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Species richness and range restricted species of liverworts in Europe and Macaronesia

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Abstract: Species richness and range size patterns of European liverworts are analyzed at global scale. At the scale used in the study, species richness decrease from west to east and from the boreal areas towards both south and north. There is a trend that the larger the areas are the more species there are, but this trend is weak and cannot explain much of the patterns. Of the 490 liverwort species occurring in Europe and Macaronesia, 14.5 % have very small distribution ranges (as defined here; H'<1), which is a much lower figure than e.g. Malesia where over 50 % has small distribution ranges. Number of range restricted and very range restricted species is correlated exponentially with number of species. The geographic patterns of species richness and range restriction are not the same as for vascular plants. The more range restricted a liverwort species is in Europe the more it tends to be an oceanic species. Great Britain and France have most range restricted species but Portugal and the Macaronesian Islands have a larger proportion of liverwort species with small distribution ranges. However, the calculated rarity index is low compared with e.g. Malesia due to both lower number of species and lower proportion of range restricted species.

Kokkuvõte: Helviksammalde liigirikkus ja piiratud levikuga liigid Euroopas ja Makaroneesias

Käeolev töö analüüsib Euroopa helviksammalde liigirikkust ja levila suuruse mustreid globaalses skaalas. Uurimuses kasutatud skaalas väheneb liigirikkus läänest itta ja boreaalsest piirkonnast lõuna ja põhja poole. Esineb suundumus, et mida suurem ala, seda rohkem liike, kuid see trend on nõrk ning ei seleta kõiki levikumustreid. 490 Euroopas ja Makaroneesias esinevast helviksamblaliigist on 14,5 protsendil väga väike levila (siin defineeritud kui H'<1), mis on palju väiksem kui näiteks Maleesias, kus üle 50% liikidest on piiratud levikuga. Piiratud ja väga piiratud levikuga liikide arv on eksponentsiaalselt korreleeritud liikide koguarvuga. Liigirikkuse ja piiratud leviku geograafilised mustrid erinevad soontaimede omast. Mida piiratuma levikuga on helviksambla liik Euroopas, seda enam kaldub ta olema okeaaniline. Kõige piiratuma levikuga liigid on Suurbritannias ja Prantsusmaal, kuid Portugalis ja Makaroneesia saartel on kõige suurem hulk väikse levilaga helviksamblaid. Siiski on piiratud leviku indeks seal madalam kui näiteks Maleesias nii väiksema liikide üldarvu kui ka piiratud levikuga liikide madalama osakaalu tõttu.

INTRODUCTION

In Europe, the Mediterranean areas are most species rich and host most endemic vascular plants (Akeroyd & Heywood, 1994). However, those areas are not the most species rich for liverworts (Söderström et al., 2007). It is also a wide-spread opinion that bryophyte generally have wider distribution ranges, especially in boreal and temperate regions, and are therefore not so much in need for conservation. In Europe about 28% of the c. 12,500 vascular plant species are endemic (Akeroyd & Heywood, 1994) while only 9% of the liverworts (4 of 490 species) are endemic.

Liverworts are usually regarded as difficult to find and to identify in the field except for specialists. Although they are widely recognized as an important part of the total biodiversity, their conservation needs have mostly been neglected or assumed to be taken care of through conservation actions directed to other, more easily identified species. However, it is shown that bryophytes (including liverworts) sometimes show different distribution patterns than vascular plants (Pharo *et al.*, 2000). In order to get a good background for the conservation of the European liverworts, patterns of distribution and rarity at several scales must be analyzed.

In this paper the first step is taken to analyze the range sizes of European and Macaronesian liverworts. The aims are to see if there are any large-scale geographic patterns and therefore large units are used to see how widespread the European taxa are on a global scale and which areas of Europe and Macaronesia host most globally range restricted species.

