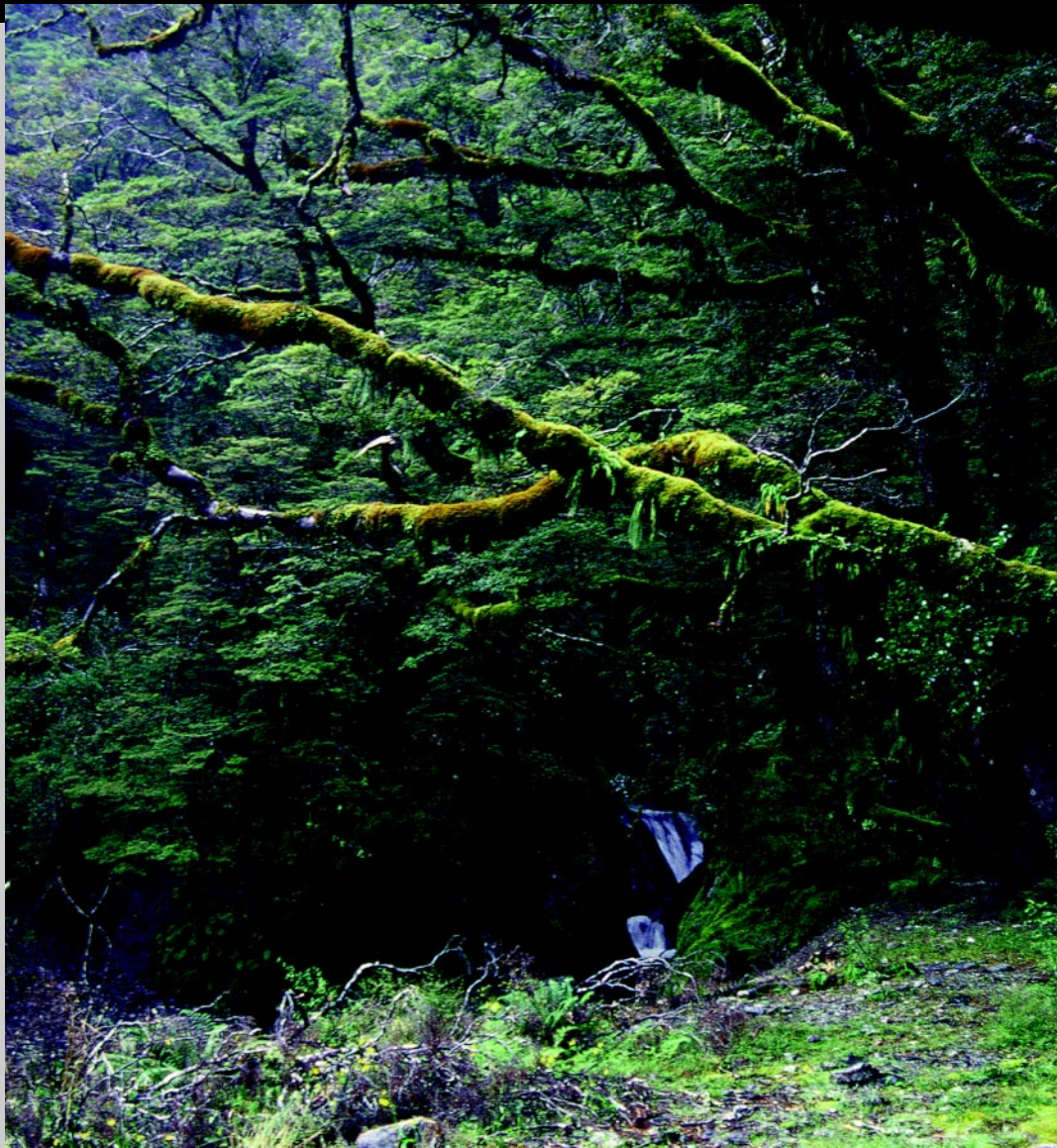


Status Survey and Conservation Action Plan for Bryophytes

Mosses, Liverworts, and Hornworts

Compiled by Tomas Hallingbäck and Nick Hodgetts



IUCN/SSC Bryophyte Specialist Group

Status Survey and Conservation Action Plan for Bryophytes

Mosses, Liverworts, and Hornworts

Compiled by Tomas Hallingbäck and Nick Hodgetts

IUCN/SSC Bryophyte Specialist Group

with contributions from:



ArtDatabanken



The designation of geographical entities in this book, and the presentation of the material, do not imply the expression of any opinion whatsoever on the part of IUCN concerning the legal status of any country, territory, or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

The views expressed in this publication do not necessarily reflect those of IUCN.

Published by: IUCN, Gland, Switzerland and Cambridge, UK in collaboration with the Swedish Threatened Species Unit.

Copyright: © 2000 International Union for Conservation of Nature and Natural Resources.

Reproduction of this publication for educational or other non-commercial purposes is authorized without prior written permission from the copyright holder provided the source is fully acknowledged.

Reproduction of this publication for resale or other commercial purposes is prohibited without prior written permission of the copyright holder.

Citation: Hallingbäck, T. and Hodgetts, N. (compilers). (2000). *Mosses, Liverworts, and Hornworts. Status Survey and Conservation Action Plan for Bryophytes*. IUCN/SSC Bryophyte Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. x + 106pp.

ISBN: 2-8317-0466-9

Cover photo: The temperate rainforest is an important habitat for bryophytes. New Zealand, South Island. Photo: Jan-Peter Frahm.

Produced by: The Nature Conservation Bureau Ltd, Newbury, UK.

Printed by: Information Press, Oxford, UK.

Available from: IUCN Publications Services Unit
219c Huntingdon Road, Cambridge CB3 0DL, UK
Tel: +44 1223 277894, Fax: +44 1223 277175
E-mail: info@books.iucn.org
<http://www.iucn.org>
A catalogue of IUCN publications is also available.

The text of this book is printed on 115 gsm Zone Silk, which is rated as 4-star under the Eco-Check system and is made from 100% sustainable fibre sources using chlorine-free processes.

This Action Plan is dedicated to the memory of Dr. Patricia Geissler, who was tragically killed as a result of a traffic accident in Geneva on the morning of March 28th, 2000. She was a devoted and expert bryologist, and a good friend and colleague. She contributed a great deal to this Action Plan as the principal editor for liverworts. She will be missed very much.

Contents

Foreword	vi
Acknowledgements	vii
The IUCN/SSC Bryophyte Specialist Group	vii
Executive Summary	viii
Resúmen	ix
Résumé	x
1. Introduction	1
2. Classification and Number of Bryophyte Species	2
2.1 Classification	3
2.2 Identification	4
2.3 Origin	5
2.4 Number of species	5
3. The Importance of Bryophytes	6
3.1 The ecological role of bryophytes	6
3.1.1 Water retention	6
3.1.2 Large biomass	7
3.1.3 Colonisation, soil stabilisation, and accumulation of humus	7
3.1.4 Peat formation	7
3.1.5 Relationships with other organisms	7
3.2 The economic and medicinal uses of bryophytes	7
3.3 Bryophytes as indicators	8
3.3.1 Pollution indicators	8
3.3.2 Indicators of natural environmental conditions	8
3.4 The cultural and aesthetic qualities of bryophytes	9
3.5 Bryophytes in science and education	10
4. Threats to Bryophytes	11
4.1 General threats	11
4.2 Lack of bryophyte conservation awareness ...	12
4.3 Gaps in the current knowledge base	12
5. Key Habitats and their Specific Threats and Recommendations	14
5.1 Habitat destruction and degradation	14
5.2 Forests	14
5.2.1 Threats	14
5.2.2 Recommendations	15
5.2.3 Montane tropical cloud forest	15
5.2.4 Lowland old-growth tropical rainforest	15
5.2.5 Lowland old-growth boreal forest	16
5.2.6 Lowland secondary forest, including park and pasture woodland	16
5.3 Non-forested habitats	16
5.3.1 Montane cliffs, rocks, and soil slopes ...	16
5.3.2 Tundra	17
5.3.3 Ravines	17
5.3.4 Lowland rock exposures	18
5.3.5 Coastal grassland, rocks, and thin turf	18
5.3.6 Lowland riverine and aquatic systems, including pools, and reservoirs	18
5.3.7 Upland flushes, springs, mountain streams, and waterfalls	19
5.3.8 Cultivated fields	19
5.3.9 Lowland fens	19
5.3.10 Lowland bogs	20
5.3.11 Heavy metal-rich rocks and mine waste	20
5.3.12 Páramos	21
5.3.13 Prairie, steppe, salt steppe, and gypsum-rich soils	21
6. Regional Overviews	22
6.1 Australasia	22
6.2 East and Southeast Asia	27
6.3 Sub-Saharan Africa	31
6.4 Southern South America	35
6.5 Tropical America (incl. Mexico)	38
6.6 Europe (incl. Macaronesia)	44
6.7 North America	50
7. Conservation Measures	54
7.1 Habitat approach	54
7.1.1 Achieving habitat protection	54
7.1.2 Habitat function approach to habitat protection	54
7.1.3 Funding habitat protection	54
7.2 Species approach	56
7.2.1. Species approach to habitat protection ..	56
7.2.2 Flagship and indicator species	56
7.2.3 Keystone species	56
7.3 Legal instruments	56
8. Recommendations	57
References	58
Glossary	69
Appendix 1. Guidelines for Application of the 1994 IUCN Red List Categories of Threats to Bryophytes ..	71
Appendix 2. The 2000 IUCN World Red List of Bryophytes	77
Appendix 3. Examples of Projects for Bryophyte Conservation	91
Appendix 4. Resolutions from the Second Symposium on Conservation of Bryophytes in Europe held in Zürich, 5th–8th September 1994	94
Appendix 5. Resolutions Adopted by the Second Planta Europa Conference, Uppsala, 13 June 1998	95
Appendix 6. IUCN/SSC Bryophyte Specialist Group Members and Contributing Authors	96
Appendix 7. IUCN Red List Categories	97

Foreword

In the beginning this Action Plan was simply called “Bryophytes” However, once our communications people saw it they pleaded that it be renamed “Mosses, Liverworts, and Hornworts”. We hope that this will make the subject clearer, but whatever the title, I highly recommend this Action Plan to both botanists and non-botanists, and especially to anyone concerned with conservation issues. Since bryophyte conservation in so many cases equals habitat conservation, it is critical that decision-makers know where important areas to conserve are found. In addition, the reader will gain a much greater appreciation and knowledge about these beautiful, and in many cases, highly threatened plants.

For interest, the foreword to the recently published *African Rhino: Status Survey and Conservation Action Plan* began by saying, “The black and white rhinoceroses are two of the most charismatic megaherbivores left on our planet...”

Now no one (apart from some bryologists), would ever say that bryophytes...that is, mosses, liverworts, and hornworts...are among the most charismatic species left on our planet. And even if someone did, which one or two among the thousands of species would he or she choose? However, after working with the Bryophyte Specialist Group and reading their Action Plan, I have an increased respect for what many people, botanists included, regard simply as “moss”. The intricate structure and life strategies of these plants, and the increased risk to their continued survival due to the same factors that threaten the survival of other, more easily identified species, highlights conservation problems throughout the world. If we can’t save what must be considered true survivors—these tenacious green things that cling to trees and rocks, and survive in the most inhospitable of environments— then what hope have we for saving the rest?

Bryophytes are the “canaries in the coal mine”. Sensitive to pollution and other environmental changes, bryophytes can send out the alarm calls that we will need to quickly heed if we are to prevent their loss, as well as the loss of many other species found in the same habitats. In addition, bryophytes are fundamental for ecosystem function, yet being so vulnerable to habitat change, need increased care if we wish to maintain life as we know it (or, if possible, even improve on the environment that we live in today).

Another striking characteristic of bryophytes is that there are a lot of them, an estimated 14,000 to 15,000 species. Yet very few people in the world can actually identify them (and with the tragic loss of Patricia Geissler, who was a major player in the botanical world, there is sadly even one less). Much reference is made in this Action Plan to the Convention on Biological Diversity (CBD). But what is diversity? Recognised by the CBD as “the variability among living organisms from all sources...”, bryophytes certainly comprise a significant segment of the biodiversity that the world’s governments have agreed must be conserved. This Action Plan provides proposals and makes recommendations for what needs to be done to ensure their continued survival. Bryophytes can also serve as indicators as to whether conservation measures are really having any effect.

For such a group where there are so few experts and so many taxa, it is extraordinary that a detailed list of 83 threatened species can be enumerated (see Appendix 2). Sadly though, this is just the tip of the iceberg, and it is likely that with increased knowledge of bryophytes, the number of species considered threatened will only increase. However, it is hoped that at the same time new knowledge is being generated, conservation measures for the species known to be threatened will be implemented.

It must also be added that what is good for a rhino may not necessarily help the bryophytes. Thus, care must be taken to ensure that significant habitats, as well as microhabitats, are conserved to ensure the future survival of these species. In some respects the task is easier: bryophytes take up a lot less space than a rhino. But people need to respect and be concerned about the welfare of all creatures, both charismatic and less so, if we are to really conserve biodiversity.

The message coming from this Action Plan is that while there is a great need for increased knowledge about bryophytes, at the same time a lot is already known. But to only a few. This Action Plan must get this knowledge out to a wider public so that these fascinating organisms—so much smaller than an African rhino, but possibly even more fundamental to our future well-being—can be conserved.

Wendy Strahm
Plants Officer, IUCN Species Survival Commission

Acknowledgements

This Action Plan has been written by the members of the Bryophyte Specialist Group and other experts: René Belland, Patricia Geissler (†), S. Rob Gradstein, Tomas Hallingbäck, Nick Hodgetts, Celina Matteri, Brian O'Shea, Tamás Pócs, Geert Raeymaekers, Wilfred Schofield, Cecilia Sérgio, Lars Söderström, Heinar Streimann, and Benito C. Tan, Edwin Urmi, and Jiří Váňa. It was compiled by Tomas Hallingbäck and Nick Hodgetts. Members contact details can be found in Appendix 6.

We would like to thank all those who kindly forwarded information and suggestions for the Plan, especially Helène Bischler, Steven Churchill, Johannes Enroth, Jan-Peter Frahm, Jiro Hasegawa, Lars Hedenäs, Michail Ignatov, Zen Iwatsuki, S. Jovet-Ast, Nadja Konstaninova,

David Long, B. Jesus Muñoz, Giribala Pant, Ron A. Pursell, William D. Reese, P.W. Richards, Garry Smith-Merrill, Tony Spribille, John Steel, Pierre Tixier, Alan Whittemore, and Richard H. Zander. Other members of the European subgroup of the IUCN/SSC Bryophyte Specialist Group whom we would also like to thank, suggested several new inputs and proposals discussed in this paper.

Last, but not least, we would like to thank the SSC staff involved in editing Action Plans for guidance and encouragement in developing this document.

Tomas Hallingbäck
Chairman IUCN/SSC Bryophyte Specialist Group

The IUCN/SSC Bryophyte Specialist Group

The Bryophyte Specialist Group (BSG) was formed in 1991, shortly after the first international conference on endangered bryophytes held in Uppsala in 1990. It convenes once every two years on the occasion of the International Symposia organised by the International Association of Bryologists (IAB). Members of the BSG

are kept informed of developments through correspondence and regional meetings, most specifically those arranged by the European Committee for the Conservation of Bryophytes (ECCB). One of its main aims is to provide an Action Plan for bryophyte conservation. This is the first attempt.

Executive Summary

Mosses, liverworts, and hornworts belong to a division of the Plant Kingdom known as Bryophyta – the bryophytes. Morphologically, bryophytes are usually small organisms, typically green, and lacking some of the complex structures found in vascular plants. They do not produce flowers or seeds, and the majority have no internal mechanism for transporting water or nutrients. Although they have no roots they do have root-like structures for anchoring and water absorption.

Bryophytes range from a few millimetres to half a metre in height; mosses may be erect, lateral, or multiple-branched in structure. They are found on soil, rocks, and trees throughout the world, from coastal Antarctica to the tundra of the Northern Hemisphere, and from the Australian deserts to the Amazon rainforests. Although small in stature, they are an essential part of the earth's biodiversity and play a significant role in diverse terrestrial and aquatic ecosystems; some species even dominate pond and river habitats.

Bryophytes assist in the stabilisation of soil crust by colonising bare ground and rocks, and are essential in nutrient recycling, biomass production, and carbon fixing. In general, they are very efficient at regulating water flow by means of an effective water-retention mechanism. They also have an economic value, whether it is as peat for fuel, horticulture, oil absorption, or as sources for a wide variety of chemical compounds. Bryophytes have long been used for medicinal purposes and their value as pollution indicators is also well known. They are also a food source for animals in cold environments.

However, the worldwide reduction, fragmentation, and degradation of habitats important for bryophytes has led to a loss of species richness and genetic diversity. Threats to bryophytes include deforestation, forest cultivation, land reclamation, urbanisation, road and dam construction, mining, wetland drainage, and over-grazing. Invasive, introduced vascular plant species can also devastate native bryophyte floras.

Bryophytes are threatened partly because of their morphology and reproduction rates. They are fragile organisms, sensitive to drought, and have a relatively low growth rate and therefore desiccate quickly during periods of dry weather. They are highly vulnerable to disturbance and also extremely sensitive to pollution as they lack a cuticle (a layer on the outer cell surface that protects the tissue from, for example, harmful chemicals). Bryophytes are also threatened because of their lack of “image” within the sphere of nature conservation. They are not large, charismatic species, and this, coupled with a lack of understanding of how they contribute towards ecosystem functioning, often results in their being overlooked by the general public and conservation groups. Unfortunately, many areas where species diversity is extremely high are

highly threatened by habitat destruction, for example the lowland regions of East and Southeast Asia.

