A miniature world in decline:
European Red List of Mosses, Liverworts and Hornworts

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Preface

This publication has been prepared by IUCN (International Union for Conservation of Nature) as a deliverable of the LIFE European Red Lists project (LIFE14 PRE BE 001). The European Red List of Mosses, Liverworts and Hornworts is, therefore, a part of a series of publications released since 2015, when the project began, that also include:

- European Red List of Lycopods and Ferns, 2017
- European Red List of Saproxylic Beetles, 2018
- European Red List of Terrestrial molluscs: slugs, snails, and semi-slugs, to be released in 2019
- European Red List of Trees, to be released in 2019
- European Red List of selected endemic Shrubs, to be released in 2019

Based on other European Red List assessments, 59% of freshwater molluscs, 40% of freshwater fishes, 28% of grasshoppers, crickets and bush-crickets, 23% of amphibians, 20% of reptiles, 20% of ferns and lycopods, 17% of mammals, 16% of dragonflies, 13% of birds, 9% of butterflies and bees, 8% of aquatic plants and 2% of medicinal plants are threatened at the European level (IUCN 2015, Hochkirch et al. 2016). Additional European Red Lists assessing a selection of species showed that 22% of terrestrial molluscs, 16% of crop wild relatives, 20% of ferns and lycopods and 18% of saproxylic beetles are also threatened (Cuttelod et al. 2011, Bilz et al. 2011, García Criado et al. 2017, Cálix et al. 2018). The findings of this work suggest that 22% of bryophytes are threatened species in Europe, which corresponds to a similar percentage as terrestrial molluscs, representing the third most threatened group of plants assessed so far.

Acknowledgements

All of IUCN’s Red Listing processes rely on the willingness of scientists to contribute and pool their collective knowledge to make the most reliable estimates of the status of a species. Without their enthusiastic commitment to species conservation, this kind of regional overview would not be possible. Bryophytes are no exception, and the knowledge mobilized through the Europe-wide network of members of the European Committee for the Conservation of Bryophytes (ECCB) has been pivotal to the completion of this Red List. We are therefore indebted for their support and contributions.

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Lindenberg’s featherwort *Adelanthus lindenbergianus* (Endangered liverwort) © Rory Hodd

*Cneistrum glaucescens* (Near Threatened moss) © Michael Lüth
Executive summary

Aim

- This Red List is a summary of the conservation status of the European species of mosses, liverworts and hornworts, collectively known as bryophytes, evaluated according to IUCN’s Guidelines for application of IUCN Red List criteria at regional level. It provides the first comprehensive, region-wide assessment of bryophytes and it identifies those species that are threatened with extinction at a European level, so that appropriate policy measures and conservation action, based on the best available evidence, can be taken to improve their status.

Scope

- All bryophytes native to or naturalised in Europe (a total of 1,817 species), have been included in this Red List. In Europe, 1,796 species were assessed, with the remaining 21 species considered Not Applicable (NA). For the EU 28, 1,728 species were assessed, with 20 species considered NA and 69 species were Not Evaluated (NE). The geographical scope is continent-wide, extending from Iceland in the west to the Urals in the east, and from Franz Josef Land in the north to the Canary Islands in the south. The Caucasus region is not included. Red List assessments were made at two regional levels: for pan-Europe and for the 28 Member States of the European Union.

Results

- Overall, 22.4% of European bryophyte species assessed in this study are considered threatened in Europe, with two species classified as Extinct and six assessed as Regionally Extinct (RE). A further 9.6% (173 species) are considered Near Threatened and 63.5% (1,140 species) are assessed as Least Concern. For 93 species (5.3%), there was insufficient information available to be able to evaluate their risk of extinction and thus they were classified as Data Deficient (DD).

Recommendations

- Policy measures
  - Use the European Red List as the scientific basis to inform regional/national lists of rare and threatened species and to identify priorities for conservation action in addition to the requirements of the Habitats Directive, thereby advancing the conservation status of bryophytes at the regional/local level.
  - Use the European Red List to support the integration of conservation policy with the CAP and other national and international policies. For example, CAP Strategic Plans should include biodiversity recovery commitments that could anticipate, among others, the creation of Important Bryophyte Areas. An increased involvement of national environmental agencies in the preparation of these strategic plans, and more broadly in ongoing discussions on the Future CAP Green Architecture, would likely also ensure the design of conservation measures better tailored to conserve bryophytes in agricultural landscapes.
  - Update the European Red List every decade to ensure that the data remains current and relevant.
  - Develop Key Biodiversity Areas for bryophytes in Europe with a view to ensuring adequate site-based protection for bryophytes.

- Research and monitoring
o Use the European Red List as a basis for future targeted fieldwork on possibly extinct and understudied species.

o Establish a monitoring programme for targeted species (for example, threatened species and/or arable bryophytes).

o Use the European Red List to obtain funding for research into the biology and ecology of key targeted species.

• **Action on the ground**

  o Use the European Red List as evidence to support multi-scale conservation initiatives, including designation of protected areas, reform of agricultural practices and land management, habitat restoration and rewilding, and pollution reduction measures.

  o Use the European Red List as a tool to target species that would benefit the most from the widespread implementation of the solutions offered by the 1991 Nitrates Directive (Council Directive 91/676/EEC), including the application of correct amounts of nutrients for each crop, only in periods of crop growth under suitable climatic conditions and never during periods of heavy rainfall or on frozen ground, and the creation of buffer zones to protect waters from run-off from the application of fertilizers.

• **Ex-situ conservation**

  o Undertake ex-situ conservation of species of conservation concern in botanical gardens and spore and gene banks, with a view to reintroduction where appropriate.

*Exormotheca welwitschii* (Endangered liverwort) © Michael Lüth
1. Background

1.1 The European context

Europe is the world’s second smallest continent in terms of area after Australia, covering approximately 10.4 million km², or 2% of the Earth’s surface. In terms of human population, Europe is the third largest continent (after Asia and Africa) with a population of around 546 million (UN DESA 2018) – about 13% of the world’s population. Therefore, Europe is one of the smallest and one of the most densely populated continents in the world.

The European Union (EU), consisting of 28 Member States, is Europe’s largest political and economic entity. The EU 28’s ecological footprint has been estimated to exceed the region’s biological capacity (the total area of cropland, pasture, forest, and fishing grounds available to produce food, fibre and timber, and absorb waste) by 2.6 times (EEA 2015).

Europe contains areas of great diversity of landscapes and habitats and a wealth of flora and fauna. For example, the Mediterranean Basin, which is especially rich in plant and animal species, many of them endemic to that region, has been recognised as a global biodiversity hotspot (Mittermeier et al. 2004, Cuttelod et al. 2008).

The European continent has a highly fragmented landscape, and up to 80% of land in Europe is currently used for settlement, industry, production systems (including agriculture and forestry) and infrastructure (EEA 2006, Pedrol and Meiner 2017). Consequently, European species are to a large extent dependent upon habitats created and maintained by human activity, and many are affected by overexploitation, persecution and the impacts of invasive alien species. Additionally, climate change is set to become an increasingly serious threat. Europe is a diverse region and the relative importance of different threats varies widely across its biogeographic regions and countries.

Although considerable efforts have been made to protect and conserve European habitats and species (see Sections 4.1 and 4.2), and the Natura 2000 network of protected areas covers more than 18% of the EU terrestrial territory, biodiversity decline and the associated loss of vital ecosystem services (such as water purification, pollination, flood protection and carbon sequestration) continues to be a major concern in the region.

1.2 European mosses, liverworts and hornworts

Bryophytes are a large, diverse group of plants. According to Villareal et al. (2010), there are somewhere between 16,000 and 17,000 described species worldwide, comprising about 11,000-13,000 mosses, 7,000-9,000 liverworts and 200-250 hornworts, making them second only to flowering plants in terms of species richness. This could however be an underestimate, with molecular studies revealing ‘new’ species all the time. Each of the three groups of bryophytes has been traditionally considered to be a separate phylum (or division): Bryophyta (mosses), Marchantiophyta (liverworts) and Anthocerotophyta (hornworts) (Frey & Stech 2009), although the latest evidence, with increasing support, suggests that mosses and liverworts form a clade, termed “Setaphyta” (Puttick et al. 2018). Nevertheless a number of biological and ecological characters are common to the three groups: They are small (rarely larger than a few centimeters), unable to produce lignin (they cannot become woody), have their life cycle dominated by the gametophyte (rather than the sporophyte) generation – see Box 1 - and are able to dry out completely in dry periods, quickly resuming their metabolism when rewetted. They fulfill a range of important...
ecological functions, particularly in water retention, soil-building and in their relationships with other organisms. For example, bog-moss (*Sphagnum* spp.) is one of the most important plants, and certainly the most important peat producer in the world, locking away an enormous amount of carbon and holding vast quantities of water: bogs are essentially huge sponges. Bryophytes, particularly epiphytes, are also great indicators of air pollution. Bryophytes show a vast range of specific sensitivity and visible symptoms to pollutants greatly exceeding that of higher plants (Govindapyari *et al*. 2010).

**Box 1 - The life history of bryophytes**

What distinguishes bryophytes collectively from all other land plants is that their life cycle is dominated by the gametophyte generation; that is, by the haploid, or sexual phase, as opposed to the diploid, spore-producing phase. In contrast, all flowering plants, conifers and ferns are dominated by the sporophyte generation, with the gametophyte much reduced, often to just a few cells. In other words, the main plant that one sees, the leafy green part, that is mainly photosynthetic, is the gametophyte in bryophytes, whereas it is the sporophyte in all other plants. The bryophyte sporophyte is usually reduced to a spore-producing, stalked capsule that remains attached to the gametophyte, and is entirely dependent on it for sustenance.

**Figure 1. The life cycle of a bryophyte © Htpaul/Wikipedia (CC BY-SA 3.0)**

The spore is the first stage in the haploid gametophyte generation, with a single set of unpaired chromosomes. Spores germinate into a green protonema, from which the mature gametophyte grows, either producing a structure with a stem and leaves (as in mosses and leafy liverworts) or a structure with no differentiation, usually a flat plate of tissue called a thallus (as in thallose liverworts and hornworts). The gametophyte produces (either on the same plant [bisexual, Fig. 1] or on separate plants [unisexual, Fig. 1]) male and female sex organs (antheridia and archegonia, respectively). The antheridia produce sperm, which swim in a film of water to the archegonia. In each archegonium only a single egg cell is found which may be fertilized by a sperm cell. If fertilization has been successful, i.e. if male and female elements of the gametophyte have fused, a new sporophyte starts to develop. The sporophyte relies largely on the gametophyte for its nutrition. At maturity it eventually produces spores by the process of meiosis, the kind of cell
division that halves the number of chromosomes. In other words, the brief reign of the sporophyte is over, and a new gametophyte generation is ready to develop.

While there is a lot of variation in the detail of how bryophytes conduct their life cycle, they all conform to this basic pattern. In addition, many of them produce specialised asexual reproductive organs, such as gemmae, which circumvent the sporophyte generation entirely, simply replicating the gametophyte parent. In addition, all bryophytes are to some extent totipotent: they can regenerate from fragments, or even single cells, making them great survivors.