METHODS

Geographical units, species lists and distribution

The geographical units used follow mainly Brummit (2001) and are scored on 3 levels. Level 1 is basically the continents and has 9 units. Level 2 is regions within continents and has 51 units (5 in Europe, 10 in North America, 10 in Africa, etc.). Level 3 are basically countries except that large countries (e.g. Russia) are separated in smaller units and that very small countries are included in a neighbor (e.g. Liechtenstein in Austria and San Marino in Italy). Brummit's (2001) level 3 areas (here named areas) are used but adjusted for Europe to follow Söderström, Urmi & Váňa (2002; 2007). This gives a total of 384 units (57 in Europe). Those areas are clustered in Brummit's level 2 areas (here named regions). Europe and Macaronesia include 7 regions.

Distributions were registered world-wide for all species recognized to occur in Europe and Macaronesia. Söderström, Urmi & Váňa (2002; 2007) was used as base for the taxa and their distribution in Europe. For distribution outside Europe, data was retrieved from a database compiled by us that covers distribution of all European taxa worldwide, registered in level 3 units.

Defining range restricted species

Distribution ranges were calculated in a way analogous with diversity in ecological investigations. The simplest measure is to count the number of known areas a species occur in. This is analogous with species richness in ecology. However, when talking of diversity in ecology one often use other measures including both number of species and their relative abundance. One of the most used diversity index is the Shannon-Wiener index (Zar, 1984) which indicates how large chance there is that the next individual you see or catch is a different species. This index was transformed to estimate how large chance there is to see the same species in the next region visited. The diversity index often uses number of individuals or cover as the abundance measurement. The most obvious here would be to use number of areas in each region. However, as number of areas varies in regions, the only suitable variable to use as abundance variable is the proportion of areas occupied in each region giving the following formula

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

where p is the proportion of areas occupied in each region.

Range restricted species were defined in 2 ways, the 1/3 of the species with lowest H' (H' ≤ 1.6; 161 species) and all with H' ≤ 1 (70 species). The former is here termed range restricted and the latter very range restricted species.

Defining importance of areas for range restricted species

Proportion of range restricted species may be used as a measure of the relative importance of an area for range restricted species. However, this measure has some unwanted effects. A range restricted species occurring in a species poor area will give a much higher proportion than a range restricted species in a species rich area. Thus, species poor areas will come out as more important just because they are species poor. Therefore, 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.

None of the variables compared were normal distributed and all correlations were for this reason performed with Spearman correlation test.

RESULTS

Number of species

A total of 484 liverwort species occur in Europe and Macaronesia. However, there is a large variation in number of species between the different areas (Fig. 1). For France 308 species are reported whilst only 9 is known from Moldova and none from the European part of Kazachstan (the latter excluded from the analyses).

From classical island biogeography theory the number of species should be positively related to the size of the area. In this study (Fig. 2) the species richness was significantly correlated with size (Spearman corr. coeff. = 0.459; n = 54; $P < 0.001$).

Number of range restricted species

In this study 29 species (6.0 %) had an H' = 0 and 70 species (14.5 %) had H' < 1. Number of range restricted or very range restricted species

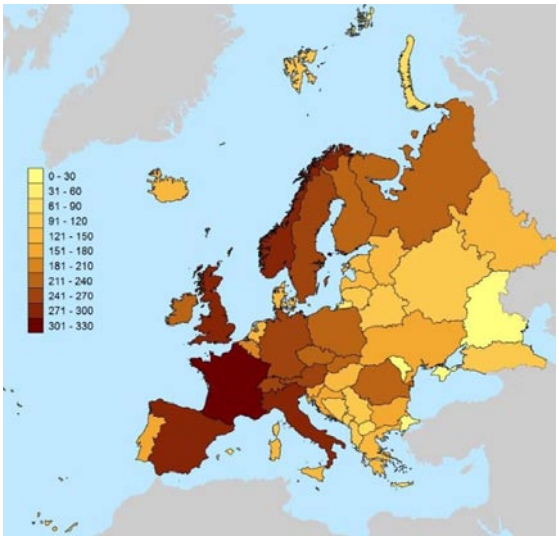

Fig. 1. Number of species of liverworts in various parts of Europe.