This Action Plan reviews the status of bryophytes worldwide and provides examples of habitats currently rich in bryophytes. It is aimed at individuals who work in the field of, and have an interest in, nature conservation and wish to take steps to conserve bryophytes. It is also aimed at governmental and non-governmental organisations, politicians, and the general public. These individuals and organisations have the ability to implement the recommendations and general initiatives forwarded within this plan. The United Nations Convention on Biological Diversity (CBD) may be a legislative option for effective bryophyte conservation in some countries. One hundred and seventy-seven countries have now ratified this convention, and bryophytes should be included in the National Biodiversity Strategy and Action Plan of each country.

This Action Plan suggests a number of more general initiatives, including:

- increasing inventories in the tropics to determine bryophyte richness in different regions and habitat types and to determine which species are locally common, rare, or threatened;
- establishing protected areas or national systems of protected areas where endangered bryophytes occur;
- incorporating bryophyte conservation in development and industrial activities;
- comparing bryophyte floras of undisturbed and disturbed habitats to determine the impact of disturbance, and to identify those species unable to survive in disturbed areas. Without reliable information on the habitat requirements of species, including information on the quality of the habitats, it is impossible to determine appropriate conservation actions;
- studying the taxonomy and distribution of individual species to determine how species can be identified, to determine their ranges, and to help identify those that are narrowly endemic (i.e., occur only within a small region);
- training local people to become specialists. Because of the speed at which natural environments are disappearing worldwide, this initiative is extremely urgent and should be implemented immediately; and
- creating user-friendly regional identification guides.

Examples of priority projects for bryophyte conservation and a list of the most endangered bryophyte species throughout the world can be found in the appendices of this Action Plan. The 2000 IUCN World Red List of Bryophytes can be found at the following Internet site: <www.dha.slu.se/guest/WorldBryo.htm>.

Resumen

Los briófitos incluyen los musgos, las hepáticas y las antocerotas, todos ellos pertenecen a la división Bryophyta del Reino Vegetal. Morfológicamente, suelen ser organismos pequeños, típicamente verdes y que carecen de algunas estructuras complejas presentes en las plantas vasculares. No producen flores ni semillas y la mayoría no disponen de mecanismos internos para el transporte de agua o nutrientes. No desarrollan raíces aunque presentan unas estructuras de aspecto similar cuya misión es básicamente la fijación al sustrato y la absorción de agua.

El tamaño de los briófitos varía desde unos pocos milímetros hasta el medio metro de altura; estructuralmente, los musgos pueden ser erectos, laterales o multirramificados. Se encuentran sobre suelo, roca y árboles de todo el mundo, desde las costas antárticas hasta las turberas del Hemisferio Norte, y desde los desiertos australianos hasta la selva lluviosa amazónica. A pesar de su pequeña talla, son parte esencial de la biodiversidad del planeta y juegan un importante papel en diferentes ecosistemas terrestres y acuáticos; algunas especies incluso llegan a dominar en lugares encharcados y ecosistemas fluviales.

Los briófitos colaboran en la estabilización de las capas más superficiales del suelo colonizando rocas y suelos desnudos y son fundamentales en el reciclaje de nutrientes, en la producción de biomasa y en la fijación del carbono. En general, son muy eficientes regulando el flujo hídrico ya que poseen mecanismos muy efectivos para la retención de agua. También hay que destacar su valor económico, ya sea como combustible (turba), en horticultura, en la absorción de aceites, o como fuente de una gran variedad de compuestos químicos. Desde siempre se han utilizado con fines medicinales y su valor como bioindicadores de la polución ambiental es bien conocido. También son una fuente de alimento para animales de ambientes fríos.

Sin embargo, la reducción, fragmentación y degradación de los diferentes hábitats que se está produciendo a nivel mundial, ha llevado a una pérdida en la riqueza de especies y diversidad genética. Las principales amenazas a la que están expuestos los briófitos son deforestación, cultivo forestal, demanda de suelo, urbanización, construcción de presas y carreteras, explotaciones mineras, drenaje de zonas pantanosas y pastoreo intensivo. La introducción invasiva de algunas plantas vasculares también puede afectar muy seriamente a la brioflora nativa.

Los briófitos se ven en parte amenazados por su morfología y tasas de reproducción. Son organismos frágiles, sensibles a la sequía y con tasas de crecimiento relativamente bajas, por ello se deshidratan rápidamente cuando el tiempo es seco. Son muy vulnerables a perturbaciones en su entorno y extremadamente sensibles a la polución ya que carecen de cutícula (capa externa de células que protege a los tejidos, por ejemplo de productos químicos dañinos). Por sus características morfológicas, los briófitos pasan desapercibidos en el campo de la conservación natural; el hecho de ser organismos poco aparentes y el gran desconocimiento que existe sobre su contribución al funcionamiento de diversos ecosistemas, hace que sean ignorados por el gran público y por los grupos interesados en la conservación de espacios naturales. Desgraciadamente, muchas áreas de gran

riqueza en diversidad de especies están altamente amenazadas por la destrucción de sus hábitats, es por ejemplo el caso de las tierras bajas del este y el sudeste asiático.

Este Plan de Acción estudia el status de los briófitos en todo el mundo y ofrece ejemplos de los hábitats que son, actualmente, ricos en briófitos. Este estudio está dirigido a las personas que trabajan y están interesadas en el campo de la conservación natural, y desean tomar medidas para la conservación de los briófitos. También está destinado a las organizaciones gubernamentales y no gubernamentales, políticos y público en general. Estas personas y organizaciones tienen la capacidad de implementar las recomendaciones y las iniciativas generales promovidas en este plan. La Convención sobre la Diversidad Biológica (CDB) de las Naciones Unidas, puede ser una opción legislativa para la conservación efectiva de los briófitos en algunos países. Ciento setenta y siete países han ratificado recientemente esta convención, y los briófitos deberían ser incluidos en la Estrategia Nacional de Biodiversidad y Plan de Acción de cada país.

Este Plan de Acción sugiere una serie de iniciativas más generales que incluyen:

- aumentar los inventarios en los trópicos para determinar la riqueza briofítica en diferentes regiones y tipos de hábitats y determinar qué especies son localmente comunes, raras o amenazadas;
- establecer áreas protegidas o sistemas nacionales para la protección de áreas;
- incorporar la conservación de briófitos cuando se realizan actividades industriales y de desarrollo;
- comparar la brioflora de hábitats alterados y no alterados para determinar el impacto de tal alteración y para identificar aquellas especies incapaces de sobrevivir en zonas alteradas. Sin una información fiable sobre las exigencias ecológicas de las especies, incluyendo información sobre la calidad de los hábitats, es imposible determinar que acciones son las más apropiadas para su conservación;
- estudiar la taxonomía y la distribución de las especies a nivel individual para determinar como pueden ser identificadas, cual es su área de distribución y poder identificar aquellas que son estrictamente endémicas (es decir, las que sólo están presentes en pequeñas zonas);
- formar a especialistas entre la población autóctona. Debido a la velocidad con la que el entorno natural está desapareciendo en todo el mundo, esta iniciativa es extremadamente urgente y debe ser puesta en marcha de inmediato; y
- crear guías de identificación a nivel regional de uso fácil.

Ejemplos de proyectos prioritarios para la conservación de briófitos y una lista de las especies más amenazadas en el mundo se pueden encontrar en los apéndices de este Plan de Acción. “The 2000 IUCN World Red List of Bryophytes” se puede consultar en la siguiente dirección de Internet: <www.dha.slu.se/guest/WorldBryo.htm>.

Introduction

Most researchers studying this plant group are aware of the negative changes in the bryophyte flora in many parts of the world, and conservationists have admitted that conservation of non-seed plants has been neglected in the past (Akeroyd 1995). In 1990, the International Association of Bryologists (IAB) established a standing committee for endangered bryophytes. One year later, IUCN – The World Conservation Union established a Species Survival Commission Specialist Group for Bryophytes to promote the conservation of bryophytes, and to explain their role and importance in ecosystems. The two groups jointly established a worldwide network to coordinate bryophyte conservation. Today, the group also promotes international cooperation and communication between bryologists and conservationists; heightens awareness of

bryophytes among conservation organisations, non-governmental organisations, and other interested parties; publicises the threats to bryophyte species and habitats; and explains the need for protection.

Even if incomplete, the present bryophyte knowledge base is sufficient to produce an Action Plan for the conservation of some of the most important habitats and endangered species. We are aware of this Action Plan's bias towards well-known regions and habitats; information on the status of the bryoflora in the subcontinent of India, the near and Middle East, and the south-eastern part of the former Soviet Union is today very scarce, and these geographical units are represented very unevenly in this Action Plan. There is also taxonomic bias towards mosses; a group that has been investigated more thoroughly around the world, and that is understood to a greater extent than liverworts and hornworts. It is hoped that additional knowledge of less well-known regions, habitats, and species will gradually become available, thus increasing the scope of further Action Plans.

Bryologists are becoming increasingly aware of the threatened status of the bryophyte flora, and resolutions expressing concern have been adopted at various conferences (e.g., Geissler and Greene 1982, Tan *et al.* 1991, Koponen 1992, Bisang and Urmi 1995). Therefore, it is disturbing to note that very little action has been taken to counteract the deterioration of the bryophyte flora in a global context, and even less has been done in terms of local, practical bryophyte conservation (Hallingbäck 1995). The reason for this inactivity is not a lack of interest in the subject, but rather a lack of bryologists, and poor communication and information exchange between bryologists and conservationists. This Action Plan attempts to increase communication between these two groups.

Chapter 2 of this Plan describes the biology, the classification, the origin, and the number of species of mosses, liverworts, and hornworts. The importance and the uses of bryophytes are briefly described in Chapter 3. Chapter 4 discusses the threats to bryophytes, and the causes of these threats together with the gaps in our knowledge. Specific conservation actions are discussed in the chapters on Habitats (Chapter 5) and Regional Overviews (Chapter 6). In Chapter 7 current conservation measures are presented. The recommendations of this Action Plan are proposed in Chapter 8. Red Data Sheets throughout the document provide examples of globally threatened bryophytes, and a 2000 IUCN World Red List of Bryophytes is presented in Appendix 2.

Figure 1.1. A magnificent moss such as *Spiridens reinwardtii* can be used as a flagship species.



H. Streimann

Classification and Number of Bryophyte Species

Wilfred B. Schofield

Bryophytes are a distinctive group of green land plants. This division includes the mosses (Bryopsida or Musci), liverworts (Hepaticopsida or Hepaticae), and hornworts (Anthocerotopsida or Anthocerotae). These three classes form a loosely related group of plants that have in common a number of distinctive features that separate them from the more conspicuous vascular plants. Bryophytes have a perennial, physiologically independent sexual stage (the gametophyte) of the life cycle, compared to the parasitic gametophyte in vascular plants. In bryophytes, the spore-producing stage (the sporophyte) bears a single spore-producing organ (the sporangium) that is largely parasitic on the gametophyte. In vascular plants, the sporophyte is generally perennial, physiologically independent, and produces innumerable sporangia. In most bryophytes, the

spores are expelled into moving air when the sporangium is mature.

The gametophyte is a photosynthetic plant and is usually attached to its substratum by hair-like rhizoids. In mosses and liverworts, the gametophyte is generally leafy, while in some liverworts and most hornworts it is thallose (i.e., strap-shaped). Water and dissolved minerals enter the gametophyte by simple diffusion through the cell walls; complex structures for absorption are absent. Gametophytes are usually small, varying from less than 1 millimetre to occasionally as tall as 20 centimetres. A few aquatic mosses (*Fontinalis*) can reach lengths of nearly one metre.

The male sex organ (antheridium) is an extremely small sac that produces many motile sperms. The female sex organ (archegonium) is a flask-shaped structure that contains a single non-motile egg. Fertilisation occurs when sperms are shed and swim, aided by two flagellae, to the entrance at the apex of the neck of the flask. They are attracted by substances derived from the disintegrated cells of the neck canal cells of the mature archegonium; these substances are diffused in water that bathes the sex organs. The greatest concentration of these substances is near the egg where the sperm swims. One sperm unites with an egg, beginning the growth of the sporophyte. Bryophytes also reproduce vegetatively by fragmentation, as well as by production of small gemmae. Gametophytes can form extensive clones. Indeed, in a few bryophytes in which sporophytes are unknown, it is possible that all individuals are part of a clone.

Since water is necessary for growth and sexual reproduction, bryophytes are limited mainly to sites where water is available for the growing season. In many bryophytes, dormancy allows survival during the dry season; others are intolerant of extended drying. Bryophytes tend to be most abundant and luxuriant in humid climates. Their diversity often corresponds with habitat diversity.

Bryophytes are especially vulnerable to disturbance. The destruction of seed plant vegetation results in the elimination of the bryophytes that are dependent on that vegetation for shelter. The survival of seed plant vegetation is also intimately linked to the bryophyte vegetation; bryophytes are important in the retention of soil moisture, nutrient recycling, and seedling survival, as well as for providing habitat for other organisms that are vital for vegetation health.

Figure 2.1. *Schistochila aligera*, an example of a liverwort restricted to humid mountain rainforest.



T. Hallingbäck

2.1 Classification

The differences among the main classes of bryophytes are very clear. The hornworts possess a thallose (or essentially thallose) gametophyte in which the sex organs are completely embedded in the thallus. The sporophyte is always horn-shaped and consists mainly of a sporangium that matures from the apex downward to its foot in the thallus. In most hornworts, spores are shed from the mature apex while growth above the foot continues to produce new spores as long as the growing period is favourable (Fig. 2.2).

Liverworts may also have thallose gametophytes (Fig. 2.3), but most are leafy with leaves in two or three rows (Fig. 2.4). Sex organs are discrete and generally on the surface, but protected by enveloping structures. Rhizoids are unicellular. Leaves are often lobed and lack a midrib, and the whole leaf is almost entirely one cell thick. In most cases, the sporangium matures when protected by the enveloping structures; once mature, the colourless seta pushes it above the protective sheath. The seta is held erect by water pressure within its cells. Spores are shed when the sporangium ruptures, generally along four longitudinal lines, to expose the spores and admixed coiled cells (elaters) to drying air. The elaters uncoil rapidly

when dry and throw the spores into the air, then the seta collapses.

In mosses, the mature gametophyte is leafy with leaves generally in more than three rows. Sex organs are usually protected by sheathing leaves. Rhizoids are multicellular and much branched. Leaves are not lobed and often possess a midrib several cells in thickness. The sporangium is produced after the photosynthetic seta elongates; the seta is rigid with thick-walled cells, and contains a

Figure 2.3. A typical thallose liverwort *Monoclea gottschei* Lindb.



T. Hallingbäck

Figure 2.2. The hornwort *Phaeoceros carolinianus* with sporophytes.



T. Hallingbäck

Figure 2.4. *Jungermannia leiantha* with sporophytes; a typical leafy liverwort.



T. Hallingbäck

conducting system that transfers absorbed water and nutrients produced by the gametophyte to the developing sporophyte. The seta usually has a cuticle and, therefore, is unable to absorb water directly (Fig. 2.5). When mature, the sporangium usually has a lid differentiated near its apex; beneath this lid are usually teeth that move inward and outward in response to available moisture – these control the shedding of the spores over an extended period (Fig. 2.6).

Within the mosses, there are exceptions to the usual spore dispersal devices. In the peat mosses (*Sphagnum*), for example, there is no seta; the sporangium is raised on

a stalk of leafless, gametophytic stem tissue (Fig. 2.7). The sporangium ruptures explosively, casting both the lid and the contained spores into the air.

2.2 Identification

Bryophytes are identified using characteristics of both the gametophyte and sporophyte. Using living sporophytic material greatly assists identification, though it is possible to identify bryophytes from dried, non-living specimens. A compound microscope is an important, if not essential



Figure 2.5. Young sporangia protected by caps and attached to an elongated seta. To the left are cups with male sex organs (antheridia) *Polytrichum juniperinum*.

I. Holmåsén

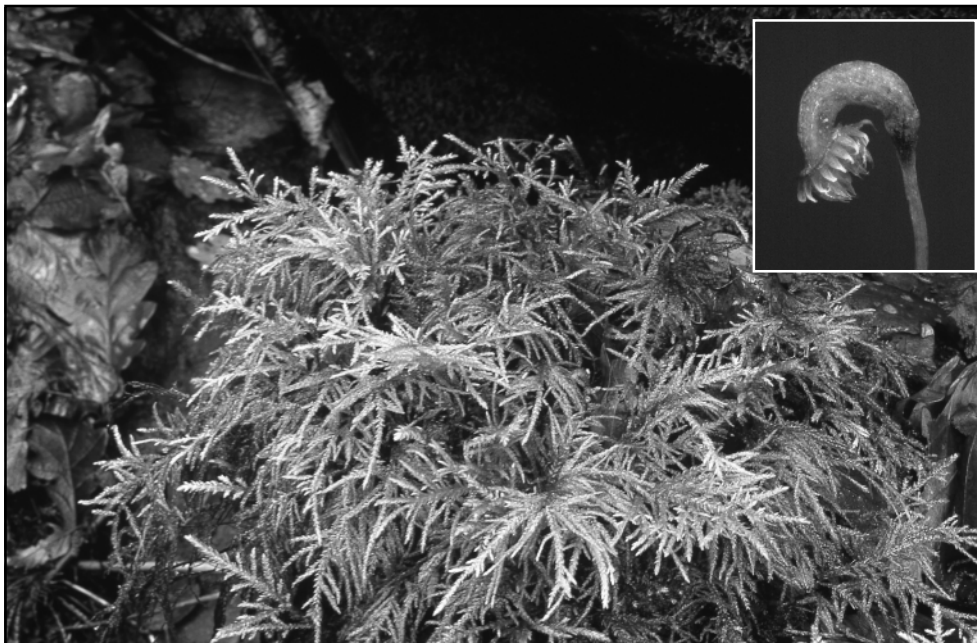


Figure 2.6. *Eurhynchium stokesii*; a pleurocarpous moss. Inset picture is a sporangium.