Mosses
The most species-rich of the three main groups of bryophytes, mosses, encompasses an enormous range of forms. ‘Typical’ mosses (Class Bryopsida) are mostly small, rather delicate, often translucent plants that absorb water and nutrients externally, over their entire surface. The sporophyte consists of a capsule in which the spores are produced supported by a stalk (seta). When mature, the capsule releases its spores through an opening at the top, which is usually surrounded by a ring of tooth-like structures (the peristome).

Not all mosses conform to this general template. There are a few groups occurring in Europe that are so distinctive they are put in their own classes within the Bryophyta. Most obviously, and certainly most importantly, are the bog-mosses, the genus *Sphagnum* (Class Sphagnopsida) with 61 species in Europe. They differ from typical mosses in almost every respect, except for the dominance of the gametophyte generation. Its unique cell structure allows *Sphagnum* to take up water quickly by capillary action, and release it only very slowly, like a sponge. Other features of its physiology and morphology make it possible for *Sphagnum* to dominate entire landscapes, as in the extensive boglands of northern Europe, which store tremendous amounts of peat built by thousands of years of *Sphagnum* growth.

A further oddity among the mosses is *Andreaea* (rock-moss, Class Andreaeopsida), tiny black or very dark red-brown tufts on acid rocks in the mountains, with a capsule that splits into four lobes joined at the top, a bit like a miniature Japanese lantern. Then there are the haircap mosses, the genus *Polytrichum* and its allies (Class Polytrichopsida). As well as having a distinctive spore capsule, these plants have an internal conduction system somewhat analogous to the xylem and phloem of vascular plants, enabling them to grow much bigger than ‘ordinary’ mosses, and shoots of *Polytrichum* are capable of attaining heights of half a metre or even more. Another couple of small Classes, the Oedipodiopsida and the Tetraphidopsida, differ fundamentally from the Bryopsida in features of the sporophyte, but have few species.
Liverworts

A less species-rich group than mosses, yet showing a greater range of forms, liverworts can be subdivided into leafy (Class Jungermanniopsida) and thallose (Class Marchantiopsida), plus a group of rather anomalous plants that show features of both leafy and thallose liverworts (Class Haplomitriopsida, with only a single species in Europe).

Leafy liverworts are especially diverse in the form of the leaves, which range from entire and rounded, through simply bilobed or trilobed, to deeply divided into filaments or asymmetrically divided so that one lobe is larger than the other, or even modified into a tiny pocket or helmet-shaped structure. Furthermore, while leafy liverworts typically have two rows of main (lateral) leaves running down opposite sides of the stem, many species have an additional row of leaves on the under-surface of the stem (underleaves, or amphigastria): these are usually smaller than the lateral leaves, and often quite different in shape.

The form of the sporophyte is relatively uniform among the liverworts, although there is great variation in the various gametophytic structures that support and protect it. Unlike mosses, where the spore capsule and seta mature slowly together, and then spores are released gradually, the liverwort capsule matures inside a protective sheath (usually a structure derived from modified leaves called a perianth), and is raised up on a seta only when ready to release its spores. The seta therefore grows at a tremendously fast rate, by sudden elongation of its cells, and forms a delicate,
ephemeral structure which lasts just long enough for the mature capsule to release all its spores at once.

**Hornworts**
The least species-rich group of bryophytes, the hornworts, superficially resemble thallose liverworts, but are not closely related. They probably emerged as a group at about the same time as the other bryophytes, in the Ordovician period about 470 million years ago, or even earlier (Morris et al. 2018), but whether they were even then part of the same taxonomic group as other bryophytes is still a matter for research. They have an unusual combination of features, some shared with other bryophytes, some having more in common with vascular plants or algae. For example, the thallus cells contain just one large chloroplast, while the sporophyte, which is a long narrow structure with no differentiation into seta and capsule, has stomata. Hornworts reach their greatest diversity in the tropics, with only a small handful of species occurring in Europe. Nonetheless, certain species can be locally abundant given the right conditions.

a) *Mannia triandra* (Vulnerable liverwort) © Christian Schröck, b) *Phaeoceros carolinianus* (Near Threatened hornwort) © Michael Lüth

**Distribution, habitats and ecology**
Bryophytes occur on all continents and in many different habitats except in the sea. They are almost ubiquitous, growing even in very dry semi-deserts, but require some moisture, at least at some stages of their life cycle. Unlike vascular plants, most species are poorly equipped to regulate their water content internally, instead drying out and rewetting rapidly according to external conditions (poikilohydric). This means that they are often luxuriant in moist forest and in high rainfall areas. Bryophytes absorb water, along with the minimal amounts of nutrients they require, over their entire surface from the surrounding environment, rather than taking it up through roots and a vascular system. However, many bryophytes, and most of the European bryophytes, have a physiology that allows them to dry out completely in the absence of moisture, suspend physiological activity, and then ‘come back to life’ when wetted again. Different species do this to different degrees, but herbarium specimens of the Great Hairy Screw-moss (*Syntrichia ruralis*) were recently found to have retained their vitality after over 20 years dried in a packet (Stark et al. 2016), and there are unsubstantiated anecdotes about much longer periods of survival in the herbarium. Many species which grow directly on rock in exposed conditions (*Grimmia, Didymodon*, etc.) dry out and rehydrate virtually on a daily basis, particularly in warmer climates; this is their strategy for enduring drought. This contrasts with most vascular plants, which could not survive this level of dehydration.

Bryophytes, then, have several ecological attributes that are very distinctive:
They are poikilohydric, i.e., they dry out and rewet rapidly according to external conditions.

They grow in 'microhabitats': whether they grow in woodland, heathland or grassland is less important than the immediate micro-environment, such as a rock crevice or a moist patch of soil.

A large proportion of species are colonists, and therefore form pioneer communities and assemblages. There are, for example, many short-lived ruderal (weedy) species that colonise bare ground, disappearing as vegetational succession proceeds.

They are very efficient at dispersal, with spores and vegetative propagules potentially capable of travelling worldwide in the air or via vectors such as migratory birds.

Due to the latter, levels of endemism are low (in Europe, ca. 10% compared to ca. 28% vascular plants; Patino & Vanderpoorten 2018), but levels of disjunction are high (for example, occurring in western Europe, the Himalayas and British Columbia).

They are often excellent ecological indicators (for example, of nutrient status or pH).

Grimmia mollis (Vulnerable moss) © Michael Lüth

Ecosystem services and commercial use
The ecosystem services that bryophyte species provide might not be conspicuous, but a bit of thought and research soon tells us that these small plants, useless as food or building materials, are actually of vital importance. In particular, there are three main features of bryophytes that make them important in the ecosystem:

- Their ability to retain water. All bryophytes act to some extent as sponges, taking up water rapidly, holding it, and releasing it only slowly. This is most obvious in bog-moss *Sphagnum*, which dominates vast areas of mire in northern Europe. On hillsides and hilltops, *Sphagnum* is an important stabilising influence in areas with heavy rainfall. A similar effect is seen in forest ecosystems. A substantial part of the water-holding capacity of forests is bound up in the bryophytes, and when it is clear-felled, the resultant erosion, flooding and destabilisation is at least partly because the bryophytes have been removed from the landscape along with the trees.
They are efficient colonisers and stabilisers of bare substrates. When natural erosion occurs, bryophytes are usually the first plants to appear on the newly exposed surfaces. After volcanic eruptions, bryophytes are the first to try their luck on the cooling lava flows. In post-industrial landscapes, and in urban habitats more generally, bryophytes often build up thick carpets over crumbling concrete and tarmac, trapping detritus, building new soils, providing rooting substrates for larger plants and ultimately the basis for entire new ecosystems.

They serve as hosts for blue-green algae (cyanobacteria), which have an important role in nitrogen (N) fixation, and provide a major source of N for boreal ecosystems (for example, Ackerman 2013). It is likely that epiphytic cyanobacteria are a key factor in determining the abundance of feather mosses across the boreal biome (Zackrisson et al. 2019). Additionally, they provide habitats for other organisms; seed-beds for vascular plants, shelter for invertebrates, nesting material for birds and small mammals. Bogs in particular form entire ecosystems fundamentally dependent on bryophytes.

Sphagnum mosses are used commercially - peat is (or has been, historically) burned for fuel. However, this has rarely been done in a sustainable way, and several countries have established peat-burning power stations, which have had a devastating effect on peatlands. It has also been used as a mildly antiseptic dressing for wounds (it was harvested for this purpose during the First World War), and as an absorbent material in babies’ nappies. Bryophytes are harvested commercially (sustainably or otherwise) for horticultural purposes such as packing material for bulbs or a water-retentive substrate for hanging baskets. Sphagnum harvested for horticultural purposes is also not usually sustainable. A more modern use is that of mosses, particularly the Habitats Directive Annex V Leucobryum, for ‘moss walls’ and other ‘green’ architectural purposes. Other commercial uses are largely historical or minor: Polytrichum commune for brooms, mosses as insulation for homes, decorative garlands and even clothing for the famous ‘moss men’ of Béjar in Spain.
The procession of ‘moss men’ in Béjar, Spain, commemorating the use of moss as camouflage in battles during the 12th century by local Christians © Eloy Díaz-Redondo

1.3 Assessment of species extinction risk

The conservation status of plants, animals and fungi is one of the most widely used indicators for assessing the extinction risk of ecosystems and their biodiversity. At the global scale, the primary source of information on the conservation status of plants and animals is the IUCN Red List of Threatened Species™ (www.iucnredlist.org).

The IUCN Red List Categories and Criteria (IUCN 2012a) are designed to determine the relative risk of extinction of a taxon, with the main purpose of cataloguing and highlighting those taxa that are facing a high risk of extinction. The IUCN Red List Categories are based on a set of quantitative criteria linked to population trends, size and structure, threats, and geographic ranges of species. When conducting regional or national assessments, the IUCN Red List Regional Guidelines (IUCN 2012b) are applied to assign the IUCN Red List Categories (Fig. 2).

As the extinction risk of a species can be assessed at global, regional or national levels, a species may have a different Red List Category in the global Red List than in the regional Red List. Logically, an endemic species should have the same Category at regional and global levels, as it is not present anywhere else in the world.

Figure 2. The IUCN Red List Categories at the regional scale.
1.4 Objectives of the assessment

The European Red List of Mosses, Liverworts and Hornworts has four main objectives:

- to contribute to regional conservation planning through provision of a baseline dataset reporting the conservation status of European bryophyte species;
- to identify those priority geographic areas and habitats needing to be conserved to prevent extinctions and to ensure that European bryophytes reach and maintain a favourable conservation status;
- to identify the major threats and to propose potential mitigating measures and conservation actions to address them;
- to strengthen the network of experts focused on bryophyte conservation in Europe, so that the assessment information can be kept current and expertise can be targeted to address the highest conservation priorities.