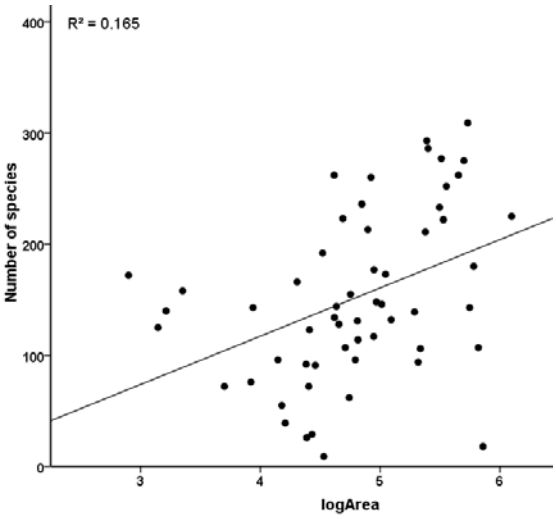

Fig 2. Correlation between number of liverwort species and area (log transformed) in Europe and Macaronesia.

showed no correlation with size of the area. Number of range restricted species (H'<1.6; Fig. 3a) is highly correlated with species richness and number of very range restricted species (H'<1; Fig. 3b) is also correlated with species richness but not so strongly. However, these two relations are not linear but rather exponential (Fig. 4a, b).

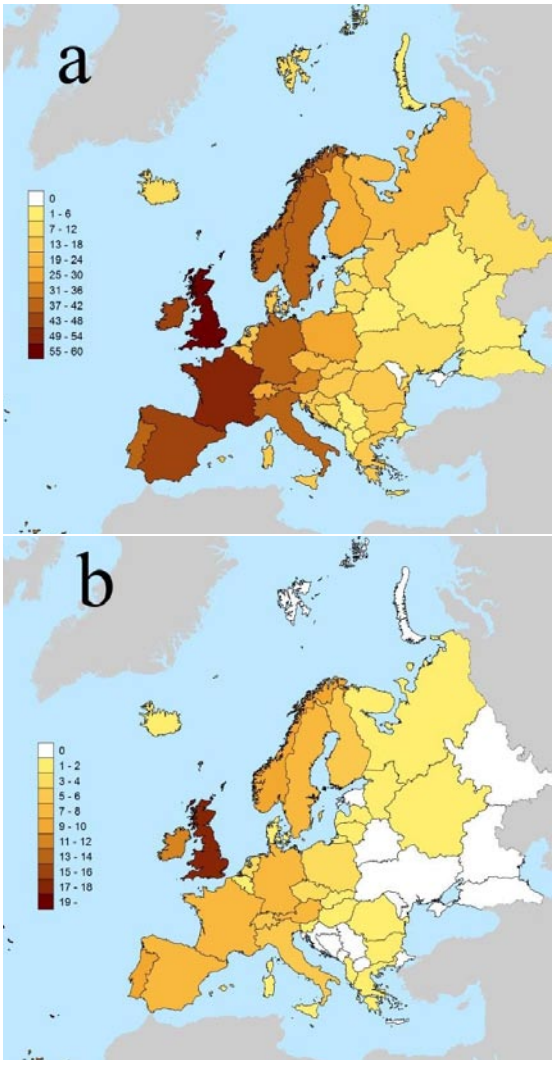

Fig. 3. No of range restricted species (a) and number of very range restricted species (b) in Europe and Macaronesia.

Proportion of range restricted species (Fig. 5) follows about the same pattern as species richness. However, four areas deviated having more range restricted species than the number of species would suggest, i.e. the Macaronesian Islands and Portugal.