Photos: T. Hallingbäck



T. Hallingbäck

Figure 2.7. A *Sphagnum* moss with a mature sporangium on an elongated pseudopodia.

tool. However, with experience it is possible to identify many bryophytes to both genus and species level after casual examination. The structures of larger bryophytes are more distinctive, and identification is often quicker and can be made with more confidence than with smaller forms.

In hornworts, the thallus structure, especially the internal anatomy and cell contents, are important for classification. So too is the sporophyte (containing the sporangial wall, the spores and their ornamentation, and sterile cells intermixed with spores) and the structure of the sterile cylinder (if present) in the sporangium.

In liverworts, identification is aided through determination of the shape of the gametophyte, the internal anatomy and cell contents in the thallose species, and the position of the sex organs and their protective structures. Features of the sporophytes, such as internal anatomy of the seta, ornamentation of sporangial jackets, spore ornamentation, and elater structure, are also important for identification. In leafy genera, these same internal and external features, in addition to leaf arrangement and

shape, cellular detail, oil body form, and the position and branching patterns of rhizoids, are also important for classification purposes.

In mosses, gametophytic features of the leaf structure (particularly cellular details and leaf shape), the detail of leaf margins, cellular ornamentation, cross-sections of the midrib, and the position of the sex organ in relation to the stem apex, assist classification. Sporophytic features important for identification are primarily related to the sporangium, in particular its orientation, shape, the sporangial jacket structure (specifically the stomata and cell shape of the outermost cells), and the detailed structure of the teeth within the sporangial mouth.

In many genera, however, the status of the current knowledge base is inadequate and microscopic examination is necessary. Often the specimen must be classified by an “expert” who has considerable experience with the species, as well as with others with which it can be confused. Although new technologies provide additional information, readily observable features are helpful to quickly discriminate between species. Relevant literature regarding bryophyte classification, both old and new, is highly valuable.

2.3 Origin

The bryophytes appear to be among the most ancient divisions of the land plants. Fossils of spores and probable gametophytes have been discovered that closely resemble some modern bryophytes (especially hepatics). These are dated to 400 million years or older. And whilst fossils are highly fragmented in their distribution so that it is impossible to fully identify their origins with confidence, it is clear that aspects of the bryophyte “lifestyle” originated many million years ago.

2.4 Number of species

The number of bryophyte species is difficult to estimate because careful study has been confined to only a fraction of those that have been described. The validity of many of these species is questionable. A reasonable estimate suggests the existence of 14,000 to 15,000 species, of which approximately 8,000 are mosses, 6,000 are liverworts, and 200 are hornworts. Further classification and study will yield additional species that have not yet been described, whilst careful study of those already described will reveal many to be unsatisfactorily classified and their names redundant.

The Importance of Bryophytes

The following information is provided in this chapter:

- The ecological roles of bryophytes in the environment.
- The economic value of bryophytes.
- The use of bryophytes in medicine.
- The use of bryophytes as indicators of pollution and natural habitat quality.
- The cultural and aesthetic qualities of bryophytes.
- The importance of bryophytes in scientific research and as experimental model organisms.
- The use of bryophytes as a food source for animals.

3.1 The ecological role of bryophytes

Bryophytes are an important component of the vegetation in many regions of the world. They play a vital role in, and constitute a major part of, the biodiversity in moist forest, wetland, mountain, and tundra ecosystems. In temperate forests, for example, bryophytes form extensive mixed communities and contribute significantly to community structure and ecosystem functioning. In Arctic regions, bryophytes are important in maintaining permafrost whilst bryophyte-rich peatlands are important carbon sinks in both Arctic and temperate zones. Bryophytes frequently dominate (or co-dominate with lichens) severely stressed

environments, such as exposed mountain summits, upland stream communities, and toxic environments (e.g., soil rich in heavy metals), where most vascular plants are unable to compete successfully.

3.1.1 Water retention

Bryophytes have a high water-retention capacity due to their structure, and tend to be most abundant in regions with high levels of atmospheric humidity and low rates of evaporation. They can quickly absorb water and release it slowly into the surrounding environment, and can, therefore, contribute to the retention of humid forest microclimates and the regulation of water flow. Perhaps more importantly, these properties allow forests to gradually release water into watercourses, preventing flash floods, erosion, and landslides downstream.

The water retention properties of bogs are particularly impressive because of the absorptive properties of *Sphagnum* moss (Fig. 3.1). A bog within a watershed, as can be found on some upland moorlands, is important far beyond its own geographical extent. If such a bog is unable to function, the disruption to the local hydrology can be catastrophic.



Figure 3.1. A *Sphagnum* moss, *S. strictum*. This species has a worldwide distribution and occurs in Europe, Africa, Southeast Asia, and tropical America.

Pär Johansson

3.1.2 Large biomass

In some tropical montane forests (for example, those in Los Nevados, Colombia), the dry weight of epiphytic material in the upper canopy has been recorded at over 100kg/m², or about 12% of the total above-ground, dry tree weight (Hofstede *et al.* 1993). The total dry weight of epiphytes in these forests was estimated at 44 tons/ha (90% being bryophytes). Bryophytes formed more of the photosynthetically active (i.e., green) biomass in these forests than all the other plant groups put together. It is important to state that the bryophyte mass in this type of forest is a major component of the total biomass and is, therefore, an important component of the hydrological, chemical, and organic matter cycles (Hofstede *et al.* 1993, Rhoades 1995).

3.1.3 Colonisation, soil stabilisation, and accumulation of humus

Mosses are often the first plants to colonise newly exposed ground, bare rocks, and other abiotic surfaces. They are important in stabilising the soil crust, both in recently established and existing habitats, such as steep, sloping banks in woodland. They are also valuable in controlling erosion and hydric cycling. In semi-arid woodlands, bryophytes play important roles as colonisers and soil stabilisers in areas where soil surface conditions have declined as a result of increased infiltration (Eldridge 1993).

In the tree canopy in tropical forests, where the soil often lacks a humus layer and is poor in nutrients, bryophytes also assist in the accumulation of humus on branches and twigs. Epiphytic humus accumulated by bryophytes can amount to as much as 2.5 tons/ha of dry matter in elfin cloudforests of East Africa (Pócs 1980).

3.1.4 Peat formation

Sphagnum is often the most important plant in bogs and in peat formation. Peat is the accumulated and compressed remains of vascular and non-vascular plants (mainly bryophytes, particularly *Sphagnum*). The vast and deep peat bogs in temperate and sub-Arctic zones are estimated to cover 1% of the world's surface (Clymo 1970). A deposit 1.5 metres thick may have taken about 6,000 years to accumulate. Today, many of these peatlands are subject to exploitation.

Peatlands are recognised as carbon sinks and it is, therefore, important that they remain undisturbed. Human activities, including drainage, fertilisation, and peatland cultivation, can increase the amount of carbon dioxide released from peat, owing to increases in microbiological activity. These disturbed peatlands then become sources

rather than sinks for carbon in the global ecosystem (Francez and Vasander 1995).

3.1.5 Relationships with other organisms

Bryophyte communities are critical to the survival of a tremendous diversity of organisms, including insects, millipedes, and earthworms. Numerous arthropods, such as acarinae and collembola, and tardigrades, are dependent on mosses and liverworts as habitat, or as a food source. The nutrient-rich, spore-producing capsules are particularly palatable to some insects, and molluscs such as slugs. Bryophytes are also a food source for birds and mammals in cold environments, and are eaten by reindeer, geese, ducks, sheep, musk-ox, lemmings, and other rodents (cf. Longton 1992).

Bryophytes may also be important as nesting material for birds or act as protective habitat for amphibians. For example, in tropical montane forests, pendant or trailing mosses, specifically *Papillaria*, *Floribundaria*, *Meteorium*, and *Squamidium*, and a number of liverworts (e.g., *Frullania* and *Plagiochila*) are used in nest construction. Bryophytes also provide suitable substrates for blue-green algae (*cyanobacteria*); this species fixes nitrogen from the air into solid nitrogen compounds that are then accessible to plants (Bentley and Carpenter 1984).

3.2 The economic and medicinal uses of bryophytes

Funding and the resources of research institutions are generally directed to studies that have a likelihood of yielding financial rewards. Bryophytes are neglected largely because they have little direct commercial significance. However, peat is an exception, and has been exploited commercially for more than 150 years both as a fuel source and as a soil additive. The use of peat for fuel has increased in many countries, and it is now cheaper to exploit homegrown peat than to import other expensive raw fuel material. Ireland is a prime example of this, where peatlands have been exploited on a large scale and peatland habitat has been dramatically reduced in area. Because of the water-retentive properties of *Sphagnum* moss (a principal component of peat, holding up to 20 times its own weight [Welch 1948]), peat is also highly valued as a soil conditioner and a plant-growing medium.

Sphagnum moss has been used as an effective filtering and absorption agent for the treatment of waste water and effluents from factories with acid and toxic discharges containing heavy metals, organic substances such as oils, detergents, and dyes (Poots *et al.* 1976), and micro-organisms (Rozmey and Kwiatkowski 1976). Peat can also be used as an absorbing agent for oil spills (D'Hennezel

and Coupal 1972), and as a filtering agent for oily waste water in vegetable oil factories (Ruel *et al.* 1977).

Because *Sphagnum* is soft in texture it is useful as a packing material when shipping products such as fresh vegetables and flowers. Other, more minor but relatively well-documented, uses of bryophytes include the use of *Sphagnum* in babies' nappies (because of its absorptive properties), hair-moss (*Polytrichum*) in home-made besoms, moss as a stuffing in pillows, and moss as decoration, particularly in the ceremonial costumes of indigenous peoples. Mosses are also often used as a top-dressing for flowerpots to prevent desiccation of the underlying soil. In the Philippines, eggs in crocodile farms are placed in an incubator covered with *Sphagnum* moss as it is believed that peat moss is an effective material in ensuring that the eggs remain at the required temperature.

Potentially more important is the use of bryophytes in medicine. North American Indians have used various bryophytes as herbal medicines (Flowers 1957), and the Chinese still use some species for the treatment of cardiovascular diseases, boils, eczema, cuts, bites, wounds, and burns (Wu 1977, Ding 1982, Ando 1983).

Chemical analysis has revealed that most bryophytes, including *Sphagnum*, have antibiotic properties (Banerjee 1974). Extracts of many species of mosses and liverworts contain phenolic compounds that inhibit growth of pathogenic fungi and bacteria. Dried *Sphagnum* is, therefore, an excellent surgical dressing because of its absorptive qualities (absorbing more liquid than cotton pads [Richardson 1981]), and its ability to prevent infection. Because of these properties, it was used extensively during World War I.

Adamek (1976) found that peat had a retarding effect on the growth of human cancer tissue cultures. Many other bryophytes, notably the liverworts, contain biologically active substances and research in the United States on the anti-cancer properties of bryophytes has been rewarding. Some of the results of this research can be found in Spjut *et al.* (1986, 1988).

3.3 Bryophytes as indicators

3.3.1 Pollution indicators

As bryophytes lack a protective layer or cuticle, they are extremely sensitive to pollutants in the immediate environment. Bryophytes can be used as indicator species, as the presence of pollution-sensitive species can help indicate low levels of air pollution. Air pollution can also create "moss deserts" and force many sensitive species to retreat. Taoda (1972) first demonstrated the use of bryophytes in assessing the impact of air pollution in Japan, and bryophytes have long been used for air pollution monitoring in both Europe (Greven 1992) and North

America (Rao 1982). They are very widely used to measure heavy metal air pollution, especially in large cities and in areas surrounding power stations and metallurgical works (Maschke 1981, Mäkinen 1987). Heavy metals, such as lead, chromium, copper, cadmium, nickel, and vanadium, accumulate in the cell walls.

Bryophytes are also suitable as bio-indicators of water pollution (Glime and Saxena 1991), and for the monitoring of radioactive caesium (Isomura *et al.* 1993). Other species may indicate specific ecological conditions, such as pH levels in soil and water. Bryophytes are, in general, considered to be just as sensitive to air pollution as lichen (Dässler and Ranft 1969).

3.3.2 Indicators of natural environmental conditions

Bryophytes are also sensitive to natural fluctuations in humidity. Many species are, therefore, restricted to microhabitats with specific microclimates (Jeglum 1971, Pospisil 1975). Unlike flowering plants, bryophytes lack a leaf cuticle and are, therefore, capable of gaining and losing water more quickly. This means that bryophytes dry out very quickly, but they can also absorb minute quantities of available moisture from fog, mist, and dew – sources of water that other plants cannot utilise. However, during dry days there may be little physiological activity, and during droughts all physiological processes are quickly reduced to a minimum. Reproduction is highly dependable on water availability as the spermatozoids (male gametes) must swim from the antheridia to the archegonia in order to fuse with egg cells, initiating the spore-producing capsule generation; drought hampers this process. Plants in a dry state are also more vulnerable to disturbance, and since most bryophytes are not firmly attached to the substrate, a severe drought can eradicate these plants by desiccating their anchoring appendages. Activities that lead to a drier environment can, therefore, be considered potential threats to bryophytes.

Some species are strongly associated with calcareous substrates (e.g., *Tortella tortuosa*), while others will grow only on acid ground (e.g., *Racomitrium lanuginosum*). Certain bryophytes have been found to be closely associated with particular mineral or metal deposits such as copper ore. Bryophytes can, therefore, assist in geobotanical prospecting (Shacklette 1984) and are very useful ecological indicators for botanical survey work, capable of revealing subtle changes in substrate.

Bryophytes may also be used as indicators of ecological continuity. Lists of species thought to be characteristic of ancient, semi-natural temperate forests have been devised for lowland Britain (Hodgetts 1992) and for boreal sites with high nature conservation values in Sweden (Hallingbäck 1991).

3.4 The cultural and aesthetic qualities of bryophytes

Bryophytes have a deep, but generally unappreciated and unrecognised place in the cultural heritage of many peoples. They are an intrinsic part of the diversity and beauty of life. They are worthy of protection at a level equivalent to that afforded to other species, habitats, ancient monuments, and great works of art.

In Japan, growing mosses is a traditional part of horticulture (Ishikawa 1974), and there is a long history of

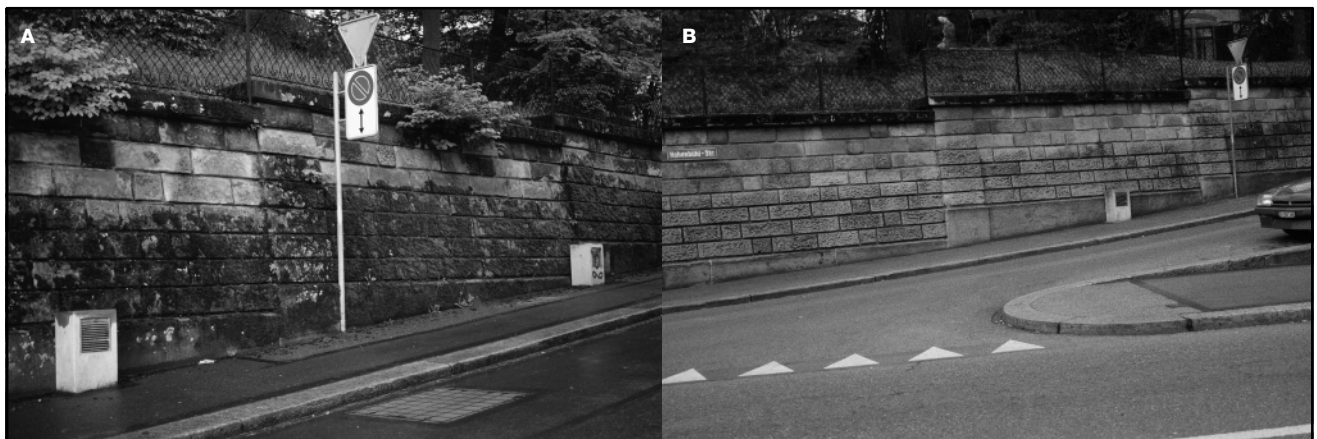
bryophytes being used in gardening (Perin 1962) and as ornamental material for cultivation in landscape trays (Hirota 1981); the miniature landscapes beneath bonsai trees are created with mosses. Mosses are also planted in “moss-gardens”, particularly at Buddhist temples, where they create an atmosphere of beauty, harmony, and serenity, reflecting the spirit of Buddhism (Fig. 3.2). In urban environments, bryophytes are very often a component of the surrounding vegetation, and can be found on buildings, trees, and walls (Fig. 3.3). Bryophytes can even prevent the negative effects of weathering of ancient buildings.

Figure 3.2. A Japanese moss garden (Kyoto, Japan).



T. Hallingbäck

Figure 3.3. A cemented wall before (A) and after (B) the removal of moss vegetation. The differences in weathering are evident.



Edwin Urmi



Figure 3.4. A beautiful liverwort *Scapania lepida* Mitt., known only from Mt. Kinabalu and a mountain on Sri Lanka.