The assessment provides three main outputs:

- summary reports on the status of all 1,817 European bryophyte species;
- a freely available database holding the baseline data on the status and distribution of European bryophytes;
- a website and data portal (http://ec.europa.eu/environment/nature/conservation/species/redlist and www.iucnredlist.org/initiatives/europe) showcasing these data in the form of species factsheets for all European bryophytes included in this study, along with background and other interpretative material.

This new Red List provides the first comprehensive, region-wide assessment of bryophytes and builds on the previous work of the European Committee for the Conservation of Bryophytes (ECCB). The enormous amount of new fieldwork, data and knowledge accumulated since then means that it should be much more robust and authoritative. Efforts will continue to update the database which will also be made freely and widely available.
Matted bryum *Bryum calophyllum* (Endangered moss) © Neil Lockhart
2. Assessment methodology

2.1 Geographic scope

The geographic scope is continent-wide, extending from Iceland in the west to the Urals in the east (including European parts of the Russian Federation), and from Franz Josef Land in the north to the Mediterranean in the south (Fig. 3). The Canary Islands, Selvagens, Madeira, the Azores, Malta and Cyprus are also included. In the southeast, the Caucasus region and Anatolia are excluded.

Red List assessments were made at two regional levels: 1) for geographical Europe (limits described above); and 2) for the area of the 28 Member States of the European Union (as of 2018).

Figure 3. European assessment boundaries*.

* Regional assessments were made for two areas: geographical Europe and the EU 28.

2.2 Taxonomic scope

The European Red List of Mosses, Liverworts and Hornworts has assessed the status of all bryophyte species considered native to or naturalised in Europe. The original list of species was based on Hodgetts (2015), which was itself based on Hill et al. (2006) for the mosses and Söderström et al. (2007) for the liverworts and hornworts. The inclusion of newly described or modified taxa (up to the end of 2019) was undertaken following consultation with the relevant experts. When there were discrepancies in the identity of a species, consultation was sought among the different specialists and decisions were made through consensus.
2.3 Assessment protocol

For all the bryophyte species assessments, the following data were compiled:
- Taxonomic classification and notes
- Geographic range and list of countries of occurrence (including a range map)
- Population information and overall population trends
- Habitat preferences and primary ecological requirements, including pertinent biological information (for example, generation length, maximum size and age, etc.)
- Species use and trade
- Major threats
- Research needs
- Conservation measures (in place and needed)
- IUCN Red List Category and Criteria and rationale
- Key literature references

Some critical terms like ‘individual’, ‘generation length’, and ‘fragmentation’ had to be defined in a pragmatic way so that they became applicable to bryophytes. Work over several years (for example, Hallingbäck et al. 1998) and collaboration with the IUCN under this project, has culminated in a paper addressing these issues (Bergamini et al. in press).

The task of collecting the initial data was divided geographically between 12 Lead Assessors (Appendix 1), and information on each species was based on published and unpublished data and expert knowledge. The IUCN Species Information Service (SIS) was used to enter and store all species data.

A training workshop was held in October 2015 in Paris (France) in order to train the experts on the IUCN Red List methodology. After the preliminary information was collected by the Lead Assessors, five assessment workshops were held to review and discuss all the assessments and distribution maps, add new information to the assessments, and agree on the final IUCN Red List Category and Criteria for the species. The workshops took place at the Faculty of Sciences of the University of Lisbon (Portugal; December 2016), the Ministry of Environment of the Czech Republic (Prague; January 2017), the IUCN European Regional Office in Brussels (Belgium; February 2017), the National Botanical Gardens of Ireland (Dublin; April 2017), and ArtDatabanken at the Swedish University of Agricultural Sciences (Uppsala, June 2017). In addition, some discussions on the exact methodology were held at an external workshop in Ekenäs (Sweden). Overall, 60 experts participated in the assessment workshops.

Following the workshops, the information was edited and the remaining questions were resolved through communications with the Lead Assessors. An additional peer-review process was carried out, with all assessments checked by external reviewers who had not been previously involved in the assessment process. Consistency in the use of IUCN Categories and Criteria was systematically checked by IUCN staff. The resulting finalised IUCN Red List assessments are a product of scientific consensus concerning species status and are supported by relevant literature and data sources (Appendix 2).

2.4 Species mapping

Distribution data were mainly obtained through published literature, herbarium specimens, internet sources (for example, GBIF) and several global and regional citizen science projects. The species experts provided the distribution data to the Ministry of Environment of the Czech Republic (MZP) where Jan Vrba compiled the data in order to produce the final distribution maps.
Range maps were created using the distribution data available, which varied in terms of quality; for some regions, distributional data were available as point locality data (latitude/longitude) or in grid cell format, and were therefore spatially precise. Where point or grid data were available, these were projected in a Geographical Information System (GIS) (ESRI ArcMap). Polygons were then drawn manually, clustering occurrence data where appropriate. In some rare cases where no point data was available and it was only possible to assign presence at the country level, the distribution was mapped for the whole country.

The spatial analyses presented in this publication (see section 3.3) were done using a geodesic discrete global grid system, defined on an icosahedron and projected to the sphere using the inverse Icosahedral Snyder Equal Area (ISEA) Projection (S39). This corresponds to a hexagonal grid composed of individual units (cells) that retain their shape and area (864 km²) throughout the globe. These are more suitable for a range of ecological applications rather than the most commonly used rectangular grids (S40). The known current distributions (IUCN 2014) of extant and possibly extant species were converted to the hexagonal grid for the purposes of the analysis. Coastal cells were clipped to the coastline.

3. Results

3.1 Threat status
At the European level, 22.4% of bryophyte species are considered threatened (i.e., assessed as having an elevated risk of extinction). However, the proportion of threatened species is uncertain given the number of Data Deficient (DD) species and could lie between 21.3% (if all DD species are not threatened) and 26.5% (if all DD species are threatened) for Europe (IUCN 2011, Table 1). The mid-point figure provides the best estimation of the proportion of threatened species (IUCN 2011). In the EU 28, 24.2% of species are considered to be threatened, with the proportion of threatened species lying between 22.4% (if all DD species are not threatened) and 27.9% (if all DD species are threatened, Table 1). Appendix 3 provides an exhaustive list of all bryophyte species assessed under the current European Red List and corresponding conservation status in Europe, EU28 also indicating if the species is endemic or not to Europe.

<table>
<thead>
<tr>
<th></th>
<th>Europe % threat</th>
<th>EU 28 % threat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lower bound</strong></td>
<td>(CR+EN+VU) / (assessed – EX)</td>
<td>21.3</td>
</tr>
<tr>
<td><strong>Mid-point</strong></td>
<td>(CR+EN+VU) / (assessed – EX – DD)</td>
<td>22.4</td>
</tr>
<tr>
<td><strong>Upper bound</strong></td>
<td>(CR+EN+VU+DD) / (assessed – EX)</td>
<td>26.4</td>
</tr>
</tbody>
</table>

In Europe, six species (0.3%) are assessed as Regionally Extinct, with two endemic species assessed as Extinct (0.1%). 59 species (3.3%) are Critically Endangered, 143 species (8%) are Endangered, and 180 species (10%) are Vulnerable (Table 2). A further 173 species (9.6%) are classified as Near Threatened. For 93 species (5.3%) there were insufficient data to evaluate their risk of extinction and so they were classified as Data Deficient (Table 2, Figure 4). There were 21 species that were classed as Not Applicable in Europe (species introduced after AD 1500 or species of marginal occurrence).
more data become available and taxonomic issues are clarified, it is possible that some of these species may also prove to be threatened.

In the EU 28, six species (0.3%) are assessed as Regionally Extinct, two are assessed as Extinct (0.1%). 65 species (3.8%) are Critically Endangered, 150 species (8.7%) are Endangered, and 183 species (10.6%) are Vulnerable. A further 173 species (10%) are classified as Near Threatened. For 82 species (4.8%) in the EU 28 there were insufficient data to evaluate their risk of extinction and so they were classified as Data Deficient (Table 2, Figure 4). Not Evaluated refers to species occurring at the European level that did not occur within the EU Member States (for example, only occurs in European Russia).

Table 2. Summary of numbers of mosses, liverworts and hornworts within each Category of threat. Numbers of endemic species are included in brackets

<table>
<thead>
<tr>
<th>IUCN Red List Categories</th>
<th>No. species Europe (no. endemic species)</th>
<th>No. species EU 28 (no. endemic species)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extinct (EX)</td>
<td>2 (2)</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Extinct in the Wild (EW)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Regionally Extinct (RE)</td>
<td>6 (0)</td>
<td>6 (0)</td>
</tr>
<tr>
<td>Critically Endangered (CR)</td>
<td>59 (18)</td>
<td>65 (15)</td>
</tr>
<tr>
<td>Endangered (EN)</td>
<td>143 (40)</td>
<td>150 (28)</td>
</tr>
<tr>
<td>Vulnerable (VU)</td>
<td>180 (36)</td>
<td>183 (25)</td>
</tr>
<tr>
<td>Near Threatened (NT)</td>
<td>173 (33)</td>
<td>173 (22)</td>
</tr>
<tr>
<td>Least Concern (LC)</td>
<td>1140 (45)</td>
<td>1067 (13)</td>
</tr>
<tr>
<td>Data Deficient (DD)</td>
<td>93 (17)</td>
<td>82 (11)</td>
</tr>
<tr>
<td><strong>Total number of species analysed</strong></td>
<td><strong>1,796 (191)</strong></td>
<td><strong>1,728 (116)</strong></td>
</tr>
<tr>
<td>Not Applicable (NA)</td>
<td>21 (0)</td>
<td>20 (0)</td>
</tr>
<tr>
<td>Not Evaluated (NE)</td>
<td>-</td>
<td>69 (0)</td>
</tr>
<tr>
<td><strong>Total number of species assessed</strong></td>
<td><strong>1,817 (191)</strong></td>
<td><strong>1,817 (116)</strong></td>
</tr>
</tbody>
</table>
Figure 4. IUCN Red List status of mosses, liverworts and hornworts in Europe.

Figure 5. IUCN Red List status of mosses, liverworts and hornworts in the EU 28.
3.2 Status by taxonomic group

Table 3 presents the status of European bryophyte species organised by major group, split into mosses, liverworts and hornworts. It is not considered useful to break it down further into orders or families because the higher classification of bryophytes is continually changing with ongoing research. A stable consensus on the higher classification of bryophytes will probably not be reached within several years. There are many more species of mosses (1,327) than liverworts (461) and hornworts (8) in Europe.

Table 3. IUCN Red List status (at the European level) of mosses, liverworts and hornworts.