Rarity index

Rarity Index (RI; Fig. 6a) has values from 0 (Crimea and Moldova) up to 12.3 for Madeira (11.5 for Great Britain, 11.2 for Azores and 10.3 for

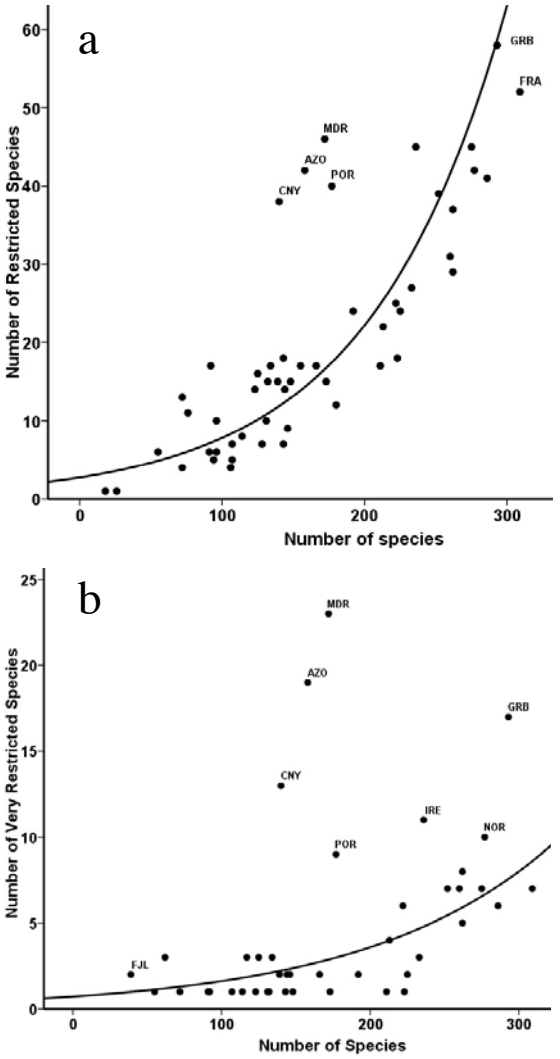

Fig 4. Number of species in relation to (a) number of restricted species, (b) number of very restricted species. Some areas are marked with name (AZO Azores, CNY Canary Is, FJL Franz Josef Land, FRA France, GRB Great Britain, IRE Ireland, MDR Madeira, NOR Norway, POR Portugal).