The beauty of bryophytes as shown in Figures 3.4 and 3.5, and their contribution to the landscape, has been an inspiration to many artists and writers. Mossy forests are magical places in which to walk. This is not something that can be quantified, but Keats (1820) has captured their spirit:

...But here there is no light, Save from what heaven
is with the breezes blown.
Through verdurous glooms and winding mossy ways...
(Keats, "Ode to a nightingale")

3.5 Bryophytes in science and education

Bryophytes are important as model organisms in basic research since they are sound subjects for physiological and biochemical experiments. They have the advantage of being relatively simple plants, with a potentially rapid turnover of generations, and a dominant generation that is haploid; they are, therefore, particularly suited for genetic studies. The teaching of botany can be greatly enhanced by using bryophytes; it is relatively easy to examine the leaf cells as they are transparent and usually only one cell thick. They are also good subjects for the study of reproduction as the antheridia and archegonia are often clearly visible and easy to dissect. Because examining their parts is relatively easy, they are ideal organisms for learning how to use a microscope.



Figure 3.5. An example of a beautiful moss genus, *Hypnodendron*. This species is widespread in rainforest of several tropical countries.

Threats to Bryophytes

The most serious threats to bryophytes worldwide are habitat loss (Fig. 4.1) and habitat degradation. Degradation reduces the quality of the habitat and sensitive species are lost (Fig. 4.2). Threats to bryophytes are local, national, and international in scope, and susceptibility varies with species. Some general threats to bryophytes are discussed below, whilst specific threats to different habitat types are discussed in Chapter 5.

4.1 General threats

Modern agriculture threatens bryophyte diversity through a variety of processes, including physical disturbance of the soil by heavy machinery, excessive use of fertiliser resulting in eutrophication of aquatic habitats, and excessive herbicide use.

Because of the lack of epidermis, bryophyte tissue readily absorbs many different substances from the

immediate environment. Bryophyte populations are affected by pollution regardless of whether they are located near to or far from the area of discharge, or in what habitat they are found. As pollution does not recognise boundaries, bryophytes within protected areas are as susceptible as those outside.

Sulphur dioxide is generally the most harmful component of air pollution for terrestrial bryophytes, causing chlorophyll plasmolysis (Coker 1967), whereas sewage and chemical waste have the greatest effect on aquatic species (Empain *et al.* 1980). Damage may affect sexual reproduction before any visible signs of damage to mature specimens are noted (Rao 1982).

As bryophytes are efficient accumulators of nutrients, they also absorb heavy metals which, once incorporated, become strongly bound and retained in the tissue. Heavy metals, specifically mercury, lead, copper, and cadmium, are toxic to nearly all bryophyte species (Niebor and Richardson 1980).

Figure 4.1. The exploitation of a peat bog in southern South America.



Celina Matteri

Figure 4.2. Those species exclusively pendant from tree branches and twigs are extremely sensitive to disturbances in the forest structure, for example: forest fire, tree thinning, and clear-felling.



T. Hallingbäck

Invasive, introduced species of flowering plants and bryophytes can also have a negative impact upon floral vegetation as has been observed in the Seychelles (T. Pócs pers. comm.).

The collection of bryophytes, whether discriminate or not, can pose a threat to the survival of some species. In several countries (e.g., the USA, India, and China), an increase in indiscriminate bryophyte harvesting from natural or semi-natural habitats has been recorded. Large mats of material are collected, irrespective of species, usually for horticultural use. This threat is not generally monitored by government or international authorities and can result in considerable ecological damage.

Collecting of specimens by botanists is highly selective on individual species, often rarities. Although this is seldom a real threat to the survival of rare species, and modern bryologists tend to recognise they have a responsibility to conserve, there have been cases where collecting has led to the extinction of a species. This occurred particularly when botanical collecting took place on a much larger scale and with little or no regard for the consequences; the moss *Bryum lawersianum* was probably collected to extinction in Scotland by 1925.

4.2 Lack of bryophyte conservation awareness

Perhaps the most serious threat to bryophytes, and to the natural world as a whole, is the attitude many governments, businesses, and other groups with influential roles have towards environmental conservation. Often governments place economic development before environmental

concerns, despite the fact that they broadly share a belief in the idea of biodiversity conservation. And although today many development projects incorporate an element of environmental responsibility (for example, through the use of Environmental Impact Assessments), the resources allocated to outright environmental projects compared to those allocated to development projects are minimal.

Over one hundred and seventy countries have ratified the 1992 United Nations Convention on Biological Diversity (CBD) accord and recognise the need for conservation. However, this must be translated into a genuine commitment, such as incorporating environmental programmes as an integral part of development programmes (Fig. 4.3). A lack of bryophyte knowledge amongst the general public, which then leads to a lack of concern for this division of the plant kingdom, is also an area requiring attention. Increasing the level of bryophyte conservation awareness amongst the general public will, and must, involve the use of mass media communications, i.e., the publication of popular and illustrated books on bryophytes, and the production and distribution of attractive documentaries and exhibitions. Nature trails must also be created in areas where bryophytes exist, regardless of whether they occur in protected areas or not.

4.3 Gaps in the current knowledge base

The extent of bryophyte information varies between regions. There is a lack of detailed information on threatened habitats of bryophyte species and the causes of these threats, particularly in tropical regions and, to a

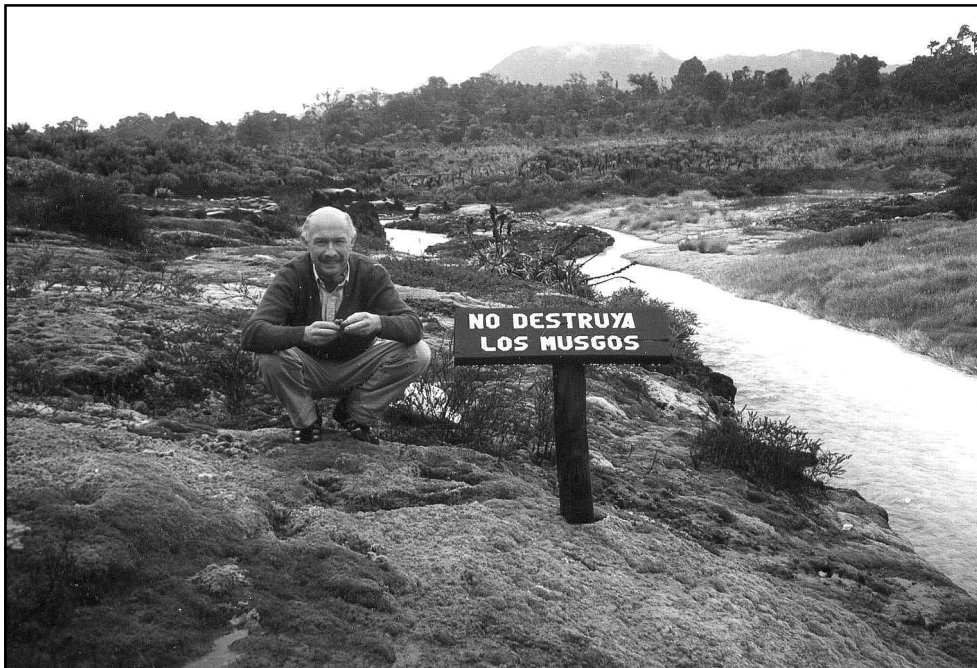


Figure 4.3. It is important to recognise the need for conservation and to translate this need into practical measures. An example of this is a protected hot spring area "Termales de San Juan" in the Andes in Colombia.

Mrs. Gradstein

lesser extent, in the subtropical and southern temperate zones. In contrast, detailed information exists for the northern temperate zones.

The main reason for this regional imbalance of information is due to the shortage of active bryologists resident in tropical, subtropical, and southern temperate zones. Urgent survey work is required in the countries within these regions to obtain data on reproduction, dispersal capacities, and distribution of bryophytes. Attention should be focused on rare species and species whose numbers are declining.

Information on the methods to halt species decline is also lacking. Research is, therefore, necessary to determine the processes that lead to the decline and extinction of species so that the measures to ensure their recovery and survival may be established.

The 2000 IUCN World Red List of Bryophytes presented in this Action Plan (Appendix 2) is a first attempt to highlight a selection of the world's threatened bryophytes. However, critics have claimed that stating that a species does not occur in a particular remote region of the world may not necessarily be true since many areas of the world lack complete inventories. Whilst this comment is acknowledged, it should be recognised that Red Lists are designed to change continually and the lack of knowledge, relative to other species groups, cannot be used as an excuse for inaction.

Despite these gaps, opportunities for bryophyte conservation exist. Actions from which bryophytes can benefit and that can be undertaken immediately are discussed in Chapters 8 and 9.

Key Habitats and their Specific Threats and Recommendations

5.1 Habitat destruction and degradation

The causes of loss and degradation of bryophyte habitat are many and long-standing, and are both natural and man-made. Numerous human activities cause habitat destruction and degradation, including land reclamation, urbanisation, road and dam construction, mining, forestry, wetland drainage, and overgrazing. In many cases, these activities alter air and soil conditions that then affect floral communities. In some regions of the world, especially tropical lowlands with fertile soils, these processes have already had a significant detrimental impact on bryophytic biological diversity.

Habitat fragmentation has also led to the isolation of many bryophyte communities. Where communities are fragmented, dispersal and reproduction are hampered. Some of the most endangered bryophyte habitats are the remaining pieces of natural vegetation in often densely populated areas. However, in less accessible areas, such as Arctic, alpine, and remote montane regions, natural vegetation still covers a relatively large and continuous area.

5.2 Forests

Different bryophyte species can be found on tree bases, trunks, branches, twigs, or leaves, or on fallen logs in various stages of decay in dense, undisturbed forest. Bryophytes occur in such a variety of microhabitats because the differences in the ecological conditions of the substrate (water supply, light, nutrients, etc.) provide an array of ecological niches in which they can exist. Some species occur exclusively in the moist, shaded understorey of the forest, and in the inner tree canopy high above the ground. These species are known collectively as “shade epiphytes”. Other species found in the drier, outer sections of the canopy are known as “sun epiphytes” (Richards 1984). Species referred to as ecological “specialists” also occur and have a narrow vertical distribution (Fig. 4.2). In comparison, “generalists” exhibit wide vertical distributions.

Hyvönen *et al.* (1987) compared the bryophyte flora of undisturbed rainforest in Papua New Guinea with that of moderately disturbed vegetation in the same general area. They found that the bryophyte flora of the disturbed

habitats included many “newcomers”, which were absent from the virgin forest, as well as “stayers”, which occurred in both areas. The newcomers were mainly weedy, ruderal species characteristic of man-made environments. About 30% of the species of the undisturbed forest were lacking in the disturbed areas.

Very different results were obtained in a study at Mt Kilimanjaro, Tanzania (T. Pócs, pers. comm.), where the bryophyte flora of natural forest on the slope of the mountain was compared with that of a nearby plantation of exotic tree species. Only 10% of the forest species reappeared in the plantation and thus, 90% of the rainforest flora had been lost.

Many bryophytes are unable to re-establish themselves in plantations for two reasons. First, an overall depletion of diverse, rich, and available habitats may limit the number of sites available for re-colonisation. Second, a predominance of faster-growing species, common in plantations, may out-compete bryophytes in the acquisition of resources.

In single-species plantations and in forests where clear-felling occurs, the flora is much more impoverished than in areas of shifting cultivation and small-scale forest damage. Evidence also exists demonstrating that shade epiphytes of the forest undergrowth are more seriously affected by disturbance than sun epiphytes (Gradstein 1992a). The shade epiphytes are, predictably, less well adapted to desiccation and are, therefore, the first species to disappear when the forest canopy is disturbed. The sun epiphytes, on the other hand, are adapted to relatively dry habitats and are, equally predictably, more capable of surviving in disturbed areas. Generalist species may also be expected to survive disturbance better.

5.2.1 Threats

- Inappropriate forestry practices (logging, thinning, clear-felling, replanting with non-native species, felling of old trees).*
- Slash and burn cultivation.*
- Agricultural encroachment.
- Under-cropping.
- Invasion of alien species.
- Air pollution.

* most threatening activities

5.2.2 Recommendations

- Forests where globally threatened species still occur must be legally protected.
- Protected areas should include a buffer zone.
- Silviculture or partial timber exploitation or both should be prohibited, or be conducted using an approach that is sensitive to the environment.
- Forestry activities should be minimised in areas of old-growth forest.
- The logging of old trees in woodland should occur at a more sustainable level than at present.
- Felling should be prevented or severely limited in all sites where endangered bryophytes occur.
- Planting and pollarding of trees could be considered to provide suitable host trees for the future.

5.2.3 Montane tropical cloud forest

One of the most bryophyte-rich forest types is montane forest located in the cloud zone. This habitat is extremely humid and is cooler than lowland tropical forest. Epiphytic bryophytes are dominant and reach their maximum species diversity and coverage in this habitat. In dense forest, where the level of humidity is high, species exist, especially small liverworts, which grow exclusively on the surface of evergreen leaves. These species are known as epiphylls (Fig. 5.1). Leaves of trees, shrubs, ferns, and herbs, covered with epiphylls, can be observed where moist conditions prevail throughout the year. Several species of epiphylls are usually found growing together as a micro-community, especially along stream banks in deep gorges. The number of bryophytes that typically grow as epiphylls exceeds 500

species worldwide. Besides humidity and temperature, the age of the trees within the forest and the area of tree coverage also determine the level of epiphyte and epiphyll diversity.

Examples of threatened species:

- Globally Critically Endangered or Endangered epiphyllous liverwort species that occur in montane rainforest include *Cladolejeunea aberrans* (Tanzania), *Drepanolejeunea aculeata* (Brazil), and *Sphaerolejeunea umbilicata* (Colombia).
- Critically Endangered mosses include *Bryomela tutezona* (a moss found only in the crowns of trees in Panama).
- Endangered species include the mosses *Acritodon nephophilus* (Mexico) and *Merrillibryum fabronioides*. This latter species is known only from a small number of bryophyte collections from the Philippine montane cloudforests.
- Common species in this habitat include the moss *Flabellidium spinosum* (Bolivia).

5.2.4 Lowland old-growth tropical rainforest

Bryophytes from old natural forest in tropical lowland regions largely consist of members of pan-tropical families, such as Calymperaceae, Hookeriaceae, and Lejeuneaceae. Species richness typically increases with altitude. The lowland forest has been used for logging, and slash and burn purposes to a much greater extent. The total area of remaining tropical moist lowland forest worldwide is small and fragmented.



Figure 5.1. Epiphyllous liverwort flora on a leaf in montane rainforest in Borneo.

T. Hallingbäck

Examples of threatened species:

- In lowland forest in tropical regions, the most threatened species are shade-demanding epiphytes that are restricted to the understorey and the lower portions of the canopy (Gradstein 1992a), and include many epiphyllous species (Fig. 5.1).
- Critically Endangered species in tropical lowland rainforests include the mosses *Neckeropsis pocsii* (Comoro Islands) and *Taxitheliella richardsii* (Borneo).
- Endangered liverwort species include *Caudalejeunea grolleana* (Madagascar).
- Vulnerable liverworts include *Fulfordianthus evansii* (Central America).

5.2.5 Lowland old-growth boreal forest

In boreal regions of North America, Europe, and Asia, old forests in the lowlands are particularly important for bryophytes. This is especially true if they have a long history of ecological continuity, i.e., they have existed at the site over a long, uninterrupted period. A number of species, particularly those with very inefficient reproductive mechanisms and a low dispersal capacity, are limited to ancient, undisturbed forest (often referred to as old-growth). In these forests, both old trees and dead wood are important substrates. Perhaps dead wood is more crucial for bryophytes in boreal than in tropical zones, as it persists for a longer time. Large logs that persist for a number of years are richer in flora than thin logs. Decaying logs in swamp forest form a substrate that is especially rich in bryophytes specific to that habitat. Some of the wood-inhabiting species are specialists of certain stages of decomposition (Söderström 1988). Some liverwort species, for example, grow only on rotten wood that is in the advanced stages of decay. These bryophytes cover the logs, keeping them moist and restricting the activities of rot fungi. Since many species are restricted to specific microclimatic pockets, any change in the original structure of the forest will decrease species diversity. Deforestation of old forest also leads to the removal of decaying logs and stumps.

Examples of threatened species:

- *Orthodontopsis bardunovii* is an Endangered moss species in *Pinus-Larix* forest in the Siberian taiga.
- *Scapania massalongi* is a threatened liverwort species in Northern Europe.

5.2.6 Lowland secondary forest, including park and pasture woodland

Secondary forest refers to the vegetation type which usually replaces the original forest (unmodified by human activities) following its removal, always resulting in a

decrease in species diversity. In relatively exposed woodlands with many large, solitary trees, and which are typically grazed by cattle, deer, etc., a more light-demanding bryophyte flora occurs. Bryophytes can grow on tree bases, buttresses, trunks, branches, and even twigs. Species growing on branches and twigs are adapted to higher light intensity, and although they suffer from accelerated desiccation, they can absorb water at a faster rate than most other species. Tree bark structure is an important factor for bryophyte colonisation. The best substrate is fissured, spongy bark that retains moisture longer and provides small niches for bryophyte attachment.

Examples of threatened species:

- In semi-open forest with large old trees some globally Endangered or Vulnerable species have been documented, including: *Hypodontopsis apiculata* (Japan; Endangered), *Orthotrichum scanicum* (Europe; Vulnerable), and *O. truncato-dentatum* (S America; considered Endangered).
- The moss *Cyrtohypnum monte*, known only from a park on Madeira Island (1939), is now considered Extinct.
- Some regionally threatened species, such as *Zygodon forsteri* and several *Orthotrichum* species, still occur in Europe on old trees in open agricultural landscapes with low levels of air pollution.
- *Bryoerythrophyllum campylocarpum* only occurs on soil in a recreation park in Portugal. The principal threat to *B. campylocarpum* is the aggressive invasion of the flowering plant *Tradescantia* sp. that covers all forest soil.