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>CR</th>
<th>EN</th>
<th>VU</th>
<th>NT</th>
<th>LC</th>
<th>DD</th>
<th>EX or RE</th>
<th>Best estimate of % threatened *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mosses</td>
<td>1,327</td>
<td>43 (3.2%)</td>
<td>103 (7.8%)</td>
<td>137 (10.3%)</td>
<td>120 (9.0%)</td>
<td>853 (64.3%)</td>
<td>64 (4.8%)</td>
<td>7 (0.5%)</td>
<td>22.4</td>
</tr>
<tr>
<td>Liverworts</td>
<td>461</td>
<td>16 (3.5%)</td>
<td>38 (8.2%)</td>
<td>43 (9.3%)</td>
<td>51 (11.1%)</td>
<td>283 (61.4%)</td>
<td>29 (6.3%)</td>
<td>1 (0.2%)</td>
<td>22.5</td>
</tr>
<tr>
<td>Hornworts</td>
<td>8</td>
<td>0</td>
<td>2 (25.0%)</td>
<td>0</td>
<td>2 (25.0%)</td>
<td>4 (50.0%)</td>
<td>0</td>
<td>0</td>
<td>25.0</td>
</tr>
<tr>
<td>Total</td>
<td>1,796</td>
<td>59 (3.3%)</td>
<td>143 (8.0%)</td>
<td>180 (10.0%)</td>
<td>173 (9.6%)</td>
<td>1,140 (63.5%)</td>
<td>93 (5.2%)</td>
<td>8 (0.4%)</td>
<td>22.4</td>
</tr>
</tbody>
</table>

*The percentage of threatened species provides the mid-point figure as the best estimation of extinction risk. In addition, 21 NA species were not included in this table.

The percentages of species in different threat categories are similar for mosses and liverworts. This similarity may reflect the fact that there is nothing particularly distinctive about their ecology or distribution that may influence extinction risk. Instead, different life strategies and ecologies are spread widely throughout both liverworts and mosses, with plants in closely related genera and families often having quite different ecological requirements. The percentage figure for hornworts cannot be directly compared with that for mosses or liverworts because there are only eight species occurring in Europe. Of these, only two species are considered endangered in Europe.
False Dog-tooth *Cynodontium fallax* (Near threatened liverwort) © Tomas Hallingbäck

*Polytrichum juniperinum* (Least Concern moss) © Lars Hedenäs
3.3 Spatial distribution of species

3.3.1. Species richness

The geographic distribution of bryophyte richness in Europe is shown in Figure 6 and is based on all native and naturalised species (post 1500) with extant and possibly extant occurrence (1,796 species).

Figure 6. Species richness of European mosses, liverworts and hornworts.

The areas with the highest species richness include central Europe, namely mountainous areas in the Alps, and to some degree in Scandinavia, Scotland, Wales, Pyrenees, and Eastern Europe. Species richness gradually declines towards the south and the east of Europe. It is also clear that mountainous areas score most highly in terms of species richness. While there is some overlap of species, each of these areas has its own distinctive character, with the Scottish mountains, for example, supporting a high diversity of oceanic species, in contrast to the Austrian Alps, where the flora is more continental.

3.3.2. Endemic and near-endemic species richness

In Figure 7, the richness of endemic European bryophyte species is shown based on the presence of 184 species (the analysis does not include species where their presence is uncertain).
The incidence of endemic species is fairly constant throughout most of Europe, with an increase in hyperoceanic and mountainous areas, particularly Macaronesia. Levels of endemism are low in bryophytes, relative to vascular plants, although recent studies are revealing an increasing number of previously unrecognised endemic species (for example, Carter et al. 2016, Patino and Vanderpoorten 2018). It is therefore more instructive to look at areas where there is high diversity and large numbers of ecologically specialised, disjunct and near-endemic species. Thus, the hyperoceanic parts of Europe, including Macaronesia, western Britain, Ireland, Norway, France (Brittany) and north-western Spain, support rich communities of oceanic species, few of which are endemic (except in Macaronesia) but many are globally rare and disjunct, elsewhere occurring only in widely-spaced but climatically similar areas, such as Yunnan in China and British Columbia in Canada (for example, Blockeel et al. 2014). This is largely because of the very efficient dispersal mechanisms in bryophytes, although some isolated and disjunct populations may be relict. For example, the large liverwort Anastrophyllum alpinum occurs in north-west Scotland, and elsewhere only in the Himalayas, Yunnan and the Aleutian Islands. Similarly, southern Europe supports a distinctive Mediterranean flora with many species restricted to the Mediterranean basin, but not necessarily endemic to Europe, occurring also in North Africa, Turkey and adjacent countries (for example, Ros et al. 2013). The tiny moss Acaulon fontiquerianum is a rare species of southern Europe and the Canary Islands that is also reported from Asiatic Turkey. There are few endemics in northern Scandinavia and Arctic Russia, but the bryophyte flora is very distinctive and largely restricted to the far north of Asia and North America, as well as Europe: Drepanoclados arcticus is a strictly Arctic moss confined to Svalbard, Arctic Russia (European and Asian) and Arctic North America.

3.3.3. Distribution of threatened species

In Figure 8, the distribution of threatened bryophytes in Europe is presented based on data for 374 threatened species (the analysis does not include species where their presence is uncertain).
Figure 8. Distribution of threatened (CR, EN, VU) mosses, liverworts and hornworts in Europe.

Figure 8 displays the number of threatened species (CR, EN, VU) per unit area (865 km2 hexagon). As for overall species richness (Fig. 6), it shows a high number of species in the Alps, especially in the eastern Alps, followed by other mountainous areas, notably the Carpathians, the eastern Pyrenees and the Scandinavian mountains. This emphasises the importance of mountain habitats for threatened bryophytes and their conservation. It may also flag the impact of climate change on the mountainous bryophyte flora, and pressure from land use change and tourist developments in the high mountains. Furthermore, many mountainous species are naturally rare and therefore vulnerable to stochastic events. Two regions notable for their numbers of threatened species are an area located in central Germany and Macaronesia (Fig. 6). The laurel forests of the latter islands, which contain many rare, threatened and endemic (Fig. 7) bryophytes, are under considerable threat from climate change, wildfires and forestry [See Box 2].

With the exception of these relatively restricted areas, numbers of threatened species are fairly constant throughout Europe. The map above (Fig. 8) clearly illustrates regions with a concentration of threatened species, which deserve special attention for conservation implementation. They largely agree with the regions with high general species richness, and partly with regions of high levels of endemism (Figs. 6 and 7). However, it does not inform on relative regional threat pressures. For this, the number of threatened species would need to be represented as proportions of total species number per region, a level of analysis that should be done in future work. It is likely that lowland areas which have experienced massive changes in land use due to agricultural intensification and rural development since the early 20th century, still face a greater negative impact than many mountainous areas; at least as long a climate change has not yet have full effect on population decline.
3.3.4. Distribution of Data Deficient species

In Figure 9, the distribution of Data Deficient (DD) species is presented based on data for 88 DD species (the analysis does not include species where their presence is uncertain). Some species are listed as DD because they have been recently described and there is no information to elucidate their trends, while others have been assessed as DD due to taxonomic uncertainty and the difficulty to differentiate between different species unless studied genetically.

Figure 9. Distribution of Data Deficient mosses, liverworts and hornworts in Europe.

The incidence of DD species is often high in mountainous areas, which could be attributed to the fact that they are merely the most species-rich areas, but also that they are usually more remote and difficult to survey than the lowlands. There are also more DD species in relatively under-recorded parts of Europe, such as Romania, than there are in well-recorded areas, such as Britain and Ireland. The low number of DD species throughout most of European Russia, which must surely be under-recorded, may simply reflect the fact that much of it has low bryological diversity; alternatively, it might indicate that this is an area where ‘we do not know what we do not know’.
Box 2 - Taking a closer look: Atlantic bryophytes

The extreme west of Europe, where the climate is warm and wet, neither too hot nor too cold, supports a rich and varied selection of mosses and liverworts that are collectively referred to as oceanic or Atlantic. These were first defined (in western Britain and Ireland) by the late Derek Ratcliffe in 1968, who identified the species that are more or less confined to parts of Britain and Ireland which have more than 200 ‘wet days’ per year, with wet days defined as days with over 1 mm of rain (Ratcliffe 1968): in other words, the extreme west, where the influence of the Atlantic is at its strongest. The same suite of species extends to the Faroe Islands and, in less abundance, to western Norway, western France (Brittany) and north-western Spain.

A lowland ravine in western Scotland may support upwards of 200 species in its sheltered, humid interior, including many oceanic species. The oceanic influence in Scotland extends into the mountains, where a community defined by Ratcliffe as the ‘mixed hepatic mat’ occurs in luxuriance in suitable north-east-facing corries. This consists of large leafy liverworts such as species of *Anastrophyllum*, *Bazzania*, *Herbertus*, *Plagiochila* and *Scapania*. Many of these species, as well as being strictly confined in Europe to the extreme west, are globally rare and more or less threatened.

*Herbertus borealis* (Vulnerable liverwort) is endemic to Scotland © Michael Lüth

The oceanic flora is even more well developed in Macaronesia, where the native laurel forest supports a very rich assemblage of species, including a higher proportion of endemic species than is usual with bryophytes, especially in Madeira. The subtropical forest is more or less constantly humid and warm and the trees are festooned with mosses and liverworts, including tiny species of *Acrobolbus* and *Lejeunea*, as well as much larger *Plagiochila* and *Herbertus*. These small areas of forest are under great threat from climate change, wildfires and developments related to tourism.

Europe’s Atlantic bryophytes have clear affinities with the tropical bryophyte flora of South America, and several species once thought to be European endemics are now known to be identical with South American plants: *Plagiochila bifaria*, for example, formerly known in Europe as *P.killarniensis* (Heinrichs et al. 1998). Long distance dispersal of some species from South America to Europe via Macaronesia is the clear implication.
3.4 Major threats to moss, liverwort and hornwort species in Europe

A fully comprehensive overview of the threats to bryophytes in Europe is not possible, as some of the threats to the species remain unknown. In total, it was possible to identify threats for 1,099 species, often with several threats listed for a species. 559 species are, based on the best available knowledge, thought to have no current or major threats, and for 159 species the threats are unknown at present. It must be realised that the threats to bryophytes, as to the rest of the natural world, are complex and difficult to categorise. Thus, climate change overlaps with most of the other threats, fire frequency overlaps with unregulated planting of *Eucalyptus* and conifer plantations, etc.

A summary of the major threats to threatened and DD, LC and NT species is shown in Figure 10.

**Figure 10. Major threats to all assessed mosses, liverworts and hornworts in Europe.** *Note:* Species can be affected by more than one threat.

The main threat to both mosses and liverworts is natural system modifications. 452 species of mosses and 180 species of liverworts are impacted by this driver of decline, of which 144 and 52 species, respectively, are threatened. For hornworts, the most prevalent threat is agriculture, affecting 7 species (of which 2 are threatened). However, it should be noted that only 8 hornwort species were assessed in total, so this result should be interpreted cautiously. Climate change ranked second in the list of threats to bryophytes in Europe.

3.4.1 Natural system modifications: mitigate impacts of dam construction and increases in fire frequency/intensity, and improve water management/use

A total of 234 species are affected by water management and use, including 83 species assessed as CR, EN or VU. This was considered the most common threat to bryophytes across Europe, including both species assessed as threatened and species assessed as Near Threatened or Least Concern. This includes the abstraction of ground and surface water for different uses, including agricultural, commercial and domestic uses, and the construction of dams. Species that are water-dependent,
such as *Campylophyllum montanum* and many of its relatives, and those that tend to grow in sites targeted for dam construction, such as *Bryum blindii*, are most at risk from these threats.