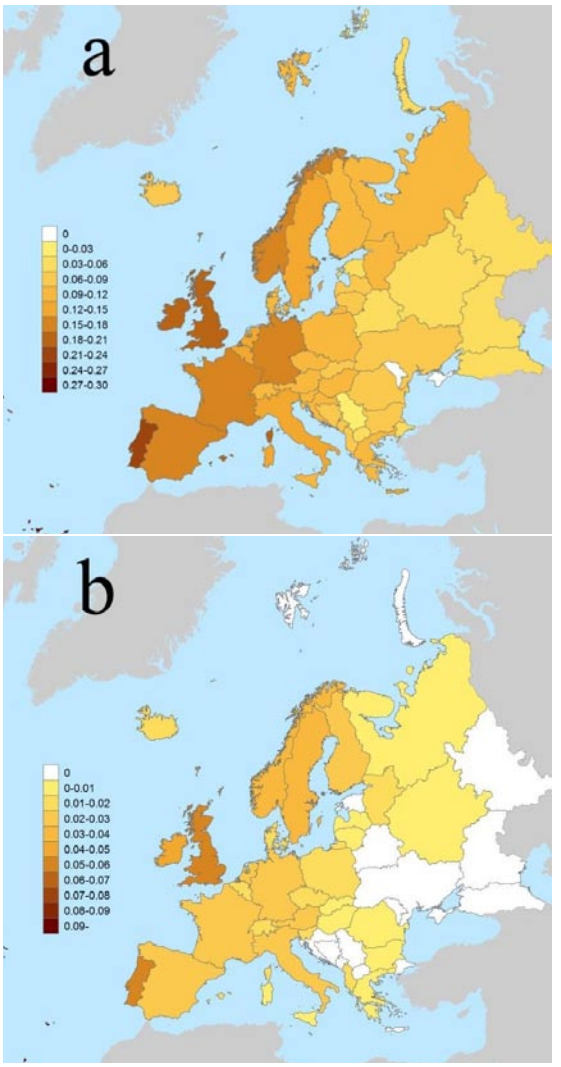

Fig 5. Proportion of range restricted (a) and very range restricted (b) liverwort species in Europe and Macaronesia.

Canary Is.). Calculating Rarity Index for very restricted species (very RI; Fig. 6b) gives values up to 3.08 (Madeira), 2.28 (Azores) and 1.21 (Canary Islands). RI is also strongly correlated with number of species (corr. coeff. = 0.764, n = 57, $P < 0.001$) as is very RI (corr. coeff. = 0.581, n = 57, $P < 0.001$). Also those correlations follow an exponential pattern (Fig. 7a, b).

DISCUSSION

All comparisons in this study show that the liverwort flora of Europe and Macaronesia consists of mainly widespread species and most of the range restricted species occur in very oceanic areas. This distribution pattern does not follow the same pattern as for vascular plants where the highest species richness and most endemism are in the Mediterranean areas (Akeroyd & Heywood, 1994). It is therefore not possible at this scale

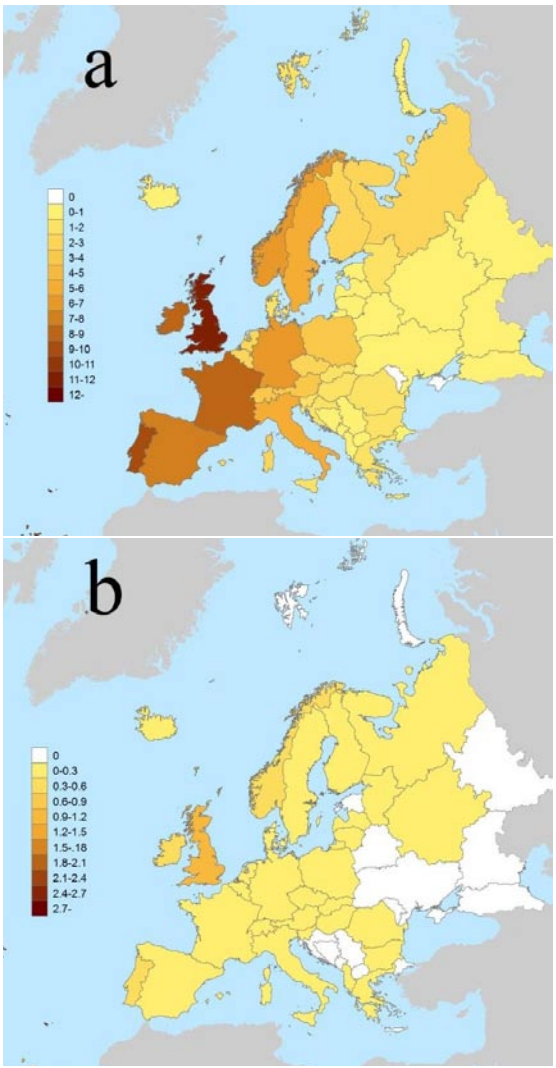

Fig 6. Rarity Index values for fore range restricted (a) and very range restricted (b) liverworts in Europe and Macaronesia.