5.3 Non-forested habitats

5.3.1 Montane cliffs, rocks, and soil slopes

At high altitudes, bryophytes are an important component of ground vegetation cover. They exist among grasses and dwarf shrubs, cliffs, and rocky outcrops, etc. Niche diversity for bryophytes at high altitudes is high, especially along streams, on steep, sheltered rock outcrops, in between boulders, in late-lying snow beds, and on bare soil. Many species colonise fissures and small irregularities in rock surfaces that are exposed to strong winds and low temperatures. A distinctive and specialised bryophyte community develops under a carpet of snow, emerging when it melts, to be sustained by meltwater. Many bryophyte and lichen species are adapted to such a hostile environment, whilst most flowering plants are not. In particular, a suite of minute liverworts such as *Marsupella* spp. and *Nardia* spp., as well as mosses such as *Andreaea* spp. can be found in this microhabitat. Several of the montane species have a very restricted distribution worldwide, and some are “narrow” endemics.

Examples of threats:

- All off-road vehicular traffic.*
- Trampling.*
- Dislodging by climbers.*
- Air pollution.*

Late-lying snow patches are threatened by:

- Skiing activities.
- Over-use of pisting machines.
- Other “snow management” systems.
- Global warming, which leads to a reduction in the number of snow beds and glaciers, etc.

* most threatening activities

Examples of threatened species:

- The liverworts *Aitchinsoniella himalayensis* (Endangered) and *Sewardiella tuberifera* (Vulnerable) can be found on muddy slopes at high elevations in the western Himalaya.
- The moss *G. teretivervis* (regionally threatened in Europe) can be found on dry, exposed calcareous rocks.
- The liverwort *Marsupella andreaeoides* (regionally threatened in Europe) is found on wet, irrigated siliceous cliffs.
- The moss *Takakia ceratophylla* (Vulnerable globally) is found on shaded, damp cliffs, and wet ground with late snow cover in the Himalaya and Alaska.

Recommendations:

- Special attention must be paid to protecting important bryophyte habitat on montane sites against, for example, inappropriate developments.
- All geographically major areas with late-lying snow patches, or snow beds that are important for bryophytes, should be protected from exploitation.

5.3.2 Tundra

Tundra, in addition to other polar ecosystems, has a diverse bryophyte flora that is often restricted to isolated sites. Water availability is most likely to be the limiting factor in terms of distribution. Particularly rich floras, including numerous endemic taxa, are known from Arctic regions (Schuster and Konstantinova 1996). Regions rich in species include Svalbard (288 moss species, 85 liverworts; Frisvoll *et al.* 1995); Iceland (426 moss species, 146 liverworts; Johannsson 1983); and Arctic Alaska (415 mosses, 135 liverworts; Longton 1988), which have extensive areas of tundra. Of particular phytogeographical interest are the floristic elements centred in glacial refugia, such as in parts of Alaska and northern Ellesmere Island. The Antarctic region is poorer in species, having about 250 moss species and 150 liverwort species (Longton 1988).

Recovery of the bryophyte vegetation from disturbance is very slow due to low growth rates, and low rates of decomposition and nutrient cycling (Longton 1988).

Examples of threats:

- Many tundra communities appear to be more sensitive to fluctuating environmental conditions than bryophyte communities in boreal biomes (Longton 1988). Therefore, Arctic and Antarctic tundra may be regarded as fragile, and vulnerable to damage by airborne pollutants, global warming, and human activity such as soil and coal extraction. The latter threat, which is increasing in this biome, is responsible for habitat destruction (Benson 1986, Longton 1988).

Examples of threatened species:

- The liverwort *Jamesoniella undulifolia*, although not restricted to tundra, is found in the tundra region of Siberia and is considered to be Vulnerable at a global level.
- The liverworts *Lophozia decolorans* and *Mesoptychia sahlbergii*, are both considered to be threatened at a European level.

Recommendations:

- Reported areas must be strictly protected from exploitation.
- Measures should be sought to ameliorate the adverse effects of off-road vehicles, and airborne pollution from industrial development and human settlements close to Arctic or Antarctic tundra.

5.3.3 Ravines

In deep, shaded ravines with high and constant levels of humidity, bryophytes are an important component of rock wall and boulder vegetation.

Examples of threats:

- Many ravines close to human settlements are being filled with domestic or other waste.
- Road and bridge construction.

Examples of threatened species:

- *Distichophyllum carinatum* is an Endangered species that occurs on wet limestone cliffs in wooded ravines in Europe and Japan.
- *Echinodium setigerum* is found only in deep and narrow valleys and is confined to Madeira (Macaronesia).

Recommendations:

- All ravines where endangered bryophyte species occur should receive protection against road and bridge construction and the dumping of waste.

5.3.4 Lowland rock exposures

Low altitude exposures of rock are often of great importance for bryophytes, particularly in heavily modified areas where they may act as refugia for formerly more widespread species. Different rock types harbour different bryophyte floras depending upon the texture and chemical composition of the rock. For example, exposed limestone will normally support a calcicolous bryophyte flora (i.e., flora which grows in calcium-rich environments), whereas the flora of a granite exposure will generally be calcifuge (i.e., flora which does not grow in calcium-rich environments). The bryophyte flora also varies according to the aspect and degree of exposure. Specialised thermophilic communities of *Grimmia* spp. and others may grow on sun-exposed rocks, but different species will grow where the rock is shaded and damp.

Examples of threats:

- Quarrying.
- Clearing of rock outcrops for agriculture.
- Nutrient enrichment through nitrogen deposition.
- Over-grazing.
- Introduced game species.

In Macaronesia and Portugal:

- Changes in land use.
- Pressure from tourism.

In England:

- The encroachment of gorse (*Ulex* spp.), bramble (*Rubus* spp.), and other rank vegetation on the bare substrates required by these species.

In Hungary:

- The increase in mouflons (*Ovis aries musimon*) of Corsican origin caused increased grazing, trampling, and serious destruction of the xeric vegetation (i.e., vegetation that is often adapted to dry conditions) and of threatened species, including bryophytes.

Example of threatened species:

- *Marsupella profunda* (extreme oceanic species of western Europe).

Recommendations:

- Statutory protection and adequate management measures are urgently needed for this habitat, and may include the control of the spread of rank vegetation and the artificial exposure of substrate.

5.3.5 Coastal grassland, rocks, and thin turf

The vegetation of coastal clifftops often consists of a low, species-rich turf of dwarf herbs, bryophytes, and lichens, growing on thin soil over a rocky substrate. This vegetation is often somewhat influenced by sea-spray. Many

bryophytes are capable of growing in this habitat. In fact, for many species it is their main stronghold. In grassland, over-fertilisation is having a negative effect on the bryophyte flora because of increased competition with vascular plants. Small, short-lived species are especially characteristic of this habitat on exposed slopes near the sea. Examples include *Riccia* spp., *Acaulon* spp., *Weissia* spp., and *Didymodon* spp.

Examples of threats:

- Urbanisation.
- Tourist development (caravan parks, golf courses, amusement parks, etc.).
- Agricultural encroachment to the cliff edge.
- Invasion of alien species.
- Dumping of refuse.

Examples of threatened species:

- On coastal rocks in New Zealand, the rare *Archidium elatum* is found in a currently threatened habitat.
- The liverwort *Riccia atlantica* (considered threatened) occurs in a similar habitat in Macaronesia.

Recommendations:

- The areas in which this habitat is found have many endemic vascular plants, and measures for their protection will probably also secure the future of some bryophytes.
- Well-developed habitats should be protected from rubbish dumping and urbanisation.
- Inappropriate modern agricultural practices, such as excessive use of herbicides and fertilisers, should be avoided.

5.3.6 Lowland riverine and aquatic systems, including pools and reservoirs

A relatively large number of ecologically specialised species grow in this habitat, often where they are periodically inundated or covered with silt, and sometimes where they are more or less permanently immersed. Many of these species are rare and threatened, and a relatively high proportion have a very restricted distribution. They may grow on soil, rock, or trees in the flood zones of streams.

Examples of threats:

- Water pollution.
- Eutrophication.
- Tree-felling.
- Inappropriate river management, including any disturbance to water flow and to the water table which is a threat to these habitats, such as dredging and canalisation of watercourses, prolonged artificial maintenance of high water levels (for example, for

fishing), and prolonged drought (leading to colonisation of rank vascular plant vegetation).

Examples of threatened species:

- In European temperate regions, *Dichelyma capillaceum* and *Cinclidotus pachylomoides* are considered to be regionally threatened.
- Globally Critically Endangered species in tropical regions include *Fissidens hydropogon* (Ecuador), *Myriocolea irrorata* (Ecuador), and *Pinnatella limbata* (India).
- In the subtropical part of southwest China, the moss *Sciariomopsis sinensis* only grows submerged in rivers, and is threatened by deforestation (which destroys the upstream catchment area) and water pollution.

Recommendations:

- Conservation bodies should work with river authorities to ensure that no potentially catastrophic changes of the water table or water flow occur.

5.3.7 Upland flushes, springs, mountain streams, and waterfalls

Spring habitat is well defined in terms of physical water properties, though characteristic vegetation which includes bryophytes usually only occurs as small strips along rivulets or is restricted to the spring outlet basin itself. Floral composition depends on how fast the water is flowing, as well as the temperature, pH, and mineral content of the outflowing water. Spring water is always rich in oxygen and the temperature, which varies significantly from that of the surrounding environment, is usually comparatively cold in summer and warm in winter. Rocks that are continuously wet year-round, such as those near waterfalls, are also rich in species requiring high humidity levels.

Examples of threats:

- Reservoir construction.*
- Eutrophication.*
- Water-abstraction.*
- Any other activity that may disrupt the existing hydrology is a potential threat to this habitat.

* most threatening activities

Examples of threatened species:

- The moss *Ochyra tatrensis* grows in rivers and is known only from two sites in the world, both in central Europe (Vána 1986).
- *Scouleria patagonica*, an endemic moss in Patagonia, is known from a few scattered localities in Chile and Argentina (Churchill 1985) and occurs in habitats that are exposed to running water.

- *Donrichardsia macroneuron* (of a monotypic genus) is restricted to calcareous springs in a small area in Texas (Wyatt and Stoneburner 1980).
- Waterfalls on Madeira (Macaronesia) support three very rare and Endangered moss species: *Bryoxiphium madeirensis*, *Nobregaea latinervis*, and *Thamnobryum fernandesii* (ECCB 1995).
- *Thamnobryum angustifolium* is restricted to only one site in England.

Recommendations:

- In existing watercourses where these endangered bryophyte species are still known to occur, the populations should be monitored and the standards of water quality should be maintained or improved.
- Water reservoir management should aim to maintain or emulate the traditional characteristics of the natural watercourse.

5.3.8 Cultivated fields

Many ephemeral bryophytes, notably hornworts, tuberous species of *Bryum*, and small Pottiaceae, specialise in inhabiting the margins of arable and stubble fields. Some species are becoming rare and need to be included in bryophyte conservation efforts.

Examples of threats:

- As most of the species need the winter months to complete their life cycle, autumn ploughing soon after harvesting removes the habitat and is, therefore, a threat.
- Application of some pesticides and fertilisers may be a threat.

Examples of threatened species:

- The hornwort *Anthoceros neesii* (restricted to central Europe) is globally Endangered.
- The hornwort *Notothylas orbicularis* is considered to be regionally threatened in Europe.

Recommendations:

- Farmers should be offered incentives to use more flora-friendly agricultural practices in appropriate fields, and to reduce the application of fertilisers and pesticides in general.

5.3.9 Lowland fens

Fens and other minerotrophic lowland mires are an increasingly scarce habitat in most parts of the world. They are usually located on or adjacent to productive farmland and, therefore, are vulnerable to land reclamation for agricultural purposes. They are capable of supporting

a rich variety of bryophytes, particularly the “brown mosses” (e.g., the genus *Sphagnum*) and associated species.

Examples of threats:

- Land reclamation for agriculture.
- Lowering of the water table due to water abstraction for nearby agriculture and industry.
- Building projects.
- Lack of management (e.g., removal of grazing animals, which then produces a dense growth of vascular plants out-competing bryophytes).

Examples of threatened species:

- At a global level, the liverwort *Jamesoniella undulifolia* is Vulnerable.
- Several species (such as the mosses *Meesia hexasticha* and *M. longiseta*) are Red-Listed at a European level.

Recommendations:

- All remaining sites where endangered fen bryophytes exist should be protected, and prevented from being drained or having the water table lowered.
- Authorities in areas where bryophyte-rich fen is still relatively abundant (e.g., parts of Canada, northern Russia, and Scandinavia) should be encouraged to recognise the importance of their regions for this internationally threatened habitat, and take steps to protect the best sites accordingly.

5.3.10 Lowland bogs

Bogs occur only in conditions of high precipitation and low nutrient availability, and they are commonly dominated by the moss genus *Sphagnum*. The *Sphagnum* bog is an important habitat in North America, western Europe, southern South America, and northern Asia. It often supports extensive, leafy liverwort communities and rare mosses. Particularly important areas include a large area of Tierra del Fuego, where there are several endemic species, and northern Scotland and Ireland.

Examples of threats:

- Commercial peat-cutting.*
- Drainage.*
- Over-grazing, leading to an increase in coarse, grassy vegetation at the expense of dwarf shrub heath, and under-grazing, leading to the invasion of scrub, are also significant threats, particularly where bogs are drying out.
- Burning, leading to the elimination of many sensitive bryophytes and colonisation by a few vigorous species is a serious threat; this is particularly an issue in game

management, where burning to produce an even-aged growth of heather is often practised.

* most threatening activities

In Europe and North and South America, bogs are being commercially excavated for gardening and horticultural purposes. Several large bogs are currently being exploited; for each bog, five tons of peat are being extracted per year. These exploitative activities strongly alter the natural habitats. Alteration may be a result of primary activities (peat extraction) or secondary activities, such as decreasing water tables, and damage caused by workers, vehicles, and destruction of surrounding forests (see Fig. 4.1).

Examples of threatened species:

- *Skottsbergia paradoxa* (Argentina) is Endangered at the global level.
- *Neomeesia paludella* and *Trematodon geniculatus* are threatened at the regional level in South America.

Recommendations:

- The remaining intact areas of this habitat should receive statutory protection from disturbance.
- Drainage or peat-extraction schemes affecting these sites should be stopped.
- The possibility of rehabilitating areas of damaged bog should be investigated.

5.3.11 Heavy metal-rich rocks and mine waste

Certain bryophytes are capable of growing on heavy metal-rich substrates that are too toxic for most plants to tolerate. Some species of *Cephaloziella*, *Ditrichum*, *Grimmia*, and *Scopelophila* are heavy metal specialists. Presumably, these species used to occur predominantly on heavy metal-rich rocks that occur naturally. However, in some areas, this rock has been mined and quarried to the point that the principle remaining habitat is the waste from such operations.

Examples of threats:

- Mining.
- Quarrying.
- Landscaping of disused mines and quarries.
- Over-collecting (in some cases).

Examples of threatened species:

- The moss *Ditrichum cornubicum* is Endangered at a global level and is restricted to a small number of sites in Cornwall, England.
- *Grimmia atrata* and *Cephaloziella nicholsonii* (a British endemic liverwort) are examples of species that are threatened at the regional level.

Recommendations:

- Bryophyte conservation must be considered when restoring or landscaping mined areas.

5.3.12 Páramos

Páramos are cold, humid, high alpine habitats of the Andes of northern South America. Páramos extend from northern Peru to Colombia, Venezuela, and Costa Rica, occurring from the treeline at about 3,000–3,800m above sea level (a.s.l.) to the perennial snowline at about 4,800m a.s.l. The neotropical páramos are famous for their rich flora, including some 800 species of bryophytes (535 mosses, 265 liverworts), of which about 25% are endemic (Gradstein, in Luteyn 1999). This floristic richness is surprising because the area occupied by páramos is relatively small, about 2% of the area in countries where they occur.

Examples of threats:

- Burning.
- Over-grazing.
- Reclamation for agriculture (often potato-planting).
- Water extraction.
- Reforestation.
- Reservoir construction.

Examples of threatened species:

- This type of habitat has a high number of endemics. Whilst it is known that páramos have an extremely species-rich and diverse bryophyte flora, not enough is known of these species to allow them to be considered as threatened.

Recommendations:

- The richest and most intact areas of this habitat type should receive statutory protection from disturbance.

5.3.13 Prairie, steppe, salt steppe, and gypsum-rich soils

Steppe vegetation and the equivalent vegetation types in southern South America (pampas, campo), North America (prairie), eastern Africa (savannahs), southern Africa (veldt), and Australia (outback) consist of dry grassland, and occupy large areas. Although usually not rich in

bryophytes, certain species occur only in this habitat. Wind-blown, loamy locations on steppes, and especially loess cliffs in Asia and eastern Europe, are known habitats for the moss *Hilpertia velenovskyi*, along with many xerophytes, including *Aloina*, *Pterygoneurum*, and *Barbula* species. Some of these species are locally or generally rare (Karcmarz 1960). Salt steppes cover large areas in Arabia, Egypt, Ukraine, Russia, Hungary, and Romania, and *Funaria hungarica* can be found in this habitat in these countries. Salt steppes with a fluctuating water table are rich in species of *Riccia* (Orbán 1976), *Phascum*, and *Pterygoneurum* (Guerra *et al.* 1992), some of which are rare or threatened. Gypsum-rich habitats are similar to salt steppe habitats and harbour interesting xerophytic bryophytes, such as *Acaulon dertosense*, *Phascum longipes*, *Pterygoneurum compactum*, and *Riella* spp. in Spain (Guerra (in letter)).