Bog and fen are among the most threatened habitats in Europe (Janssen *et al.* 2016). In the lowlands, draining wetlands has led to a disastrous decline in many bog and fen species in central Europe (for example, *Sphagnum* spp., *Hamatocaulis vernicosus*, *Scorpidium scorpioides*, etc.), that are still quite common in the far north. Remaining bryophyte-rich wetland sites, particularly in central and southern Europe, face multiple threats, and all require protection. In the uplands, construction of large-scale dams and reservoirs has destroyed many rich sites, and continues to threaten the survival of many species, including those likely to be impacted by climate change (for example, *Andreaea crassinervia*).

257 species appear to be at risk of an increase in fire frequency and/or intensity. Out of these, 94 species are considered to be threatened. This threat is clearly intimately associated with climate change, and becomes more serious with a warmer and drier environment. The problem is particularly serious in the laurel forests of Macaronesia, where many rare and endemic species confined to these forests are threatened by the increasing incidence of wildfires. There is also a greater risk of wildfires where there has been large-scale planting of non-native *Pinus* and *Eucalyptus*, as in much of southern Portugal and northern Spain.

A total of 215 species are affected by a variety of other modifications to ecosystems, 75 of which have been assessed as threatened.

### 3.4.2 Climate change: buffer impacts of droughts and temperature extremes, and better regulate habitat shifting

A total of 209 species are estimated to be or will be affected by droughts, including 146 threatened species. A total of 235 species are affected by habitat shifting and alteration, including 109 threatened species, and 163 species are considered to be at risk from temperature extremes, of which 78 species are threatened. With increasing temperatures across Europe, as a result of climate change, periods of droughts are already increasing (Vicente-Serrano 2014). The effects of climate change are often unpredictable, and it is difficult to suggest mitigations that are specific to bryophytes, but the threat will only become more prominent in the coming decades.

Some of the species most likely to be threatened by climate change are those confined to wetlands. Already greatly reduced, especially in central and southern Europe, due to land-use changes, including agriculture, drainage, pollution, construction activities and invasive species, the remaining wetlands are under unwelcomed extra pressure by desiccation caused by climate change. Species of bryophytes that are found at high elevations, and/or in northern environments, are probably significantly more prone to the impacts of climate change than other species, as they have nowhere else to go if temperatures increase significantly. For example, the survival of *Herbertus sendtneri*, a species of the high Austrian Alps, is very doubtful if the extent and duration of alpine snow-patches deteriorate significantly. On the other hand, at least the bryophytes of higher elevations are usually less accessible; for those that grow on lower mountains, climate change is just one more threat to add to the other pressures affecting them, such as land-use change.

The bryophytes of the laurel forests of Macaronesia are also at great risk through climate change (Patiño *et al.* 2016). They appear to be drying out, wildfires are becoming more frequent, and projections show a significantly increased risk of extinction for many of the special species of this habitat in the coming years, including endemic species such as *Cheilolejeunea cedercreutzii*.
*Cheilolejeunea cedercreutzii* (Endangered liverwort) © Tomas Hallingbäck

*Echinodium renauldii* (Endangered moss) © Lars Hedenäs
The bryophytes of southern Europe in general are also at an increasingly higher risk of extinction as the climate becomes warmer and drier. Already some areas have been affected by desertification, and while many species have strategies for avoiding or tolerating drought (for example *Gigaspermum mouretii*, and many species in the family Pottiaceae), even these species will be unable to survive in conditions of more extreme desertification.

### 3.4.3 Agriculture and aquaculture: better integration of agricultural practices (wood and pulp plantations, livestock farming and ranching) with conservation goals

Wood and pulp plantations affect 200 species of bryophyte in Europe, including 61 threatened species. Different species are impacted by plantations at different scales, but particularly by agro-industry plantations. At this scale, 124 species are at risk, of which 26 are threatened.

Most plantations are on sites where there used to be natural or semi-natural forest, so the main species threatened by conversion of natural forest to plantation woodland are those dependent on the long ecological continuity provided by a stable, humid, natural forest. Specialists of dead wood such as *Scapania apiculata* have been particularly hard-hit, as amounts of deadwood are often very low in managed forests.

Dead wood is an important substrate for many specialised bryophytes; this old rotting tree trunk supports many species, including *Scapania apiculata* (Near Threatened liverwort) © Michael Lüth

Generally, land-use conversion practices (including the intensification of agriculture and forestry) are considered the most common threat to biodiversity in undisturbed habitats (IPBES 2018). These have been designed to increase the production of crops (for example, by increased fertilizer and pesticide applications), livestock, aquaculture, forest biomass, as well as urban development, and are highly detrimental to these species of bryophytes.
A total of 151 species are affected by livestock farming and ranching, including 65 threatened species. This includes grazing at three levels: small-holders, agro-industry and nomadic. The majority of the species (95, of which 41 are threatened) are affected by small-holder grazing, ranching or farming. Overgrazing, under-grazing, and burning are all activities that may affect the bryophytes. One activity that is particularly associated with livestock farming is the treatment of stock with ivermectins and other chemicals to treat parasite infestations. One of the unintended consequences of this is that it makes the dung of these animals effectively sterile, which has knock-on effects on the large numbers of organisms that depend on animal dung for survival. These include a unique suite of mosses - the dung mosses - that grow only on the dung (or sometime bones) of herbivores and which have an intimate relationship with dung invertebrates for the dispersal of their spores. Most of these species, some of them among our most attractive bryophytes (Splachnum, Tetraplodon, Aplodon, etc), have declined drastically in recent years (Porley & Hodgetts 2005).

3.4.4 Other threats to bryophytes

Residential & commercial development: Tourism and recreation areas

Under the umbrella of residential and commercial development, a key threat to bryophytes in Europe was identified as the development of areas for tourism and recreation. 181 species in total are impacted by tourism and recreation, including 99 threatened species. ‘Urban sprawl’ to accommodate the ever-increasing human population often obliterates woodland, species-rich grasslands and wetlands. Tourism encompasses many sorts of threat, including uncontrolled building of hotels and other tourist facilities in rich coastal or alpine habitats, water abstraction, disturbance through increasing numbers of people, etc.

Pollution: Agricultural and forestry effluents

A total of 165 species are affected by agricultural and forestry effluents, including 58 threatened species. This includes 97 species (of which 34 of threatened) that are specifically at risk from nutrient loads, 29 species (of which 10 are threatened) that are specifically at risk from herbicides and pesticides, and 16 species (of which 10 are threatened) that are specifically at risk from soil erosion and sedimentation.

Bryophytes are also considered to be affected by other sorts of pollution in Europe. 78 species (of which 19 are threatened) are impacted by air-borne pollutants, for example acid rain and smog, and 32 species (of which 9 are threatened) are impacted by waste water, such as run-off and sewage [See Box 3].

Invasive non-native/alien species/diseases

A total of 161 species are affected by invasive alien species, including 80 threatened bryophytes. Most of these problematic species are unspecified, but 64 species (of which 40 are threatened) are affected by known species. One of the most problematic invasive plants for bryophytes in Europe is rhododendron, which covers large areas of hillside in oceanic areas, casting a deep shade and dropping very acid leaf litter that prevents anything else from growing. The effects of this invader on bryophytes are particularly important in areas of the UK and Ireland. The aquatic environment is particularly sensitive to invasive species, and plants such as Crassula helmsii are as much a threat to aquatic bryophytes as they are to vascular plants. A minority of species may be under threat from invasive alien bryophytes: In north-western Europe, Orthodonium gracile appears to be a poor competitor against the invasive southern African species O. lineare.
Human intrusions & disturbance: Recreational activities

Human disturbance to areas where bryophytes grow, specifically for access to recreational activities, is considered to impact 159 species, of which 81 are threatened. This includes intrusions relating to, for example, erosion at popular tourist sites owing to the sheer numbers of people; mountain summits in tourist areas are particularly vulnerable in this respect. Some coastal cliff top paths in southern England with rare mosses are becoming increasingly eutrophicated by dog faeces, leading to loss of habitat. Hunting and shooting for sport is not often in itself a threat to bryophytes, but when important sites are managed primarily for these activities, it can result in loss and degradation of habitat, as has taken place on the grouse moors of Scotland, where large areas are regularly burned to encourage the growth of new heather (Calluna vulgaris) shoots, resulting not only in a species-poor monoculture, but also destabilisation of soils and increased erosion.

Additional threats

There are many other threats to European bryophytes. Biological resource use, which include fishing, hunting and harvesting biological resources, affects 152 species, of which 46 are threatened. In addition, 116 species are threatened by industrial activities, such as energy production and mining, including 31 threatened species. Under this threat classification, most species (72, of which 12 are threatened) are at risk from mining and quarrying, although renewable energy production and oil and gas drilling also impact some species in Europe. In some areas, such as central Ireland, industrial-scale peat extraction for fuel has damaged or destroyed many important bryophyte sites. The remaining ones now receive statutory protection. Land-based wind farms often cause considerable damage, especially if sited on sensitive peaty substrates.

The establishment of transportation and service corridors, such as roads and service lines, affects 69 species, of which 54 are threatened.

3.5 Population trends

Documenting the population trend of a species provides key information when assessing its Red List status. As part of this process, overall populations of the species were assessed as declining, stable, increasing or unknown.

Overall, 17.1% (307 species) of bryophyte species in Europe are thought to be in decline, including 52.8% of threatened species (162 species). The majority of species (59.3%; 1,062 species) are considered to be stable, including 8.3% of threatened species (88 species), and 1.9% (34 species) are increasing (Figure 11), all of which are LC. However, 21.7% of species (389 species) have unknown population trends, with 129 threatened species (33.2%).

Figure 11. Population trends of European mosses, liverworts and hornworts.
3.6 Gaps in knowledge

While there was not enough information to assign a Red List Category to 93 species (hence considered as Data Deficient), the information collected was sufficient to identify the major knowledge gaps for bryophytes in Europe (Figure 12).

**Figure 12. Research needs for European mosses, liverworts and hornworts. Note:** Species can be included in more than one category.

Overall, the absence of, or the existence of few, data on population size and distribution, as well as trends are systematically highlighted as a knowledge gap for bryophytes by the expert community assessing the conservation status of these species. This pattern affects both threatened and
non-threatened taxa. Knowledge on habitats trends and impact of threats is also still incipient for the majority of these species, with particular regions severely understudied (for example, Russia).

While this pattern can be partially justified by the fact that some species have been recently described, and thus there is still no information available on these parameters, the reality is that monitoring efforts are becoming increasingly difficult to sustain and to fund, which coupled with the absence of baseline data (for example, historical data) on species numbers and distribution, hamper a comprehensive understanding of the threats to these species in Europe, and how these stressors interact. Collecting information on these topics is paramount for sound conservation planning and effective recovery of threatened taxa, and will allow for more concrete messages to be mainstreamed to the most impactful sectors. The establishment of an expert network to facilitate information exchange would certainly help address the knowledge gaps identified for these species throughout their European range; the experts brought together through this project provide a good departing point to expand this network. In any case, relevant conservation and management measures should move forward despite any current data gaps, while also considering taxonomic uncertainty where relevant.

