum* rich and analyzes distribution ranges to see which areas are most rich in globally range restricted species.

METHODS

The geographical units used here follow mainly Brummit (2001) but are adjusted for Europe to follow Söderström, Urmi & Váňa (2002, 2007). Europe and Macaronesia were thus scored with 57 areas (Table 1; see Söderström & Séneca, 2008, for details).

Distributions were registered world-wide for all *Sphagnum* species recognized to occur in Europe and Macaronesia. The taxonomy follows Hill *et al.* (2006) and the distribution was retrieved from a database compiled by us from various sources covering distribution of all European *Sphagnum* taxa worldwide.

Distribution ranges were calculated in a way analogous with diversity in ecological investigations. We used the Shannon-Wiener index (Zar,

Table 1. *Sphagnum* species richness and number of restricted species (H'<0.61) in each area. The abbreviations of the area names are used in some figures

Areas	No. of species	No. of restricted species
Albania (ALB)	1	0
Austria (AUT)	34	3
Azores (AZO)	14	2
Baleares (BAL)	0	0
Belarus (BLR)	36	4
Belgium (BGM)	30	2
Bosnia-Herzegovina (BOS)	19	0
Bulgaria (BUL)	26	0
Canary Is. (CNY)	2	0
Corsica (COR)	1	0
Crete (KRI)	1	0
Crimea (KRY)	1	0
Croatia (CRO)	22	0
Czech Republic (CZE)	34	3
Denmark (DEN)	36	6
Estonia (EST)	37	3
Faeroe Is. (FOR)	21	2
Finland (FIN)	39	5
France (FRA)	34	4
Franz Josef Land (FJL)	0	0
Germany (GER)	36	6
Great Britain (GRB)	34	7
Greece (GRC)	9	0
Hungary (HUN)	24	0
Iceland (ICE)	30	5
Ireland (IRE)	27	6
Italy (ITA)	31	2
Kaliningrad (KAL)	33	3
Latvia (LAT)	37	4
Lithuania (LIT)	36	4
Macedonia (MAK)	11	1
Madeira (MDR)	4	0
Moldova (MOL)	0	0
Montenegro (MNE)	0	0
Netherlands (NET)	29	3
North Caucasus (NCS)	23	0
Norway (NOR)	44	11
Novaya Zemlya (NVZ)	6	0
Poland (POL)	36	3
Portugal (POR)	18	1
Romania (ROM)	27	3
Russia Central (RUC)	35	2
Russia East (RUE)	33	3
Russia North (RUN)	40	6
Russia Northwest (RUW)	35	3
Russia South (RUS)	25	0
Sardinia (SAR)	3	0
Serbia (SER)	18	1
Sicilia (SIC)	5	0
Slovakia (SVK)	22	2
Slovenia (SLO)	29	1
Spain (SPA)	29	3
Svalbard (SVA)	13	3
Sweden (SWE)	42	9
Switzerland (SWI)	29	4
Turkey-in-Europe (TUE)	1	0
Ukraine (UKR)	33	3

1984), which indicates how large chance there is that the next individual you see or catch is a different species, as

$$H' = -\sum p_i \ln p_i$$

where p is the proportion of areas occupied in each region. In this case, the index estimates how large chance there is that the same species occurs in the next region visited.

Range restricted species were defined as the 1/3 of all the species with lowest H'.

Proportion of range restricted species may be used as a measure on the relative importance of an area for range restricted species. However, a restricted species occurring in a species poor area will have a higher impact than a restricted species occurring in a species rich area. To reduce this effect a Rarity Index was created by multiplying the proportion of range restricted species with the absolute number of them as

$$RI = p_r \times n_r$$

where p_r is the proportion of range restricted species occurring in the area and n_r is the number of range restricted species in that region.

RESULTS

Number of species

A total of 51 *Sphagnum* species occur in Europe (Hill et al., 2006). However, there is a large

variation in number of species between the different areas (Fig. 1), from 0 in Franz Josef Land, Baleares, Moldova and Montenegro to 44 in Norway.

Species richness (Fig.2) was significantly correlated with the size of the area (Spearman corr. coeff. = 0.670; n = 57; $P < 0.001$).