Examples of threats:

- Conversion of steppe habitat to agricultural land.*
- Over-grazing.*

In central Europe (specifically Hungary):

- Afforestation by alien tree species (for example, *Robinia pseudoacacia* and *Pinus nigra*).
- Over-grazing.
- Burning.
- Cultivation.

In Spain:

- Gypsum outcrops are increasingly subjected to commercial exploitation for the building industry.

* most threatening activities

Examples of threatened species:

- *Aschisma kansanum* (Kansas, USA), *Geothallus tuberosus* (California, USA), and *Ozobryum ogalalense* (Kansas, USA) are threatened species.
- Regionally threatened species in Europe include *Funaria hungarica* and *Hilpertia velenovskyi*.

Recommendations:

- Once cultivated, steppe areas do not regenerate very easily. Therefore, all remaining natural bryophyte-rich steppe, gypsum- or salt-rich habitats, which harbour threatened bryophytes, must be protected from destruction and exploitation (it is important to note that some steppe habitat has received protection in Hungary).

Regional Overviews

6.1 Australasia H. Streimann

6.2 East and Southeast Asia B. Tan

6.3 Sub-Saharan Africa B. O'Shea, T. Pócs, and N. Hodgetts

6.4 Southern South America C. Matteri

6.5 Tropical America (incl. Mexico) S.R. Gradstein and G. Raeymaekers

6.6 Europe (incl. Macaronesia) N. Hodgetts

6.7 North America W. B. Schofield

Context

It is extremely difficult to apply systematic and scientific methods to the identification of critical areas or sites on a world scale using the current level of bryophyte knowledge. Not enough information exists to allow large regional reviews of the world (i.e., for northern, central, and western Asia, northern Africa, and the Pacific Islands). Critical sites must, therefore, be identified using a pragmatic approach, adopting subjective criteria and whatever in-country expertise exists. The following factors may need to be considered during critical site identification:

- Apparent or reported species richness.
- The presence of declining, threatened, or rare taxa.
- The presence of specially adapted bryophyte communities or habitats of restricted distribution (e.g., lowland epiphyllous communities).
- The number of endemic families, genera, and species.

In general, levels of endemism in bryophytes tend to be lower than in vascular plants for two reasons. First, bryophyte dispersal mechanisms are, if conditions are suitable, extremely effective. Second, bryophytes tend to grow in microhabitats and microclimates, which may occur in a wide range of macrohabitats and macroclimates. Therefore, there is greater potential among bryophytes for wide geographical ranges and patchy distributions. Disjunctions are common; *Jamesoniella undulifolia* exhibits a typical distribution pattern for a threatened, but widespread species. It corresponds to one of the 'forms of rarity' listed by Rabinowitz (1981): large range, narrow habitat specificity, and small local populations. This species is recorded from 11 countries in Europe and is listed on the Red List in each (ECCB 1995).

The areas chosen for regional overviews are necessarily large and heterogeneous. It is suggested that regional nature conservation groups use the information here and liaise with the IUCN/SSC Bryophyte Specialist Group for the conservation of bryophytes in each region.

6.1 Australasia

Heinar Streimann, with contributions from Alan Fife and John Steel

Biodiversity, centres of diversity and endemism

Table 6.1.1. Summary of moss taxa in Australasia.

Region	Families (endemic)	Genera (endemic)	Species (endemic)
Australia	62	277	1054(300)
New Zealand	60	208(10)	522(108*)
New Caledonia	40	151(4**)	631(268***)
Continental Antarctica	5	10	15

* of the 108 endemic moss species, approximately 60 are considered rare and include *Crosbya* and *Hypnobartlettia*. Of these 60 rare species, 17 are considered Vulnerable.

** the endemic monotypic moss genera: *Cyrtopodendron*, *Franciella*, *Leratia*, and *Parisia*.

*** including revisions after Pursell and Reese (1982).

Table 6.1.2. Summary of liverwort and hornwort taxa in Australasia.

Region	Families (endemic)	Genera (endemic)	Species (endemic)
Australia	45(1)	127	670
New Zealand	47***(2)	150***(15*)	585***
New Caledonia	29(1**)	96	468(c.210)
Continental Antarctica	1	1	1

* for liverworts.

** the endemic monotypic liverwort family *Personiaceae*.

*** a new checklist has been published by Glenny (1998).

Australia

Due to considerable climatic and latitudinal variation, Australia contains many biologically diverse habitats as

reflected in the diversity of bryophyte taxa. The areas east of the Great Dividing Range generally receive high levels of rainfall and support tropical, sub-tropical, and temperate forests. Scattered drier areas support monsoon forests and monsoon scrub. This scrub (known locally as 'dry rainforest') is present along, or to the west of, sections of the Great Dividing Range. These forest types are particularly prevalent in central Queensland and along Cape York Peninsula. Further inland, the climate becomes drier and the landscape flatter. Overall bryophyte diversity decreases and soil crust bryophytes become common. *Eucalyptus* and *Acacia* scrub becomes prevalent followed by the salt bush dominated vegetation. Whilst the semi-desert areas of central Australia are generally poor in bryophytes, the pottiaceous mosses *Archidium* and *Bryum* tend to be dominant here. The liverworts *Riccia*, *Asterella*, *Plagiochasma*, and *Targionia* are also reasonably common and widespread in these areas.

The several habitat types outlined below contribute to the overall habitat biodiversity within Australia:

- *Eucalyptus* woodland is common in the northern part of Australia. Small pockets of monsoon vegetation exist in moist areas. A particularly interesting region with this latter vegetation is Arnhemland (7) in the Northern Territory which remains virtually unknown in terms of its bryophyte composition. The southwestern part of Western Australia (8) receives high levels of rainfall that supports extensive *Eucalyptus* forests (dominated by *E. diversicolor*); however, the bryoflora

is relatively poor due to the long, hot, and dry summers. Pleurocarpus mosses are extremely rare in *Eucalyptus* woodland.

- Sub-alpine areas extend from southern New South Wales into Victoria and Tasmania (9). These grassy areas are scattered with low spreading shrubs and snow gum (*Eucalyptus pauciflora*). *Lepyrodon lagurus*, not a common moss, is often found in large colonies on basalt.
- In Tasmania, the Central Highlands (10) are cold areas and are generally covered with tussock grassland or stunted woody vegetation. The west coast, an area that receives very high levels of rainfall, has forests dominated by *Nothofagus* and gymnosperms. Dense heath scrub (known as horizontal scrub) grows in the wet South West Wilderness; an area typified by numerous lakes and poorer soils. Tasmanian endemics, including *Sphagnum leucobryoides* (southwest Tasmania), *Dicranoloma eucamptodontoides*, *D. platycaulon* (Central Highlands), *Rhabdodontium buptonii*, and *Tayloria tasmanica* occur here.
- The vegetation of Lord Howe Island (2) can be roughly divided into two types. The lower areas support medium height monsoon-type forest. On the upper slopes of the mountains, the constant availability of moisture has led to the development of a stunted, dense, bryophyte-rich forest. Endemic species include *Macromitrium peraristatum*, *Pterobryella praenitens*, and *Euptychium mucronatum*.

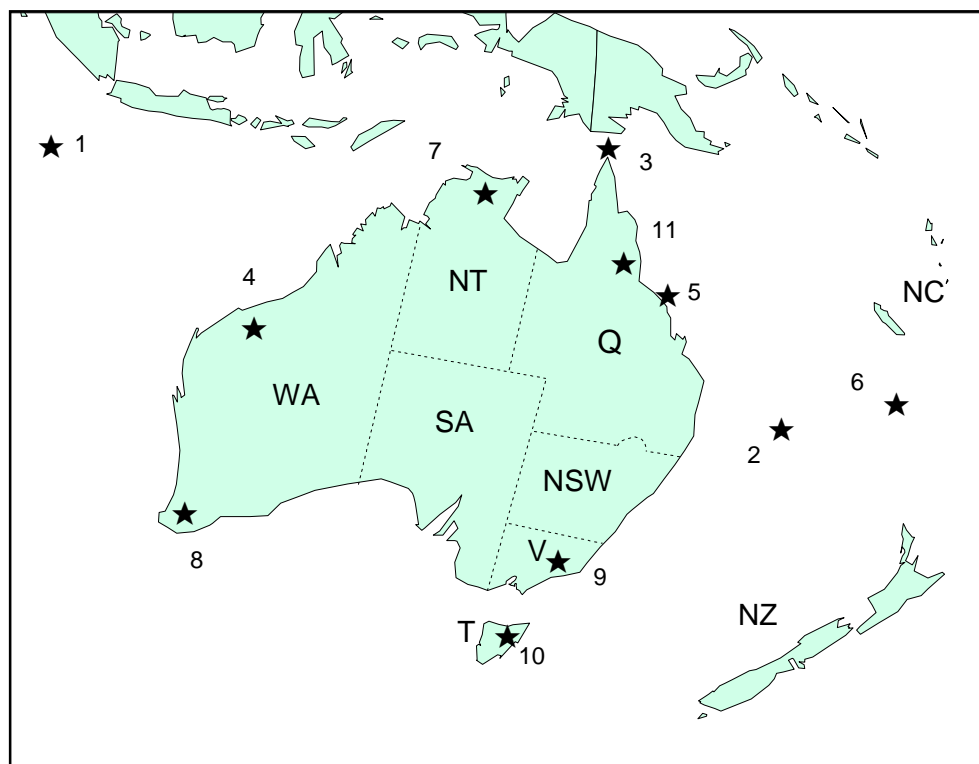


Figure 6.1.1. Hot spots and areas important for bryophytes and bryophyte conservation interest in Australasia.

1. Cocos (Keeling) Islands;
2. Lord Howe Island;
3. Thursday Island; 4. Better-vegetated enclaves in the Pilbara; 5. Brampton Island and other barrier reef islands;
6. Norfolk Island; 7. Arnhemland;
8. SW Western Australia;
9. Subalpine regions;
10. Tasmanian Central Highlands; 11. Higher peaks and ranges of Queensland.
NC New Caledonia, NSW New South Wales, NT Northern Territory, NZ New Zealand, Q Queensland, SA Southern Australia, T Tasmania, V Victoria, WA Western Australia.



Figure 6.1.2. “Mossy forest” in New Zealand.

Jan-Peter Frahm

Hot Spots in Australia

Areas in Australia with a reasonable number of endemics and restricted species are generally found in higher, more moist ranges in north Queensland and southeast Australia. The major area in north Queensland for endemic and restricted species extends from Mt Finnigan and Thornton Peak to the Bellender-Ker Range. This area includes Queensland's highest peak, Mt Bartle Frere. These isolated peaks and ranges receive high levels of rainfall and are covered by cloud for much of the year. These conditions lead to the development of some notably interesting vegetation types. Full studies have yet to be carried out in these areas, especially at Thornton Peak. However, the studies that have been undertaken here have revealed numerous endemics and some Southeast Asian species. Endemics on Mt Finnigan include *Eriopus brassii* and *Dicranoloma spiniforme*. On the Bellender-Ker Range, several rare species have been identified, including the endemic *Clastobryum dimorphum*.

The sub-alpine areas of southeast Australia and Tasmania also harbour numerous endemics and species with unusual or restricted distributions. On the mainland, these endemics include *Bartramia bogongia*, *Brachydontium intermedium*, *Conostomum curvirostre*, and *Pleuridium curvisetum*. Tasmanian endemics include *Dicranoloma perichaetiale* and *Sphagnum leucobryoides*. The sub-alpine areas still require further systematic fieldwork that will no doubt reveal more interesting taxa.

New Zealand

Forests are now quite rare in the settled lowlands and in the foothills of New Zealand, where only vulnerable remnants persist. Most of this area has been converted to agricultural and grazing land, and plantations. On the drier mountains, deforestation has extended to the tree limit. Most of the high altitude forests and those remaining in the drier areas are dominated by beech (*Nothofagus*). Warmer temperate forests, most of which are dominated by conifers, are confined to the North Island. On the South Island, forested areas are now confined to inaccessible parts of the highlands, especially rugged areas, with the most extensive forest being found on the western side of the island.

New Caledonia

Conditions affecting plant evolution in New Caledonia, primarily its long isolation, have resulted in both the conservation of archaic characters and the diversification of species. This region, with its ultrabasic (serpentine) rocks is well known for having high levels of endemism; approximately 80% in vascular plants (Pursell and Reese 1982). However, this high rate of endemism is not the case amongst the bryophytes. Pursell and Reese (1982) list 268 mosses and 210 liverworts (incl. hornworts) as endemic.

This represents 42% and 45% of the bryoflora of New Caledonia, respectively. The ultrabasic soils of this region have a high metal content that is ‘toxic’ to many plants. One moss species *Aerobryopsis longissima* (Lee *et al.* 1977) has been reported with high metal concentrations.

Australian and New Zealand endemics

There are no endemic moss or hornwort families in Australia, New Caledonia, nor in New Zealand. However, there is one endemic liverwort family (Vandiemeniaceae) in Australia, two in New Zealand (Allisoniaceae and Jubulopsidaceae), and another (Perssonelliaceae) in New Caledonia. The Vandiemeniaceae is a monotypic family with the species *Vandiemenia ratkowskiana*. This species was found once on a rotten log on Mt Wellington, near Hobart, in 1980 (Hewson 1982), and has not been found again.

The occurrence of endemic bryophyte species can be classified according to four main vegetation groups:

1. **Arid to semi-arid regions:** Mosses tend to have quite a wide distribution in inland Australia and comprise numerous endemic species in mostly non-endemic

genera, with Pottiaceae predominating, e.g., *Acaulon*, *Archidium*, *Phascum*, *Phascopsis rubicunda*, *Physcomitrium*, *Pottia*, *Tetrapterum*, and *Tortula*. These regions have not been studied to a great extent and further fieldwork may reveal these species to be more common.

2. **Northeast Queensland:** The higher mountain ranges tend to harbour endemics or species with restricted distributions. *Macromitrium dielsii*, *M. funiforme*, and *Clastobryum dimorphum* are restricted to higher areas. Genera with endemics that thrive at moist lower elevations include *Fissidens* and *Glossadelphus*.
3. **Tasmania:** Few endemics are found here, though those that do exist are spectacular and unusual in morphology. These include: *Ambuchanania* (*Sphagnum*) *leucobryoides*; *Rhabdodontium buftonii*; *Tayloria tasmanica* (SW Wilderness); *Macromitrium subulatum* (Bass Strait Islands); *Tayloria gunnii* (temperate forest); *Dicranoloma perichaetiale* (rare sub-alpine); and *Buxbaumia tasmanica*. Several predominantly New Zealand species extend into Tasmania, e.g., *Pleurophascum grandiglobum* and *Pulchrinodus inflatus*.
4. **Lord Howe Island:** The island has a reasonably high level of endemism. Moss endemics include:

Table 6.1.3. New Zealand and some Australian endemic genera and associated habitats. Refer to Fig. 6.1.1. for acronyms.

Region	Sub-region	Endemic Genera	Habitat
Australia	Australian Cap. Territory	<i>Bryostreimannia</i>	swampy, grassy frost hollows
	WA	<i>Calymperastrum</i>	coastal dunes and nearby dry sclerophyll forest
	V, Q, Lord Howe Island	<i>Mesochaete</i>	moister forest regions
	WA, SA, V	<i>Phascopsis</i>	salt marshes and edges of salt lakes
	Q, NSW	<i>Pterobryidium</i>	moist forests
	T	<i>Rhabdodontium</i>	rocks in large streams
	WA, SA, V, NSW	<i>Stonea</i>	semi-arid to arid areas
	Q	<i>Touwia</i>	on partly submerged rocks in rainforest
New Zealand	Q, NSW	<i>Wildia</i>	tropical and sub-tropical forests
		<i>Beeveria</i>	moist shaded rocks
		<i>Bryobeckettia</i>	damp disturbed soil
		<i>Crosbya</i>	deciduous forest
		<i>Cryptopodium</i>	tree-fern forest
		<i>Dichelodontium</i>	deciduous forest
		<i>Fifea</i>	tree fern forest and scrub forest
		<i>Hypnobartlettia</i>	limestone spring
		<i>Mesotus</i>	forest epiphyte
		<i>Tetracoscinodon</i>	wet limestone rocks
		<i>Archeophylla</i>	subalpine scrub and forest
		<i>Chloranthelia</i>	roadside and soil banks
		<i>Echinolejeunea</i>	epiphyll on filmy ferns
		<i>Eoisotachis</i>	aquatic
		<i>Herzogianthus</i>	along rivers
		<i>Kymatolejeunea</i>	subalpine beech forest
		<i>Lamellocolea</i>	forest, near streams, etc.
		<i>Megalembidium</i>	forest on logs
		<i>Neogrollea</i>	open bog
		<i>Stolonivector</i>	dense bush habitat
		<i>Verdoornia</i>	boggy ground among scrub
		<i>Xenothallus</i>	soil along watercourses

Vandiemenia ratkowskiana Hewson
Status: Critically Endangered (CR) (B1, 2c)

Class: Hepaticopsida **Order:** Metzgeriales **Family:** Vandiemeniaceae

Description and Biology: *Vandiemenia ratkowskiana* is a medium-sized thallose, cushion-forming plant that was collected from a log on a track to Wellington Falls in January 1980. The stems are no longer than 1 cm in length and between 0.2 and 1 mm in width without nerves, with irregular bipinnate branching. The small ventral branches may be modified male branches. Female plants and sporophytes are unknown for the family. An initial inspection may lead one to assume this species is of the *Metzgeria* genus.

Distribution and Habitat: This species is known only from the type locality on the main track to Wellington Falls on Mt Wellington situated approximately 6 km WSW of Hobart in Tasmania. The habitat is thought to be wet sclerophyll forest, dominated by *Eucalyptus delegatensis* at possibly just below 1,000 m above sea level.