*Hymenoloma compactum* (Data Deficient moss) © Tomas Hallingbäck
Box 3 - Poisoned bryophytes: the impact of over-fertilization

One of the major threats to bryophytes is habitat modification through intensification of agricultural practices and pollution (also decurring from agriculture). The greatest pollution threat in the 20th Century was sulfur dioxide pollution through the widespread burning of dirty coal. Many bryophytes, particularly epiphytic species, are very sensitive to sulphur dioxide (SO2) levels, and these plants, such as species of Orthotrichum and Ulota, virtually disappeared from large areas of Europe. When legislation for clean air was introduced in the mid- to late-20th Century, these plants gradually, and later rapidly, began to recolonise. Nowadays, trees throughout most of Europe, even in areas formerly devastated by SO2 pollution, are covered with Orthotrichum and Ulota and other species.

These days, the problem is nitrogen. Despite generally improving air quality in Europe, including reductions in nitrogen emissions, there is an ever-increasing amount of nitrogen in the environment. Locally, in agricultural areas, one can smell the ammonia because of the enthusiastic spreading of manure, and observe the poisonous green of ‘improved’ pasture devoid of wild flowers or much natural interest at all. However, the main cause is the worldwide increase in the very inefficient use of artificial nitrogen-rich fertilisers in agriculture. In Europe, fertilisers are still spread over fields, but more than half the nitrogen does not go into improved crop yields, it simply runs off into ditches, streams, rivers and ultimately the sea. Much of it, via the nitrogen cycle, is returned to the land through precipitation. The consequences for bryophytes are clear. All over Europe, even in remote upland areas, the natural species-rich bryophyte flora of streams is being replaced with a monocultural slime of green algae; even in bogs, in some areas Sphagnum hummocks are becoming overwhelmed by algal scum. On rock faces, a layer of green algae replaces the mosses and liverworts. In open habitats, the nutrient-poor ‘bare ground’ habitat of so many threatened species, is disappearing, being overtaken by vigorous, nutrient-demanding grasses.

This is a worldwide problem that can only be addressed with worldwide solutions. Most agricultural land is currently over-fertilised (Pearce 2018), and so possible solutions include more targeted, ‘precision agriculture’, distributing smaller amounts of nitrogen much more efficiently, so that it goes to plant roots but does not run off into the surrounding environment.

Urn bristle-moss Orthotrichum urnigerum (Vulnerable moss) © Michael Lüth
4. Conservation measures

4.1 Conservation of moss, liverwort and hornwort species in Europe

The results of this Red List assessment indicate that 88.2% of species (1,603 species, of which 319 are threatened) were recorded in at least one protected area (including national parks, Natura 2000 sites or nature reserves). This is positive, as site protection is the most commonly identified conservation measure for European bryophytes (Figure 13). The second most important measure is site/area management, and bryophytes are often not considered in management plans. Additional conservation measures proposed for European bryophytes are shown below (Figure 13).

Figure 13. Main conservation measures identified for European mosses, liverworts and hornworts. 
Note: More than one conservation measure was assigned to each species.

The nature conservation policy of the European Union is based on two main pieces of EU legislation - the 1979 Birds Directive (Directive 79/409/EEC) and the 1992 Habitats Directive (Directive 92/43/EEC; jointly referred to as the Nature Directives). There are 32 bryophyte species currently listed in Annex II, not all of which are endemic to Europe. No species of bryophytes is listed under Annex IV and only three genera are listed under Annex V of the Habitats Directive. The Bern Convention, on the other hand, is a binding international legal instrument that aims to conserve wild flora and fauna and their natural habitats and promote European cooperation towards that objective. It covers all European countries and some African states. In Appendix I of the Bern Convention (Strictly Protected Flora Species), a total of 26 bryophyte species are listed. Appendix 4 provides the full list of bryophytes species listed under the Habitats Directive and the Bern Convention, and the corresponding conservation status, as determined by the current Red List assessment. Of the 1,729 bryophyte species present in the EU, 28, 7.5% are endemic to the EU 28, highlighting the conservation responsibility of the EU towards these species. Some have made a remarkable recovery following listing under these two policy instruments and targeted conservation actions (for example, *Hamatocaulis vernicosus* - see Box 4).
One of the main tools to enhance and maintain biodiversity in Europe is the Natura 2000 network of protected areas, which currently consists of over 27,500 sites, covering 18% of the EU land and marine area (EC 2018). Natura 2000 sites provide an essential tool in conservation even if the sites were not specifically designated for the preservation of particular bryophyte species, as indirectly the general protection of habitats usually also benefits the bryophytes. However, it is sometimes necessary to target the ecological needs of these small plants more directly, which becomes challenging when conservation measures are usually targeted at more charismatic and well-known organisms. The well-supported agri-environmental schemes devised to promote sustainable farming across Europe are a good illustration of the limited effects on bryophytes of such widespread, untargeted conservation measures, particularly for rare bryophyte species (Valentini et al. 2016). Measures better tailored to promote bryophyte conservation include, for example, rotational set-aside and retention of winter stubbles in cereal, rape and linseed crops (Bosanquet 2003, Bisang et al. 2009).

Many threatened bryophytes occur in protected areas, and depend, like other groups, on the conservation of multi-scale areas of semi-natural habitat. However, many species tend to grow in ‘micro-habitats’ in non-protected areas. This means that the sympathetic management of the wider countryside is particularly important for bryophytes. For example, the suite of species which have their main habitat in arable fields, such as the threatened hornwort Anthoceros neesii, are entirely dependant for their survival on overwintering stubble fields, so wider agricultural policy needs to promote agricultural practices that favour this habitat. Similarly, a certain amount of dead wood needs to be left in situ in managed forestry plantations, as well as in old-growth forest, in order to provide substrate for the many bryophytes that specialise in this habitat. While the Habitats Directive and the Natura 2000 network are of vital importance, there needs to be much more ‘joined up thinking’ between different elements of policy, so that, to choose the most obvious example, policies contained within the Common Agricultural Policy (CAP) do not work against those in the Habitats Directive. Measures within other national or international policies, including Agri-Environmental Schemes that provide payments to farmers who subscribe, on a voluntary basis, to environmental commitments related to the preservation of the environment, need to be aligned with statutory protection for species to ensure that efforts to protect these species are synergistic and not in vain.

European countries and EU Member States are signatories to a number of important conventions aimed at conserving biodiversity, including the 1979 Bern Convention on the Conservation of European Wildlife and Natural Habitats, and the 1992 Convention on Biological Diversity (CBD). Through the CBD, the Strategic Plan 2011–2020 was established, which includes 20 targets (Aichi Targets) that guide the implementation of the CBD and all the other biodiversity conventions. In particular, Target 12 focuses on preventing the extinction of known threatened species and improving their status (CBD 2011). The outcomes of this Red List project certainly help to measure the progress made towards meeting these targets.

The Global Strategy for Plant Conservation (GSPC) was adopted by the CBD at the 2002 Conference of the Parties and updated at the 10th Conference of the Parties. In order to coordinate the implementation of the GSPC at the regional level, the European Strategy for Plant Conservation (ESPC) was adopted. In particular, Target 2 (calling for an assessment of the conservation status of plant species), Target 5 (through the identification of Important Plant Areas), Target 7 (in situ conservation), Target 8 (ex situ conservation), Target 12 (preventing the extinction of known threatened species and improving their status), Target 13 (sustainable practices associated with plant use) and Target 14 (awareness raising) (CBD 2011) are relevant for the conservation of bryophytes.

At the pan-European level, European countries across the continent endorsed the Pan-European 2020 Strategy for Biodiversity (UNEP 2011), which re-focuses efforts to prevent further loss of
biodiversity in the pan-European region. It also provides a European mechanism for supporting the implementation of the global Strategic Plan for Biodiversity. No native European bryophyte species are listed on the Annexes of the Convention of International Trade in Endangered Species of Flora and Fauna (CITES).

Soft brook-moss *Platyhypnum molle* (Vulnerable moss) © Tomas Hallingbäck

The EU Water Framework Directive, adopted in 2000 and aimed at protecting European waters, can also be relevant for aquatic and water-dependant bryophyte species. A good ecological status of surface waters has positive effects on ecosystem function as a habitat for plants (Janauer *et al.* 2015).

Plant habitat conservation efforts have in part been focused through the identification of Important Plant Areas (IPAs). IPAs are internationally significant sites for wild plants and threatened habitats. Identified at a national level, they provide a framework for implementing Target 5 of the CBD GSPC, and are a tool for targeting conservation actions on wild plants and *in situ* habitat protection. IPAs contain over 700 of the most threatened species in Europe and include millions of hectares of the most threatened habitats. At least 1,770 IPAs have been identified in 16 European countries (Anderson and Radford 2010). A first attempt was made to identify Important Bryophyte Areas in Europe during the production of the first Red List (European Committee for the Conservation of Bryophytes 1995), and it is anticipated that the current Red List will facilitate an update of this initiative. These exercises are incredibly valuable to ensure species protection and a stepping stone to promote nature conservation in Europe, for example, as a basis to define Key Biodiversity Areas.

The EU has committed to a long-term (2050) vision and mid-term headline target for biodiversity, which is “To halt the loss of biodiversity and the degradation of ecosystem services in the EU by 2020
and restore them in so far as possible, while stepping up the EU contribution to averting global biodiversity loss.” This target underpins the EU Biodiversity Strategy 2011-2020. The establishment of these policy instruments indicates the high political commitment to biodiversity and the need to monitor the status of biodiversity and to assess progress towards meeting conservation objectives and targets. Measuring whether policy targets have been met is only possible by establishing comprehensive monitoring programmes that allow the gathering of the necessary data for a reliable re-assessment in the coming years. In order to reach these targets, immediate conservation action for species with a high extinction risk is needed.

Grey-cushioned grimmia *Grimmia pulvinata* (Least Concern moss) © Michael Lüth

Most European countries have developed specific actions at the national or regional level in order to enhance bryophyte populations. National Red Lists or Red Data Books of bryophyte species are available for the following countries: Austria, Bulgaria, Czechia, Estonia, Finland, Germany, Great Britain (excluding Northern Ireland), Hungary, Ireland (including Northern Ireland), Italy (including Sardinia), Luxembourg, Montenegro, Netherlands, Norway, Poland, Portugal (including Madeira), Romania, Serbia, Slovakia, Slovenia, Spain and Canary Islands, Sweden, and Switzerland.

However, there are some countries in which no national Red List has been developed (for example, France). It is also noteworthy that some national Red Lists are outdated and should be maintained and updated in order to remain relevant. In addition, several countries have developed management or action plans for several species, and have legislation in place to protect certain species legally (for example, Schedule 8 of the Wildlife & Countryside Act 1981 in the UK). Some examples of successful action plans include *Tayloria rudolphiana*, an epiphytic species of central Europe for which several studies have been undertaken to count the sites or individuals of the plants (Hofmann *et al.* 2006, Hofmann *et al.* 2016, Müller 2016, Kiebacher *et al.* 2018) and attempts have been made to protect the host trees and to increase awareness for this species. LIFE projects have been undertaken at the European level to enhance the status of certain habitats and species, some of which have focused on specific species bryophytes, or produced management plans as a result of these projects.