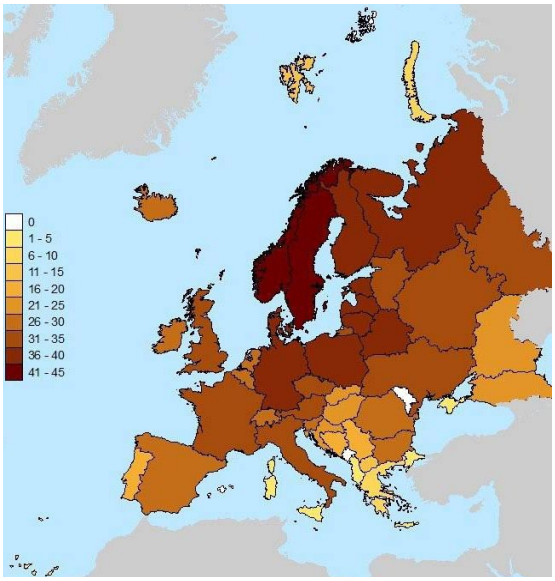

Fig. 1. Number of *Sphagnum* species in different areas of Europe and Macaronesia.

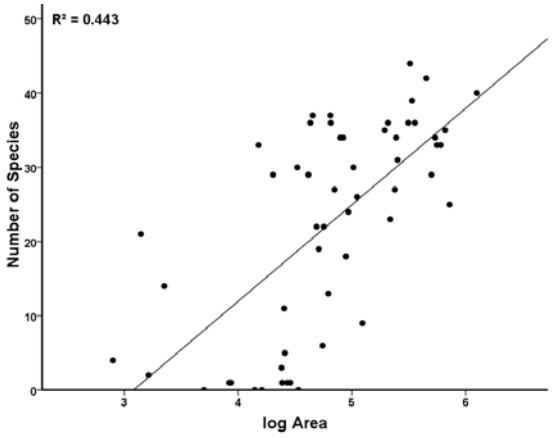

Fig. 2. Relationship between number of *Sphagnum* species and the $\log_{10}$ of the size of area.

Number and proportion of range restricted species

The one third most range restricted *Sphagnum* species (17 species) had H'≤1.6. Most of them occur in northwestern Europe (Fig 3). Number of range restricted species is correlated exponentially with species richness (Fig. 4). The number of range restricted species is also correlated with the size of the area (Spearman corr. coeff. = 0.517; n = 57; $P < 0.001$). The linear relationship has a low value of R^2 (Fig. 5) but shows two areas that fall outside the 95% confidence interval for the regression line (Norway and Sweden), indicating that they have more range restricted species than expected from the size of them alone.

Proportion of range restricted species is highest in the Scandinavian Peninsula, British Isles and Svalbard, with over 20% of registered *Sphagnum* species being range restricted (Fig. 6). The values of RI separates these areas more (Fig. 7) and are highest for Norway (2.75) followed by Sweden (1.93), Great Britain (1.44) and Ireland (1.33). The values of RI are exponentially related to the number of species (Spearman corr. coeff. = 0.779; n = 57; $P < 0.001$). They are also related to the size of the area (Spearman corr. coeff. = 0.480; n = 57; $P < 0.001$). Though the

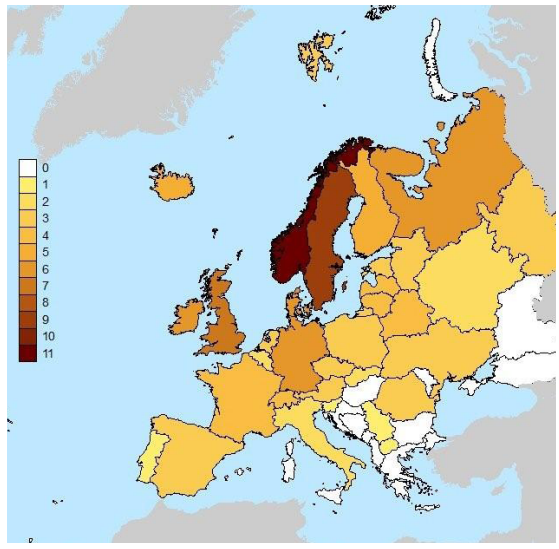

Fig. 3. Number of range restricted *Sphagnum* species in Europe and Macaronesia.