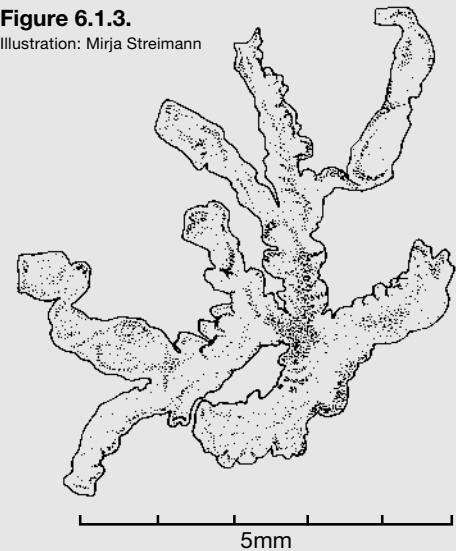
History and Outlook: *Vandiemenia ratkowskiana* was discovered in January 1980. Subsequent searches have not revealed any colonies, including the original. The locality is close to a much-used path in a national park, but the area has been burned since the original collection, and is generally fire-prone. A thorough search of similar habitats in the area should be undertaken to locate further colonies. These colonies should then receive special protection, whilst allowing further study and conservation. The conservation of this species is important as it is thought that this family is a possible link between the present-day families of Aneuraceae and Metzgeriaceae.

References: Hewson 1982

Red Data sheet author: H. Streimann, with contributions from H. Hewson.

Figure 6.1.3.

Illustration: Mirja Streimann



Distichophyllum longicuspis, *Fissidens arcuatulus*, *F. longiligulatus*, *Macromitrium peraristatum*, *Pterobryella praenitens*, and *Taxithelium muscicolum*. This island is also the only Australian locality for *Spiridens viellardii*. There are possibly eight endemic liverworts, mainly of the genus *Frullania*. The island is reasonably well-collected, although the material requires careful analysis.

Current state of knowledge

The depth of cryptogam knowledge and the numbers of practical bryophyte field studies are poor when compared to that of vascular plants. Most of Australasia is poorly known in terms of bryophyte diversity. The level of bryophyte material collected close to Hobart, thought to be one of the best collected areas, is considered minimal when compared to other floral collections. Concentrated collecting by experienced bryologists would uncover many unreported species, especially of the smaller, less attractive genera.

Threats

The majority of the interesting vegetation types in Australia, i.e., those in wet tropical forests and sub-alpine regions where many of the rarer bryophytes occur, are

protected. Protected areas include national parks, National Estates, World Heritage Sites, and Flora Reserves. Effective protection is afforded to bryophytes in these protected areas in Australia and New Zealand. However, major tourist areas could be at risk, e.g., Mt Kosciuszko in Australia, and to date it has been common to investigate the flora inside National Parks rather than in more remote, rugged areas or in state forests.

There is little doubt that there are a number of vulnerable cryptogam communities, and possibly a number of endangered species, in Australia and the Australian Territories, but given the current level of knowledge it is not possible to identify such communities or taxa. However, it is possible to identify some of the unique habitats and micro-environmental niches that are currently very limited in extent and threatened by various factors. Where these habitats are likely to be endangered, so too are their cryptogam floras. Sensitive areas that could possibly come under threat include a number of enclaves of limited area, such as:

- The Cocos (Keeling) Islands. These islands are threatened by human settlements and, as only one small island is currently a protected area (North Keeling in 1995), urgent bryophyte investigations are required.
- Lord Howe Island. Although this island is protected as a World Heritage Site (1982), the island could be threatened by tourism.

- Thursday Island. This island is not a protected area. Human settlements threaten island bryophyte diversity, and bryophyte investigations are urgently required.
 - Better-vegetated enclaves in the Pilbara Karijina National Park (established 1969) i.e., the more rugged areas with gorges that stay moist for longer due to specific habitat characteristics and seepage. Although a large area of the Pilbara is protected, urgent bryophyte investigations are required. Threats outside the national park include mining and tourism. Tourism is not yet a threat within the national park.
 - Brampton Island and other barrier reef islands. Although the majority of this area is protected, tourism is a threat. The Whitsunday Islands are a popular tourist area and the majority of the islands are national parks with controlled tourist resorts. Urgent bryophyte investigations are needed.
 - Norfolk Island. Thirteen percent of the island is a national park and was placed on the register of the national estate in 1980. Threats to this island include increasing population, invasion of weed species (olives, lantana, and guava), and tourism. This island is well protected by the National Parks Service and the cryptogam flora is not under any apparent external threat. One interesting outcome of the investigation has been the identification of a number of unusual components of Norfolk Island, e.g., a new species of the rare moss genus *Cladomnion*, and a new species of *Splachnobryum* from a site on Phillip Island. The liverwort collections of these areas have yet to be studied.
2. **Identify unique and micro-environmental niches** that are very limited in extent and threatened by various factors. Examples include river estuaries, lowland valleys, and pockets of lowland tropical and sub-tropical forests in Australia.
 3. **Investigate areas under threat**, for example: Cocos (Keeling) Islands, Lord Howe Island, Thursday Island, enclaves in the Pilbara, Brampton Island, and other barrier reef islands. Some of these areas have yet to be cryptogamically explored.
 4. **Compile a selective inventory program and undertake extensive field observations** on the habitats, substrate preferences, and local distribution of a number of rare and potentially threatened bryophyte species.
 5. **Assess the vulnerability of rare and potentially threatened bryophyte species**, so that recommendations for future conservation strategies can be made.
 6. **Increase communication channels between bryologist experts and non-experts** to ensure research is carried out with optimum efficiency and accuracy. Since the early 1970s, considerable changes in vegetation and subsequent cryptogam populations have occurred. Often, national parks management is orientated towards visitors rather than the protection of plants. On Norfolk Island, for example, the once spectacular and beautiful moss and lichen communities (commented on by visitors) have been destroyed by road and track construction/clearance. Such activity allows an increase in visitor numbers, but decreases overall bryophyte composition as a result of changes in light intensity. In sub-alpine areas, for example, simple access construction, such as raised boardwalks, increases the abundance of weeds that then compete with bryophytes for resources.
 7. **Recognise the critical need for more experienced bryologists in Australia.** It is worth noting that relevant university courses do not currently include bryology in their syllabi.
 8. **Educate the public on the importance of bryophytes and their roles in the ecosystem.**

The natural vegetation of river estuaries and lowland valleys in Australia are threatened from substantial human settlement and tourism. Pockets, and disturbed remnants of lowland tropical and sub-tropical forests, may be threatened by intense agriculture (including hobby farms), human settlements, and tourism. There are, possibly, many unique microhabitats in Australia's forests that could be under threat and which have little chance of long-term survival. If these habitats are lost, a large proportion of a unique and little-known cryptogam flora could be lost also.

Recommendations

1. **Explore bryologically:**
 - a) monsoon vine thickets that have recently revealed several previously unreported genera and species;
 - b) areas between Rockhampton and Mackay, together with Cape York and the Torres Strait Islands; These areas should receive priority;
 - c) moister and higher elevations of the Kimberly region of Western Australia and Arnhemland in Northern Territory;
 - d) pockets of lowland tropical forests.

6.2 East and Southeast Asia

Benito C. Tan

Biodiversity, centres of diversity, and endemism

East and Southeast Asia (not including the Indian Subcontinent) are extremely rich and diverse in bryophyte taxa, especially mosses. China, Siberia, Indochina, and the archipelagic Southeast Asian countries are very diverse in topography, climate, and vegetation. The result is a vast array of bryological diversity. Because comparatively little glaciation occurred in eastern Asia during the Quaternary

Ice Age (beginning approximately two and a half million years ago), many rare, endemic, and monotypic bryophyte taxa today exist, of which *Takakia*, a genus with two species in a monotypic primitive family, is a good example.

The total number of endemic taxa in Asia is difficult to estimate because information for many areas is incomplete. Few bryophyte collections have been undertaken in countries such as Korea, Myanmar (Burma), Kampuchea (Cambodia), Laos, and Sumatra, and subsequently the bryophyte floras in these countries are the least known in East and Southeast Asia. The floras of China (including Taiwan), Japan, New Guinea, the Philippines, and Borneo are rich in moss. Both the richness and percentage of endemic species in the moss floras of East and Southeast Asia are tabulated below for an approximate comparison.

The fast-diminishing deciduous broadleaf forests in central and eastern China and Japan support a rich moss flora. Many of the Sino-Japanese genera are found in this type of forest. This flora also exhibits an interesting vicarious relationship with the flora in a similar forest type in the eastern United States. The semi-deciduous rainforests in Vietnam and Thailand, which experience pronounced annual fluctuations in humidity and temperature between the dry and wet seasons, support a rich and unique bryoflora adapted to the prevailing monsoon climate. Many of the local endemics are related to the monsoon bryofloras of Australia and the Lesser Sunda Islands.

The lowland and montane rainforests of tropical Southeast Asia provide an ideal home for many endemics

Table 6.2.1. Summary of moss taxa in different subregions of East and Southeast Asia.

Subregions	Land area/km ² (approx.)	Species Number	% of Endemism
China and Hainan	9,556,100	2,000	10
Japan	377,800	1,180	10
Taiwan	36,000	900	–
New Guinea	930,000	890	15
Philippines	300,000	700	5
Borneo	297,000	660	10
Java	132,000	628	–
Thailand	513,120	620	6
Vietnam	331,690	600	6
Korea (N and S)	219,550	540	–
Malay Peninsula	131,600	470	4
Burma (Myanmar)	676,600	320	5
Sumatra	470,000	290	–
Celebes (Sulawesi)	189,000	190	–
Cambodia (Kampuchea)	181,000	152	3
Laos	236,800	145	3

and a handful of bryophytes that are otherwise considered ancestral or primitive. The extensive limestone forests in southwestern China (Guangxi and Yunnan) and northern Vietnam contain many endemics that are strongly calciphilous. The steppe and savannah vegetation in the semi-arid interiors of China and the Outer Mongolian Republic are ecologically isolated and unique. They harbour an array of rare, disjunctive or monotypic, and xeric taxa that are related to the Central Asian and Mediterranean bryofloras.

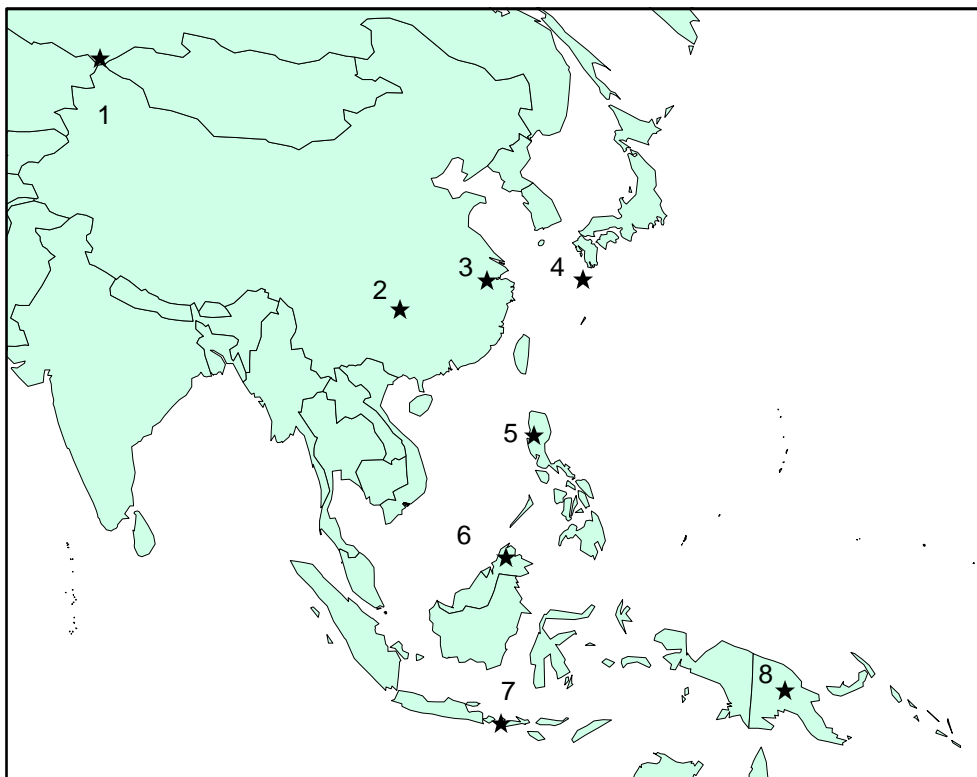


Figure 6.2.1. Important bryophyte "hot spots" in East and Southeast Asia.

1. Mt Altai, Russia and China;
2. Mt Fanjing, China;
3. Mt West Tianmu, China;
4. Yakushima Island, Japan;
5. Mt Amuyaw, Philippines;
6. Mt Kinabalu, Sabah of North Borneo, Malaysia;
7. Mt Rindjani, Lombok Island, Indonesia;
8. Mt Wilhelm, Papua New Guinea.

Centres of diversity and endemism

There are at least 27 moss genera that are restricted to East Asia:

Actinothuidium (Thuidiaceae)
Bissetia (Neckeraceae)
Boulaya (Thuidiaceae)
Bryonoguchia (Thuidiaceae)
Dolichomitra (Meteoriaceae)
Dolichomitriopsis (Meteoriaceae)
Dozya (Leucodontaceae)
Eumyurium (Myuriaceae)
Eurohypnum (Hypnaceae)
Handeliobryum (Neckeraceae)
Hondaella (Hypnaceae)
Horikawaea (Pterobryaceae)
Meteoriella (Meteoriaceae)
Miehea (Hylocomiaceae)
Miyabea (Thuidiaceae)
Neobarbella (Meteoriaceae)
Neodolichomitra (Rhytidiaceae)
Okamuraea (Leskeaceae)
Orthoamblystegium (Leskeaceae)
Palisadula (Pterobryaceae)
Pilotrichopsis (Cryphaeaceae)
Podperaea (Hypnaceae)
Rigodiadelphus (Leskeaceae)
Reimersia (Pottiaceae)

Struckia (Plagiotheciaceae)
Taiwanobryum (Prionodontaceae)
Theriotia (Diphysciaceae)

There are 33 narrowly endemic Asian moss genera that are restricted to one or two countries, or to a few islands within the regions:

Archboldiella (Hookeriaceae)
Brachymeniopsis (Funariaceae)
Brotherobryum (Dicranaceae)
Cladopodanthus (Leucobryaceae)
Cratoneurella (Brachytheciaceae)
Crepidophyllum (Hypnaceae)
Ectropotheciopsis (Hypnaceae)
Giraldiella (Hypnaceae)
Hymenodontopsis (Rhizogoniaceae)
Juratzkaella (Fabroniaceae)
Leiodontium (Hypnaceae)
Leptocladium (Thuidiaceae)
Leskeodontopsis (Hookeriaceae)
Macgregorella (Myriniaceae)
Mamillariella (Fabroniaceae)
Merrilliobryum (Fabroniaceae)
Metadistichophyllum (Hookeriaceae)
Microtheciella (Erpodiaceae)
Nanomitriella (Funariaceae)
Noguchiodendron (Neckeraceae)
Orthodontopsis (Bryaceae)

***Taxitheliella richardsii* Dixon** **Status: Critically Endangered (CR) (B1, 2c)**

Class: Bryopsida **Order:** Hypnobryales **Family:** Fabroniaceae

Description and Biology: *Taxitheliella richardsii* is a monotypic genus with creeping, slender and highly branched stems. Leaves are laxly complanate, broadly ovate, acute, without a costa, and with little cellular differentiation at the leaf basal corners. Leaf margins are weakly toothed and leaf cells are rhomboidal to shortly fusiform in shape, thin-walled and have many papillae per cell. The seta is about four millimetres long. Capsules are erect and funnel-shaped; the outer peristome is striated and furrowed. The inner peristome has only filiform segments.

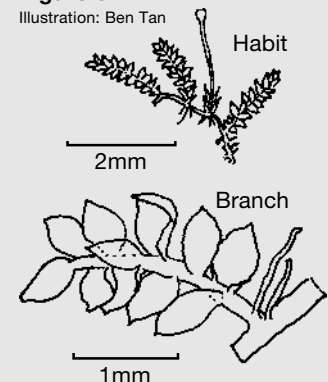
Distribution and Habitat: Endemic to the lowland rainforest of Gunong Dulit in Sarawak, North Borneo. It is known only from the type collection made by Prof. P.W. Richards in 1932. According to Dixon (1935) who described the genus, the plants grow on rotten logs and lianas in forest undergrowth and form vivid green patches. The lowland rainforests of Malaysian Borneo are very rich in plant species and include several rare Malesian mosses, for example *Fissidens beccarii* (Hampe) Broth., and *Chionoloma longifolium* Dix., both of which are known from the single type collection. These forests are also the habitat of *Taxitheliella richardsii*.

History and Outlook: These lowland rainforests in tropical Southeast Asia, including those in Malaysian Borneo, are highly threatened today by excessive logging, and slash-and-burn agriculture practiced by increasing human populations. The reported current economical and social conflicts between the logging company and tribal inhabitants in the Sarawak rainforest highlight the urgency for the conservation of rainforests to prevent the mass extinction of the indigenous flora and fauna, including *Taxitheliella richardsii*.

References: Dixon 1935, Touw 1978.
Red Data sheet author: Benito C. Tan.

Figure 6.2.2.