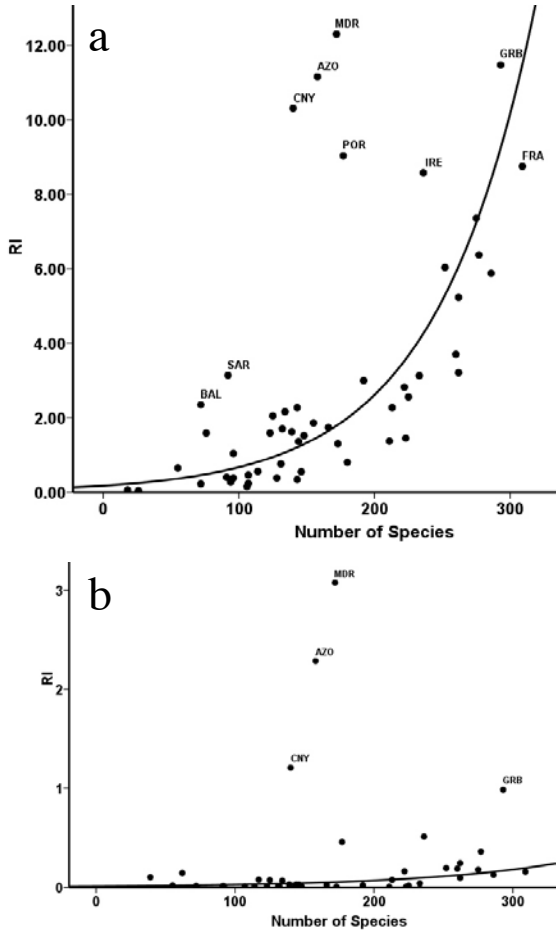

Fig 7. Number of species in relation to (a) rarity index (RI) for range restricted species and (b) RI for very range restricted species. Some areas are marked with name (AZO Azores, BAL Baleares, CNY Canary Is, FRA France, GRB Great Britain, IRE Ireland, MDR Madeira, POR Portugal, SAR Sardinia).

to use patterns in vascular plant biodiversity as a surrogate for patterns in liverwort species richness and rarity. Hepatics are most species rich in oceanic and alpine areas.

The island biogeography theory states that the larger an area is, the more species there should be. This is also true for the European hepatics but the correlation is only weak since large areas as southern and central Russia have much less number of species than expected from their size while smaller areas like Switzerland and Austria do have a higher number than expected. This can be explained in two ways. First, the bryological activity has been, and still is, higher in the Alps than in e.g. southern Russia. Thus, several areas should be expected to have more species than shown here. From our map we expect more species to be found in at least Crimea, Moldova, European Turkey and some areas on Balkan when better explored. However, the different areas also include different vegetation types. Areas with high mountain ranges have more species than surrounding lowland countries. A good example of this is Hungary, a

well explored lowland country, compared with the surrounding countries. Austria, Slovakia and Romania all have many more species. However, Croatia does not have many more species although being more mountainous with a larger variation of vegetation types rich in liverworts. We thus predict that many more species will be found in Croatia with increased exploration but we think the low number for Hungary is a reality.

The number of range restricted species is strongly correlated with number of species and shows thus the same pattern with France and Great Britain having the highest number. Number of very range restricted species is also correlated with species richness. However, here France does not separate from neighboring countries. Instead Great Britain alone does have most very range restricted species. Another change is that Portugal does have more very range restricted species than Spain while the opposite occurred when using only range restricted. Thus the more range restricted a species is in Europe, the more it tends to be an oceanic species.

There are only a few analyses on distribution ranges that are directly comparable with this. The European *Sphagnum* flora have even less globally range restricted species than the European liverwort flora (Séneca & Söderström, 2008) with only 11.8 % very range restricted (H'<1) vs. 14.5 % in liverworts but the H' values for the 1/3 most restricted species is almost equal (< 1.61 vs. <1.60). The *Lophoziaceae/Scapaniaceae* complex (a predominantly northern Hemisphere arctic and boreal group but with several range restricted species in the tropics and southern Hemisphere) has 49.5 % of the species with H' < 1 (Söderström & Séneca, 2006) and over 1/3 of the species had H'=0. Comparable data for all hepatic species in a region is available only for Malesia (Söderström & Séneca, 2008). Europe do have a much lower proportion of globally range restricted species than Malesia (51 % with H'<1) and the 1/3 of the species with lowest H' was only H'<0.62 in Malesia. This indicates generally larger distribution ranges in European liverworts than in other areas, but there is no data available for any other boreal areas.