*Tayloria rudolphiana* (Near Threatened moss) © Norbert Schnyder
Box 4 - Conservation works: bryophytes bounce back

For bryophytes, as for other organisms, conservation works. Bogs that have been damaged by peat-cutting or drainage can be restored or re-instated by blocking drains; degraded forest can be restored (eventually) merely by non-intervention; damaged wetlands can have a new lease of life through proper management. Giving species legal protection can be very effective. For example, Slender Green Feather-Moss (*Hamatocaulis vernicosus*) was one of a small handful of species placed on Appendix I of the Bern Convention in the early 1990s. Along with most of the other Bern species, it was also included on Annex II of the EU Habitats Directive soon afterwards. This means that the signatory countries to these conventions have an obligation to protect it under the Natura 2000 network, with sites designated and managed for its protection. The results of this have been dramatic, with sites established for *Hamatocaulis* all over Europe, or at least within the EU, with several non-EU countries following suit. Because it is a key species of mineral-rich, mesotrophic mires, fens and flushes, this has meant that many important and threatened wetland sites that might otherwise have been destroyed now receive statutory protection. In other words, the conservation benefits of placing this moss on the protected species list extend much further than merely protecting the moss itself: whole habitats have been saved.

Furthermore, including *Hamatocaulis* on these international conventions has resulted in a massively increased programme of research to find out more about its distribution, abundance, ecology and conservation requirements. Recent research in Sweden has even found that what we
call *H. vernicosus* actually comprises two cryptic species (genetically different but apparently morphologically identical), both of which occur in protected areas (Hedenäs 2018). Paradoxically, an increase in survey and recording effort targeted at *H. vernicosus* means that it now *seems* to be more common than was once thought. This is of course not the case: we simply now know more about it, and the increase in records in recent years is entirely due to that increase in recording effort. If we had more baseline data going back through the decades it would certainly show a decline because of habitat destruction through drainage and other anthropogenic factors.

4.2 Red List versus priority for conservation action

Assessing the extinction risk and setting conservation priorities are related but distinct processes. The purpose of the IUCN Red List assessment is to produce a relative estimate of the likelihood of extinction of a species. On the other hand, setting conservation priorities also takes into account other factors such as ecological, phylogenetic, historical, economical or cultural preferences for some taxa over others. Also, the probability of success of conservation actions, availability of funds or personnel, cost-effectiveness and legal frameworks for the conservation of threatened taxa is taken into account. In the context of regional risk assessments, a number of additional pieces of information are valuable for setting conservation priorities. For example, it is important to consider not only conditions within the region, but also the status of the taxon from a global perspective and the proportion of the global population that occurs within the region. The decision on how these three variables, and the other factors, are used for establishing conservation priorities is a matter for the regional authorities to determine, taking into account the assessment status of the species of concern.

5. Recommendations

5.1 Recommended actions
Currently, 22.3% of bryophytes are threatened at the European level. The most important threats to bryophytes in Europe come from natural systems modifications (i.e., habitat destruction and degradation), climate change, and current agricultural practices. Hence, improving the conservation status of bryophytes, and preventing current and future declines in Europe, require increasing efforts and commitments from various parties, from the EU to regional assemblies, and from statutory bodies to conservation charities. Perhaps most importantly, measures for bryophyte conservation (and indeed for nature conservation generally) need to be integrated into regular planning and land management procedures and practices. Below, a series of recommendations are proposed to strengthen the long-term survival of European bryophytes:

**Policy measures**

- Use the European Red List as the scientific basis to inform regional/national lists of rare and threatened species and to identify priorities for conservation action in addition to the requirements of the Habitats Directive, thereby advancing the conservation status of bryophytes at the regional/local level.
- Use the European Red List to support the integration of conservation policy with the CAP and other national and international policies. For example, CAP Strategic Plans should include biodiversity recovery commitments that could anticipate, among others, the creation of Important Bryophyte Areas. An increased involvement of national environmental agencies in the preparation of these strategic plans, and more broadly in ongoing discussions on the Future CAP Green Architecture, would likely also ensure the design of conservation measures better tailored to conserve bryophytes in agricultural landscapes.
- Update the European Red List every decade to ensure that the data remains current and relevant.
- Develop Key Biodiversity Areas for bryophytes in Europe with a view to ensuring adequate site-based protection for bryophytes.

**Research and monitoring**

- Use the European Red List as a basis for future targeted fieldwork on possibly extinct and understudied species.
- Establish a monitoring programme for targeted species (for example, threatened species and/or arable bryophytes).
- Use the European Red List to obtain funding for research into the biology and ecology of key targeted species.

**Action on the ground**

- Use the European Red List as evidence to support multi-scale conservation initiatives, including designation of protected areas, reform of agricultural practices and land management, habitat restoration and rewilding, and pollution reduction measures.
- Use the European Red List as a tool to target species that would benefit the most from the widespread implementation of the solutions offered by the 1991 Nitrates Directive (Council Directive 91/676/EEC), including the application of correct amount of nutrients for each crop, only in periods of crop growth under suitable climatic conditions and never during periods of heavy rainfall or on frozen ground, and the creation of buffer zones to protect waters from run-off from the application of fertilizers.

**Ex-situ conservation**
- Undertake ex-situ conservation of species of conservation concern in botanical gardens and spore and gene banks, with a view to reintroduction where appropriate.

**Awareness raising**

Mosses and liverworts are small and do not impinge very much on the public consciousness, except as things to remove from the lawn or the roof. As an integral and important part of the natural world, they deserve better. There are now many attractive publications and websites that present bryophytes as beautiful and useful, and these should receive more publicity and promotion; for example, *Sphagnum mosses - The Stars of European Mires* (Laine et al. 2018), Robert Muma’s beautiful moss paintings and sketches ([http://worldofmosses.com/paintings/index.html](http://worldofmosses.com/paintings/index.html)), Michael Lüth’s amazing photographic collection ([http://www.milueth.de/Moose/index.htm](http://www.milueth.de/Moose/index.htm)), to name but a few. Many nature reserves where bryophytes are important now have information boards and other material to promote bryophytes, and this should continue to be prioritised wherever appropriate.

In particular, this Red List should be used to publicise bryophytes and to obtain funding for future conservation work. For example, the LIFE Nature and Biodiversity provides targeted funding for species conservation actions, supporting projects aimed at conserving threatened species listed in the annexes of the EU Habitats Directive, Birds Directive and the IUCN European Red List.

**5.2 Application of project outputs**

The European Red List of mosses, liverworts and hornworts is part of a wider initiative aimed at assessing the status of all European species. It provides key resources for decision makers, policy makers, resource managers, environmental planners, NGOs and the concerned public by compiling large amounts of data on the population, ecology, habitats, threats and recommended conservation measures for each bryophyte species. Conservation status assessments are intended to be policy-relevant and can be used to inform conservation planning and priority setting processes. However, they are not intended to be policy-prescriptive and are not in themselves a system for setting biodiversity conservation priorities. These data are freely available on the IUCN Red List website ([https://www.iucnredlist.org/regions/europe](https://www.iucnredlist.org/regions/europe)), on the European Commission’s website ([http://ec.europa.eu/environment/nature/conservation/species/redlist](http://ec.europa.eu/environment/nature/conservation/species/redlist)) and through paper publications (see the list of European Red Lists published at the end of this report).

Red Lists are a dynamic tool that will evolve with time as species are re-assessed according to new information or situations. They are aimed at stimulating and supporting research, monitoring and conservation action at local, regional and international levels, especially for threatened, Near Threatened and Data Deficient species.

Each species assessment lists the major threats affecting the specific bryophyte species and conservation measures that are in place or recommended. This is useful to inform the application of conservation measures for each species. The outputs of this project can be applied to inform policies and to identify priority sites for biodiversity and priority species to include in research and monitoring programmes.
5.3 Future work

Through the strong collaboration established between the ECCB and the IUCN SSC Bryophyte Specialist Group during this project, a network of European and national bryophyte experts, and their extensive knowledge and expertise, were mobilised that will persist long after the project ends and will be instrumental in defining priorities for bryophyte conservation in Europe. The project has benefited greatly from the work and information held by additional relevant organisations and stakeholders, such as national bryophyte societies, university research programmes and statutory and voluntary conservation bodies. The wealth of knowledge and data compiled during the elaboration of this European Red List will be invaluable to expand research efforts on bryophytes at the European level, ultimately benefiting their conservation. One aspect worth noting is that the assessment of the European endemics can be transcribed directly into the corresponding global Red List.

Through the process of compiling data for the European Red List, a number of knowledge gaps have also been identified. Across Europe there are significant geographic, geopolitical and taxonomic biases in the quality of data available on the distribution and status of species, and these are aspects that a unified knowledge network will need to overcome to advance bryophyte conservation in the region.
There is a clear need for drawing together information from all data compilation initiatives, under way or planned, and for a wider European bryophyte conservation action plan to be explored, developed and progressed. It is hoped that by presenting this assessment, local, national, regional and international research will be stimulated to provide new data and to improve on the quality of the current available data.

Key challenges for the future are to improve monitoring and data quality and dissemination so that the information and analyses presented here can be updated and improved. This will contribute to recommend conservation actions based on a solid scientific basis. The further dissemination of this information to concerned European citizens will also lead to progressive policies at various jurisdictional levels that promote conservation.

If the bryophyte assessments are periodically updated, they will enable the changing status of these species to be tracked over time via the production of a Red List Index (Butchart et al. 2004, 2005, 2006, 2007). To date, this indicator has been produced for birds, mammals, amphibians and reptiles at the European level and has been adopted as one of the headline biodiversity indicators to monitor progress towards halting biodiversity loss in Europe by 2020 (EEA 2007). The development of such an index will be important to evaluate progress towards meeting Target 6 of the EU Biodiversity Strategy and for discussions shaping the Post-2020 Biodiversity Framework in order to step up its contribution to avert global biodiversity loss, and Aichi Target 12 of the CBD, which focuses on preventing the extinction of known threatened species and improving their status.

*Sphagnum arcticum* (Near Threatened moss) © Michael Lüth
References


Appendix 1. List of Lead Assessors by Geographical Region

- Central Europe: Norbert Schnyder and Christian Schröck
- Eastern Europe: Nadya Konstantinova and Elvira Baisheva
- Macaronesia: Manuela Sim Sim
- Northern Europe: Tomas Hallingbäck
- Northwestern Europe: Nick Hodgetts
- Southern Europe: Patrizia Campisi and Annalena Cogoni
- Southeastern Europe: Marko Sabovljevic
- Southwestern Europe: Cecilia Sérgio
Appendix 2. Example of species summary and distribution map

The Red List assessment below of *Orthotrichum urnigerum* provides an example of the information that has been compiled for all the European bryophyte species, including a distribution map. You can search for and download all the assessments and distribution maps from the European Red List website and data portal available online at http://ec.europa.eu/environment/nature/conservation/species/redlist/ and https://www.iucnredlist.org/regions/europe.