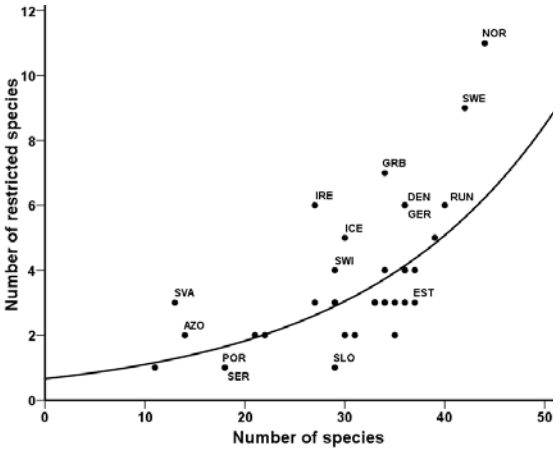

Fig. 4. Relationship between number of range restricted *Sphagnum* species and total number of species. Abbreviations of areas as in Table 1.

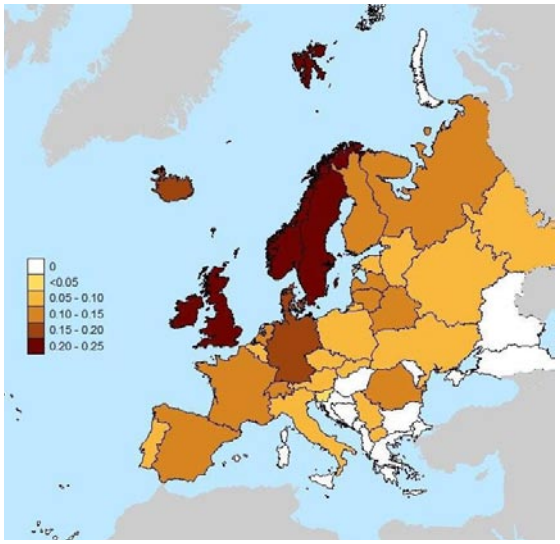

Fig. 5. Proportion of range restricted *Sphagnum* species in Europe and Macaronesia.

linear relationship between these variables is weak (R^2 = 0.093, Fig. 8), it shows four areas (Norway, Sweden, Great Britain and Ireland) lying outside the 95% confidence interval for the regression line.

DISCUSSION

The number of *Sphagnum* species is not uniformly distributed in Europe, as expected.

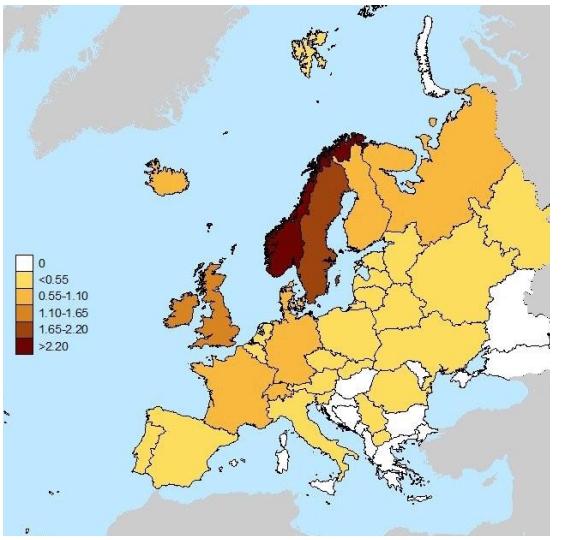

Fig. 6. Rarity Index values for range restricted *Sphagnum* species in Europe and Macaronesia.

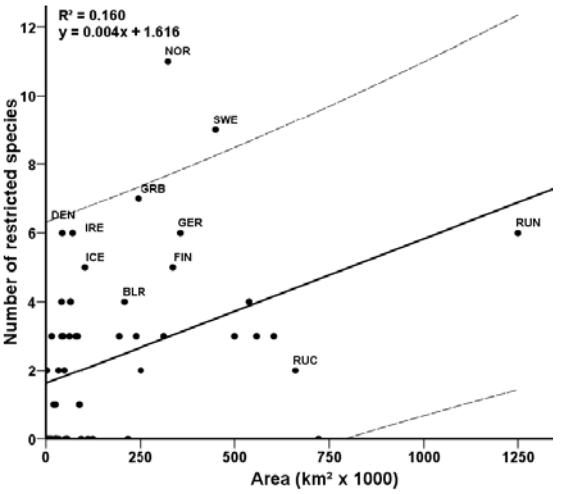

Fig. 7. Relationship between numbers of range restricted *Sphagnum* species and size of area. Dashed lines delimit the 95% confidence interval. Abbreviations of areas as in Table 1.