The relationship between number of species and number of range restricted species is not linear but exponential (Fig. 4a), which means that as more species are found a higher proportion of them are range restricted. The picture of very range restricted species is the same but less steeply rising with number of species (Fig. 4b). Four areas, Canary Islands, Azores, Madeira and Portugal, do however have more range restricted species than should be predicted from the number of species alone. Using only very range restricted species the Macaronesian areas deviates markedly from the rest while Portugal, Ireland and Great Britain also have more very range restricted species than expected from number of species. This is visible also when proportion of range restricted species is calculated (Fig. 5).

Three of the areas with the highest rarity index (RI) values (Great Britain, France and Ireland) are also species rich while four areas (Portugal, Canary Is., Madeira and Azores) are not so species rich. When calculating very RI only the three Macaronesian areas (and to some degree Great Britain) remains important. However, the highest RI values for Europe (12.3) is low compared with most areas in Malesia where Borneo have RI=140 and six of the ten areas there have RI over 20 (Söderström & Séneca, 2008).

The map over number of species (Fig. 1) clearly shows an east-west gradient. However, some of the geographic patterns in species richness are hidden since the areas used here (mainly countries) are too heterogeneous. It seems, e.g., that Ukraine is fairly species rich while in fact most of the species are reported from the Ukrainian part of the Carpathian Mts. in the extreme west of the country. An analysis using smaller units would be preferred but at present no more detailed data is available for many of the larger areas.

REFERENCES

Akeroyd, J. R. & Heywood, V. H. 1994. Regional overview: Europe. In: Davis, S. D., Heywood, V. H. & Hamilton, A. C. (eds.), *Centres of Plant Diversity. Volume 1. Europe, Africa, Southwest Asia and the Middle East.* WWF & IUCN, pp. 39-75.

Brummit, R. K. 2001. *World geographical scheme for recording plant distributions*, ed. 2. Pittsburgh: TDWG, Hunts Inst. Bot. Doc., 153 pp.

Pharo, E. J., Beattie, A. J. & Pressey, R.L. 2000. Effectiveness of using vascular plants to select reserves for bryophytes and lichens. *Biological Conservation*, 96: 371-378

Séneca, A. & Söderström, L. 2008. Species richness and distribution ranges of European *Sphagna*. *Folia Cryptog. Estonica* 44: 125–130.

Söderström, L. & Séneca, A. 2006. World distribution patterns in the Lophoziaceae/Scapaniaceae complex (Hepaticae, Bryophyta). *Journal of the Hattori Botanical Laboratory* 100: 431–441.

Söderström, L. & Séneca, A. 2008. Can species richness and richness of range restricted species be used as a tool for species conservation? In: Mohamed, H., Bakar, B., Boyce, A. N. & Lee, P. K. Y. (eds.), *Bryology in Asia in the New Millennium*. Proceedings of the World Conference of Bryology, 23 - 27 July 2007, Crystal Crown Hotel, Petaling Jaya, Malaysia. University of Malaya, International Association of Bryologists and Malaysian Ministry of Natural Resources (*in press*).

Söderström, L., Urmi, E. & Váňa, J. 2002. Distribution of Hepaticae and Anthocerotae in Europe and Macaronesia. *Lindbergia* 27: 3-47.

Söderström, L., Urmi, E. & Váňa, J. 2007. The distribution of Hepaticae and Anthocerotae in Europe and Macaronesia - Update 1-427. *Cryptogamie, Bryologie* 28: 299-350.

Zar, J.H. 1984. *Biostatistical analysis*, 2nd ed. New Jersey: Prentice Hall, 718 pp.