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**Orthotrichum urnigerum** - Myrin

PLANTAE - BRYOPHYTA - BRYOPSIDA - ORTHOTRICHALES - ORTHOTRICHACEAE - Orthotrichum - urnigerum

**Common Names:** Filthättemossa (Swedish)

**Synonyms:** No Synonyms

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**Red List Status**

VU - Vulnerable, D1 (IUCN version 3.1)

Red List Assessment

**Assessment Information**

**Date of Assessment:** 2017-04-04

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Assessor(s): Hodgetts, N., Blockeel, T., Konstantinova, N., Lönnell, N., Papp, B., Schnyder, N. & Vanderpoorten, A.

Reviewer(s): Wilbraham, J. & Cálix, M.

Regions: Europe

Regional Expert Questions: No change,-1,3,2

**Assessment Rationale**

European regional assessment: Vulnerable (VU)

EU 28 regional assessment: Vulnerable (VU)

*Orthotrichum urnigerum* is a local species with two main centres of distribution: southern Scandinavia and central and southern Europe from Portugal east to Romania and the Balkans. The species is assessed as Vulnerable since it is estimated that there are fewer than 1,000 individual-equivalents both in Europe and in the EU 28. One individual-equivalent (i.e., mature individual) is considered to be an occupied square metre of rock. Clear felling of mature hardwood forest is the main threat to this species. Protection and minimal management of woodland where there are significant stands of this species is recommended. Further research on its population size and trend is also needed.
Distribution

Geographic Range

*Orthotrichum urnigerum* is a local species with two main centres of distribution: southern Scandinavia and central and southern Europe from Portugal east to Romania and the Balkans. Elsewhere it occurs in Asia (Caucasus and Kashmir). Reports from North America are erroneous (ArtDatabanken 2016). This species' area of occupancy (AOO) in Europe is estimated to be 476 km², and its extent of occurrence (EOO) is ca 3.9 million km².

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Elevation Upper Limit (in metres above sea level): 2040

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Biogeographic Realms

Biogeographic Realm: Palearctic

Occurrence

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<td>-</td>
<td>Resident</td>
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<td>-</td>
<td>Resident</td>
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<td>Resident</td>
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<td>-</td>
<td>Resident</td>
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<td>-</td>
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<td>Italy -&gt; Italy (mainland)</td>
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<td>Native</td>
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<td>Resident</td>
</tr>
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<td>-</td>
<td>Resident</td>
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<td>Native</td>
<td>-</td>
<td>Resident</td>
</tr>
<tr>
<td>Russian Federation -&gt; European Russia</td>
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<td>Native</td>
<td>-</td>
<td>Resident</td>
</tr>
<tr>
<td>Russian Federation -&gt; European Russia -&gt; North European Russia</td>
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<td>Native</td>
<td>-</td>
<td>Resident</td>
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<td>Extant</td>
<td>Native</td>
<td>-</td>
<td>Resident</td>
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</tbody>
</table>

**Population**

This species is rather rare, and there have been some misidentifications that need to be revisited. In Hungary, where it is stable, it is estimated that each locality contains about ten individual-equivalents. One individual-equivalent (i.e., mature individual) is considered to be an occupied square metre of rock. There is no indication of decline in Scandinavia. In Sweden there are no more than 10 individual-equivalents in each subpopulation. The known subpopulations in Sweden contain around 250 individual-equivalents in total. There are probably fewer than 1,000 individual-equivalents in Europe. The overall current population trend is unknown, but in Switzerland and Austria the species is probably declining. There seems to be only one recent record from Germany. The population is not severely fragmented.

**Population Information**

Current Population Trend: Unknown

**Habits and Ecology**
This saxicolous species usually grows in shady hardwood forests, mainly of ash, maple and elm, under the trees. It occurs on siliceous rock, often on intermittently irrigated sloping stone surfaces. It also occurs on more easily weathered rocks, basalt and even on limestone. It can grow in Sweden with associates such as Parella spp., Schistidium spp., Orthotrichum rupestre and Anomodon spp. In Germany, additional associates include Pterigynandrum filiforme, Homalothecium sericeum, Radula complanata and Metzgeria furcata (Meinunger and Schröder 2007, ArtDatabanken 2015). Its altitudinal range is from 50 m up to 2,040 m Aasl.

It is monoicous.

IUCN Habitats Classification Scheme

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Season</th>
<th>Suitability</th>
<th>Major Importance?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4. Forest</td>
<td>Forest - Temperate</td>
<td>Suitable</td>
<td>Yes</td>
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Systems
System: Terrestrial

Plant Specific

<table>
<thead>
<tr>
<th>Plant Growth Forms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moss</td>
</tr>
</tbody>
</table>

Use and Trade

General Use and Trade Information

Species not utilized: true

This species is not utilised or traded.

Threats

Clear felling of mature hardwood forest is the main threat to this species (ArtDatabanken 2016).

Threats Classification Scheme

<table>
<thead>
<tr>
<th>Threat</th>
<th>Timing</th>
<th>Scope</th>
<th>Severity</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2.2. Agriculture &amp; aquaculture -&gt; Wood &amp; pulp</td>
<td>Ongoing</td>
<td>Unknown</td>
<td>Slow, Significant</td>
<td>Declines</td>
</tr>
<tr>
<td>plantations -&gt; Agro-industry plantations</td>
<td></td>
<td>Unknown</td>
<td></td>
<td></td>
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</tbody>
</table>

Conservation

This species has been assessed as Critically Endangered in Slovakia, Germany and Switzerland, as Endangered in Finland, Portugal and Hungary, as Vulnerable in the Czech Republic and Bulgaria, as Near Threatened in Sweden, as 'rare' in Poland, and as Data Deficient in Spain (Hodgetts 2015). It is unknown whether it occurs in any protected areas.
Protection and minimal management of woodland where there are significant stands of this species is recommended. Further research on its population size and trend is also needed.

Conservation Actions In- Place

<table>
<thead>
<tr>
<th>Occur in at least one PA</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
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Important Conservation Actions Needed

<table>
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<tr>
<th>Conservation Actions</th>
<th>Note</th>
</tr>
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<tbody>
<tr>
<td>1.1. Land/water protection -&gt; Site/area protection</td>
<td>-</td>
</tr>
<tr>
<td>2.1. Land/water management -&gt; Site/area management</td>
<td>-</td>
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</table>

Research Needed

<table>
<thead>
<tr>
<th>Research</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2. Research -&gt; Population size, distribution &amp; trends</td>
<td>-</td>
</tr>
</tbody>
</table>

Bibliography


Orthotrichum urnigerum

Range

Citation: International Union for Conservation of Nature (IUCN) & GBIF
Appendix 3. Red List status of European mosses, liverworts and hornworts

<table>
<thead>
<tr>
<th>Species protected under the</th>
<th>Habits Directive</th>
<th>Bern Convention</th>
<th>Conservation Status</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ANNEX II</td>
<td>ANNEX V</td>
<td>APPENDIX I</td>
</tr>
<tr>
<td><em>Bruchia vogesiaca</em> Schwaegr.</td>
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<td>√</td>
<td></td>
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<tr>
<td><em>Brachythecium novae-angliae</em> (Sull &amp; Lesq.) A.Jaeger (Bryhnia novae-angliae (Sull &amp; Lesq.) Grou)</td>
<td>√</td>
<td></td>
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<tr>
<td><em>Bryoerythrophyllum campylocarpum</em> (C. Müll.) Crum. (<em>Bryoerythrophyllum machadoanum</em> (Sergio) M.O. Hill)</td>
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<td>√</td>
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<tr>
<td><em>Buxbaumia viridis</em> (Mouq.) Moug. &amp; Nestl.</td>
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<td><em>Cephalozia macounii</em> (Aust.) Aust.</td>
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<td><em>Cynodontium suecicum</em> (H. Arn. &amp; C. Jens.) I. Hag.</td>
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<tr>
<td><em>Dichelyma capillaceum</em> (Dicks) Myr.</td>
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<td><em>Dicranum viride</em> (Sull. &amp; Lesq.) Lindb.</td>
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<td><em>Distichophyllum carinatum</em> Dix. &amp; Nich.</td>
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<td><em>Hamatocaulis (Drepanocladus) vernicosus</em> (Mitt.) Warnst.</td>
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<td><em>Encalypta mutica</em> (I. Hagen)</td>
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<td><em>Hamatocaulis lapponicus</em> (Norrl.) Hedenäs</td>
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<td><em>Herzogiella turfacea</em> (Lindb.) I. Wats.</td>
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<td><em>Hygrohypnum montanum</em> (Lindb.) Broth.</td>
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<td><em>Jungermannia handelii</em> (Schiffn.) Amak.</td>
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<td><em>Mannia triandra</em> (Scop.) Grolle</td>
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<td><em>Marsupella profunda</em> Lindb.</td>
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<td><em>Meesia longiseta</em> Hedw.</td>
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<td><em>Notothylas orbicularis</em> (Schwein.) Sull.*</td>
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<td>Orthotrichum rogeri Brid.</td>
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<td>Riella helicophylla (Bory &amp; Mont.) Mont.</td>
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<td>(Scapania massolongi (K. Müll.) K. Müll.)</td>
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<tr>
<td>Pyramidula tetragona (Brid.) Brid.</td>
<td>EN</td>
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</table>
The IUCN Red List of Threatened Species™ – European Regional Assessments

- The Status and Distribution of European Mammals. Compiled by Helen J. Temple and Andrew Terry, 2007
- European Red List of Dragonflies. Compiled by Vincent J. Kalkman, Jean-Pierre Boudot, R. Bernard, Klaus-Jurgen Conze, Geert De Knijf, Elena Dyatlova, Sonia Ferreira, Miloš Jović, Jurgen Ott, Elisa Riservato and Goran Sahlen, 2010
- European Red List of Saproxylic Beetles. Compiled by Ana Nieto and Keith Alexander, 2010
- European Red List of Freshwater Fishes. Jorg Freyhof and Emma Brooks, 2011
- European Red List of Medicinal Plants. David J. Allen, Melanie Bilz, Rebecca Miller, Jemma Window and Anastasiya Timoshyna, 2014

The European Red List is a review of the status of European species according to IUCN regional Red Listing guidelines. It identifies those species that are threatened with extinction at the regional level – in order that appropriate conservation action can be taken to improve their status.

This publication summarises results for all Europe’s native species of mosses, liverworts and hornworts (1,817 species). 22.4% of species are threatened with extinction at the European level mainly due to human-induced modifications to natural systems, climate change, and agriculture.

The European Red List was compiled by IUCN with support from the IUCN Species Survival Commission and other experts. It is the product of a LIFE project funded by the European Commission (LIFE14 PRE BE 001).

It is available online at
http://ec.europa.eu/environment/nature/conservation/species/redlist
and
https://www.iucnredlist.org/regions/europe

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