Three parameters emerge as important for the distribution pattern of the number of *Sphagnum* species: the boreal vegetation belt, the ocean influence and elevation. Fig. 1 clearly shows a gradient of decrease in species richness from the boreal areas towards the north and towards the south. To some degree, a decrease can also be recognized on a west-east gradient which can be

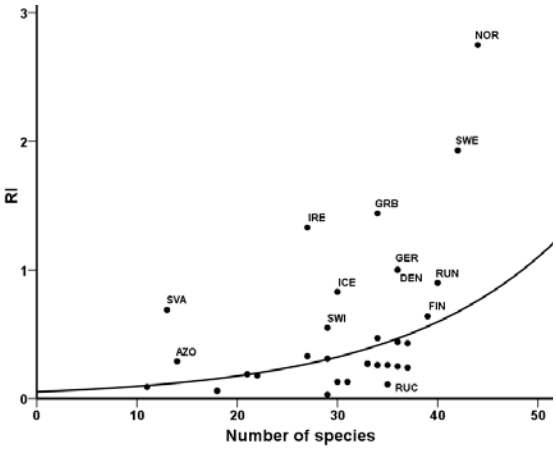

Fig. 8. Relationship between the values of the Rarity Index (RI) for the range restricted and total number of *Sphagnum* species in Europe and Macaronesia. Abbreviations of areas as in Table 1.

related both to a more continental climate and to more uniform topographic conditions.

Some areas do have very few species. With the exception of the Azores archipelago, few *Sphagnum* species occur in Macaronesia. For the Canary Islands this is related to too little precipitation, but for Madeira Island the absence of areas with slow drainage, particularly at higher altitudes, is most likely. Mediterranean areas without high mountains are also species poor, probably mostly due to high summer temperature and few areas with persistent, slow moving water courses.

Although we believe that *Sphagnum* species can be found in all areas in Europe and Macaronesia, we do not expect many species in three of the four areas where we do not have any registered yet. The absence of *Sphagnum* species in Moldova is probably related to poor exploration, but since the area consists mainly of river plains with extensive human land use, not many species will be found. The absence of species in the Baleares and Franz Josef Land is mostly related to climate, the former with a Mediterranean climate without any high mountains and the latter being an arctic desert.

It is also obvious that many areas are less studied than others. Several countries on the Balkan are poorly known bryologically. We expect that at least in Greece (with 9 species reported), Macedonia (11), Albania (1), Montenegro (0), Serbia (18), Bosnia (19) and Croatia (22) the number will increase considerably. We also think the figure for Slovakia (22 reported species) is low considering the varied topography in the area and the much higher number reported from neighboring areas with similar topography.

As for liverworts (Söderström & Séneca, 2008), a better resolution of the distribution data would give a more detailed picture, reflecting the heterogeneity of many areas, as e.g. a differentiation related either to higher elevation and/or oceanic influence in countries as France, Italy, Spain and Portugal.

There is a strong correlation between number of species and number of restricted species in an area. However, this correlation is not linear but rather exponential. This means that when more species are found in a region, a larger proportion of them will be range restricted. This almost follows from the definition of range restricted species as the most widespread occur in a large number of areas and adding species to an area the chance that it is range restricted increases. This trend is so strong among European *Sphagnum* species that it overrides all other trends. Thus the proportion of range restricted species, and even better the RI, is highest in NW Europe, especially in Scandinavia.

According to island biogeography theory number of species is positively correlated with the size of the area. However, even if this relation is significant also in our study, the relation is weak and two areas (Norway and Sweden) have higher number of range restricted species and four areas (Norway, Sweden, Great Britain and Ireland) higher RI than expected from the size alone. Norway and Sweden are also the two most species rich areas and thus Scandinavia appears to be a center for range restricted species in Europe and Macaronesia.

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