Illustration: Ben Tan



Orthomitrium (Orthotrichaceae)
Orthothuidium (Thuidiaceae)
Pachyneurospis (Pottiaceae)
Pseudopiloecium (Pterobryaceae)
Pseudopterobryum (Pterobryaceae)
Rhizohypnella (Hypnaceae)
Scabridens (Leucodontaceae)
Sciaromiopsis (Amblystegiaceae)
Sclerohypnum (Hypnaceae)
Sinocalliergon (Amblystegiaceae)
Taxiphylopsis (Hypnaceae)
Taxitheliella (Fabroniaceae)

These genera concentrate around three large areas of high plant diversity in Asia: the eastern Himalaya, extending to southwestern China; Borneo; and New Guinea. The Russian Altai Mountains, central China, central and north Vietnam, and the Philippines are areas of smaller or secondary centres of high species diversity and endemism. Special habitats, such as the limestone karst areas in southwestern China/north Vietnam and the Malay Peninsula, and a few oceanic islands, such as Yakushima Island in Japan, also harbour a large number of local endemics.

In the 2000 IUCN World Red List of Bryophytes (Appendix 2), four mosses (*Merrillibryum fabronioides* [Luzon, Philippines], *Orthodontopsis bardunovii* [Siberia, Russia], *Sciaromiopsis sinensis* [southwest China], and *Taxitheliella richardsii* [Sarawak, North Borneo]) and two liverworts (*Hattoria yakushimensis* [Yakushima, Japan], and *Schistochila undulatifolia* [Papua New Guinea]) are confined to a small range in East and Southeast Asia. Other bryophyte species recognised as rarities worldwide, and that are found in East and Southeast Asia, include *Distichophyllum carinatum* and *Takakia ceratophylla*.

Current state of knowledge

Japan, Taiwan (China), Luzon and Palawan (Philippines), Sabah (Malaysia) and Brunei (North Borneo), and the Huon Peninsula (Papua New Guinea) are today the few places in Asia where the bryoflora is sufficiently known. Only a few Asian countries, such as China, Japan, and the Philippines, have produced a partial Red List of endangered bryophytes. Information on the diversity of bryophytes in several regions, such as North Korea, Myanmar (Burma), Laos, Sumatra, and Irian Jaya in New Guinea, is derived from literature published before World War II. There are currently only three resident bryologists in the entire region of Southeast Asia and Indochina. As many Asian bryophyte families and genera have not been taxonomically revised, their true diversity and species richness are as yet unknown. Unfortunately, the bryofloras of East and Southeast Asia are far from being adequately investigated and described.

Threats

Several major threats to bryophytes of this region can be identified:

- Deforestation. Before a logging ban was imposed by the Philippine government in 1992, the rate of deforestation in the Philippines was more than 500km²/year. In a case study presented by Sastre-DJ and Tan (1995), Mt Santo Tomas in northern Luzon (Philippines) was found to have less than 80 species of mosses. This is a dramatic decrease (more than 50%) from the 175 species of mosses known in 1939 from the same location. The main cause of moss disappearance on Mt Santo Tomas is the conversion of forest to areas for human settlement and farming.

By 1994 in Indonesia, the developing wood and paper pulp processing industries were responsible for the destruction of nearly 7,770km² of virgin forest annually. This occurred mainly in the Indonesian province of Kalimantan (Borneo).

The Philippine and Indonesian cases above are only examples, and many other southeast Asian countries are still suffering from very heavy rates of deforestation.

- Soil erosion and land degradation. The population of China grew rapidly after 1949 and, subsequently, the available arable land has been reduced from 0.18 hectares to 0.08 hectares per capita today. One of the main causes in the reduction of arable land area is soil erosion caused by intensive agricultural practices.
- Pollution from industrial, commercial, and human wastes. High levels of chemical pollution produced by a large iron and steel mill in Huili County of Sichuan Province, China, were reported as having caused the disappearance of the Endangered aquatic moss *Sciaromiopsis sinensis* in the nearby river.
- Inadequate protection of nature reserves and national parks. Fortunately, existing laws governing the preservation of parks and nature reserves currently protect many of the bryophyte hot spots in Southeast Asia. However, the implementation of these laws is often inadequate, and in some cases ineffective due to insufficient financial support or lack of political will on the part of the government concerned.

Recommendations

1. **Protect immediately the eight seriously threatened areas (hot spots) of high moss diversity listed below.** These areas were identified by Tan and Iwatsuki (1996, 1999) following a review of the moss diversity of east and Southeast Asia (refer to Fig. 6.2.1)

- Mt Altai, Russia and China.
 - Mt Fanjing, China.
 - Mt West Tianmu, China.
 - Yakushima Island, Japan.
 - Mt Amuyaw, Philippines.
 - Mt Kinabalu, Sabah of North Borneo, Malaysia.
 - Mt Rindjani, Lombok Island, Indonesia.
 - Mt Wilhem, Papua New Guinea.
2. **Protect the above hot spots and other areas with similar flora and bryophyte-rich habitats** from deforestation, land conversion, farming, and other activities resulting in environmental degradation.
 3. **Ensure that hot spots, which are today fully or partly protected as nature reserves or national parks, are considered to a greater extent in management plans.**
 4. **Identify and conserve additional hot spots in Indochina and the Malay Peninsula** in order to increase the protection of regional bryophyte diversity.
 5. **Support all groups involved in the conservation of a flagship or keystone animal or plant species.** As flagship or keystone species often require large areas of natural habitat, the preservation of the natural habitat, in the form of an established nature reserve or national park, will also ensure the continued survival of the entire biotic community, including bryophytes, present inside the protected area.
 6. **Educate the public on the importance of bryophytes in natural ecosystems.**
 7. **Train future bryologists, specifically tropical bryologists.** Plant and animals are often endangered because of public ignorance of the economic and ecological importance of species, particularly bryophytes. The situation is particularly acute in the tropics, where rainforests are being cleared at an alarming rate for human settlement. It is important to train more specialists so that they are better scientifically equipped to identify and assess local biodiversity, and more importantly, to be able to communicate to government officials, society, and local people the importance of, and the need for, conservation of this particular group of plants.
 8. **Collaborate with grant-attracting projects to gain financial support to study bryophyte diversity.** Bryophytes are a group of inconspicuous and little-known plants; hence, a proposed study of bryophyte diversity will not receive funding very easily. On the other hand, a proposed study of plant phylogeny at the molecular level, or the documentation of germplasms of a country, including bryophytes, will receive both national and international funding. It is, therefore, important for bryologists to become involved in large-scale grant preparations. Bryologists will then be able to obtain funding to study and document bryophyte diversity in particular, and to contribute to the general knowledge of plant science.

6.3 Sub-Saharan Africa

Nick Hodgetts, Brian O'Shea, and Tamás Pócs

Biodiversity, centres of diversity, and endemism

Although considerably less rich in species than either tropical America or Southeast Asia, many parts of sub-Saharan Africa have a rich flora. The base data from which this assumption is derived are the three recent checklists for African bryophytes: O'Shea (1995) for mosses; Grolle (1995) and Wigginton and Grolle (1996) for liverworts and hornworts; and the paper on moss endemism and biodiversity in sub-Saharan Africa by O'Shea (1997).

To measure diversity in Africa, a unit of 10,000km² has been chosen. This is in accord with the unit used by Delgadillo (1994) for measuring the diversity of neotropical mosses. Diversity is not distributed evenly throughout the area, and the 'island effect' is pronounced. Reasonably well-collected countries, such as Tanzania, come out fairly low with only 813 moss taxa (or about 9 taxa per 10,000km²). In comparison, the UK, with 745 moss taxa, comes out higher (42 taxa per 10,000km²), as it is only about a quarter the size of Tanzania.

Bryophyte diversity in Eritrea, Somalia, and Ethiopia is artificially high due to the high numbers of taxa that have been incorrectly identified (often as *Nomina nuda*). Many of these species have been classified as endemic. The more diverse floras in Africa coincide with montane areas and islands. Much of Africa consists of lowland and arid or semi-arid regions, where the bryophyte flora is less

Table 6.3.1. Summary of moss taxa in Sub-Saharan Africa.

Region	Total no. of taxa	Genera	Families
Sub-Saharan Africa	2,849	364	74
Tropical Africa	2,666	334	71
Tropical mainland	1,970	312	65
East African islands	1,101	209	62
Mainland South Africa	538	206	62

Table 6.3.1. Summary of liverwort taxa in Sub-Saharan Africa.

Region	Total no. of taxa	Genera	Families
Sub-Saharan Africa	1,007	134	50
Tropical Africa	898	131	43
Tropical mainland	700	118	43
East African islands	445	104	32
Mainland South Africa	322	94	36

rich. However, as relatively few studies have been undertaken in these areas, ephemeral bryophyte communities are probably more widespread than is generally appreciated.

Using information currently available, 77% of the sub-Saharan African moss flora is endemic to the region. However, the exact figure is certain to be much lower than this as knowledge improves and species are synonymised. Bykov's Index of Endemicity (Bykov 1979, Major 1988) has been used to compare levels of endemism across countries. In general, the number of endemic taxa increases as the size of the area under consideration increases. The level of endemism also depends greatly on habitat diversity expressed by the number of vegetation belts. However, this generalisation is strongly modified by the state of knowledge in different countries.

Endemic Families (mosses):

Rutenbergiaceae
Serpotortellaceae

Endemic Genera (mosses):

Bryotestua (Dicranaceae)
Chamaebryum (Gigaspermaceae) *
Cladophascum (Dicranaceae) *
Cygnicollum (Funariaceae) *
Entodontella (Entodontaceae) *
Hypodontium (Pottiaceae)
Kleioweisiopsis (Pottiaceae) *
Leptoischyrodon (Fabroniaceae) *
Leucoperichaetium (Grimmiaceae) *
Neorutenbergia (Rutenbergiaceae) *
Pocsiella (Dicranaceae) *
Ptychomitriopsis (Ptychomitriaceae) *
Pylaisiobryum (Entodontaceae) *
Quathlamba (Bartramiaceae) *
Rhizofabronia (Fabroniaceae)
Rutenbergia (Rutenbergiaceae)
Schimperella (Brachytheciaceae)
Serpotortella (Serpotortellaceae)
Tisserantiella (Pottiaceae) *
Wardia (Wardiaceae) *
Wikiella (Sematophyllaceae) *
*monotypic genus

Endemic Genera (liverworts and hornworts):

Capillolejeunea (Lejeuneaceae) *
Cephalojonesia (Cephaloziellaceae) *
Cladolejeunea (Lejeuneaceae) *
Evansiolejeunea (Lejeuneaceae) *
*monotypic genus

Evolutionary centres

Much of the African continent is arid or semi-arid and does not contain many bryophyte species. It has received extremely little study, as have the large tracts of forest in Central Africa. Those species that do exist may be interesting drought-avoiding specialists. It seems likely that evolutionary centres, or areas of maximum diversity, are rather limited. It has been postulated that there were two 'refugia' in tropical Africa during the last ice age where milder conditions prevailed: one centred in West Africa, the other in the east. Taxa spread from these areas when climatic conditions became more suitable. Much of the lowland tropical forest of central Africa is thought to be less rich in bryophyte diversity than montane forest, and requires much more survey work.

Most of the centres of diversity for bryophytes in tropical Africa are located on the high, isolated mountain massifs (Fig. 6.3.1), most notably the ancient crystalline mountains of the Eastern Arc located in Tanzania (e.g., Uluguru and Usambara Mountains), and the highlands of Ethiopia through the Ruwenzori to Mt Mulanje in the south. The volcanic peaks of Kilimanjaro, Mt Kenya, Mt Elgon, the Virunga mountains, etc., are also very rich in species. In the west, the Cameroon Highlands and highland areas of Equatorial Guinea, and the islands of Bioko, Principe, Sao Tomé, and Pagalu, are also very diverse in bryophyte species. The southern mountains of the Cape and the Drakensberg Mountains are very rich in bryophyte species, and here Antarctic and sub-Antarctic taxa grow amongst African taxa.

Southern Africa has a different bryophyte flora compared to that of tropical Africa, although there are many species common to both areas. The climate, which is dry for much of the year, produces an 'austro-mediterranean' flora rich in drought-tolerant ephemeral species such as *Riccia* spp., Pottiaceae, etc. Many of these are believed to have very restricted distributions and have been collected only very infrequently. The highlands of southern Africa, i.e., those in Cape Province and the Drakensberg Mountains, have a distinctive flora. It includes several narrow endemics and the unique phenomenon of tropical and sub-tropical African species growing in close proximity to sub-Antarctic species. The southern African bryophyte flora also has strong affinities with the Australian bryophyte flora (e.g., *Bryobartramia*, *Rhacocarpus rehmannianus*). The bryophyte flora of the East African islands (i.e., Madagascar, the Comoros and the Mascarene Islands including the Seychelles, Mauritius, Reunion, and Rodrigues) is very rich and contains many narrow endemics. For their size, the variety of species on these mountain islands is extremely high and provides evidence of the islands' long geographical isolation.

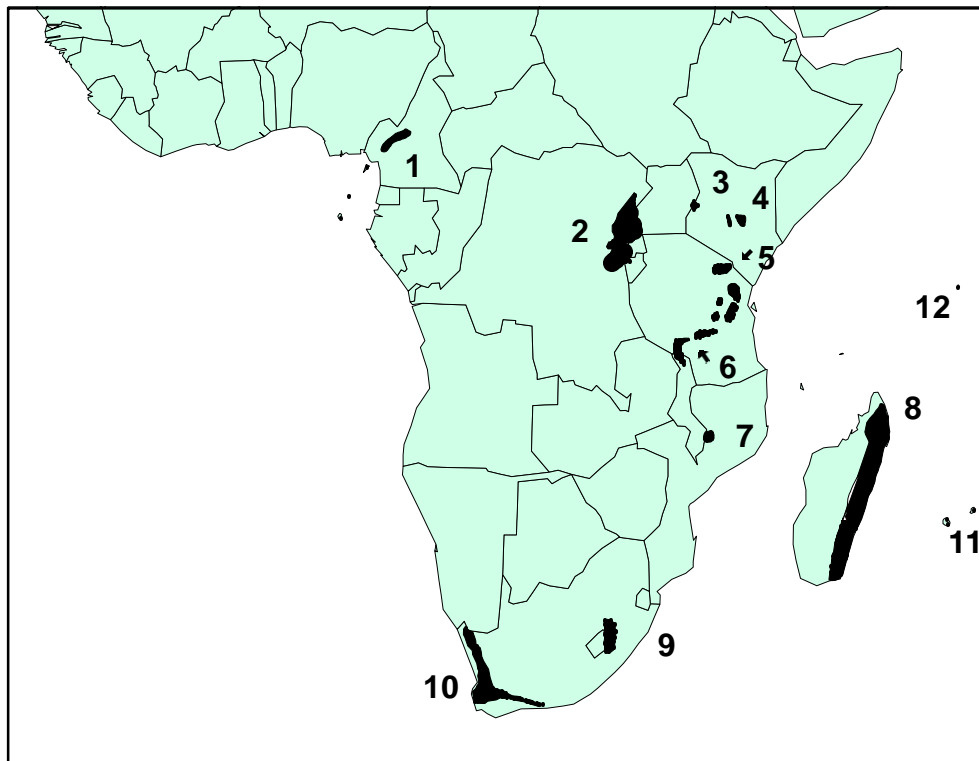


Figure 6.3.1. Important “hot spots” in sub-Saharan Africa.
1. Cameroon Highlands, including Mt Bambouto and Bioko, Principe, Sao Tomé, and Pagalu Islands; **2.** Central African Highlands, including Kahuzi-Biega National Park, Nyungwe Forest Reserve, Ruwenzori, and the Virunga Volcanoes; **3.** Mt Elgon; **4.** Aberdare and Mt Kenya National Parks; **5.** Mt Meru (including Arasha National Park) and Mt Kilimanjaro National Park; **6.** The “Eastern Arc” of Precambrian crystalline blocks from North Pare through Usambaras, Nguru, Uluguru, Usagara, Uzungwe, Ukinga, Lukwangule to Nyika Plateau; **7.** Mulanje Mts; **8.** Eastern Madagascar with the Comoro Islands; **9.** Drakensberg; **10.** Cape; **11.** Mascarene Islands; **12.** Seychelles.

Current state of knowledge

Checklists of the mosses and liverworts of sub-Saharan Africa have been made only very recently (Kis 1985, O’Shea 1995, Grolle 1995, Wigginton and Grolle 1996). However, they are actively being kept up-to-date and will greatly assist efforts to document and locate the indigenous flora. These checklists also provide conservation managers and field workers with a valuable working tool.

While the bryophyte flora has been relatively well studied in some countries, such as Tanzania and South Africa, the bryophyte flora of other countries, such as Burkina Faso, Gambia, Guinea-Bissau, and Niger, is very poorly known. Few checklists exist for individual countries and there are no Red Lists for African bryophytes.

Threats

Uncontrolled forest clearance for agriculture and logging, slash and burn agriculture, war, urbanisation, desertification, climate change, drainage, and tourism are all threats or potential threats to the African bryophyte flora. Some of the most threatened bryophytes are those of primary forests that require shade, such as many of the epiphyllous liverworts. Epiphylls are highly dependent on the microclimate created by the surrounding vegetation, much more so than corticolous or saxicolous species, which may survive in niches after extensive forest destruction has occurred. These species disappear when

primary forest is intensively logged, and do not return. They may, therefore, be regarded as ‘indicator species’ of ancient, relatively undisturbed forest.

The natural bryophyte vegetation of the Seychelles, which includes many endemic or highly restricted species, is under threat from the spread of introduced plants such as cinnamon and the Ugandan tree *Maesopsis eminii* (Pócs 1985). These plants are steadily replacing the species-rich natural habitats with a species-poor variant in which the introduced species are dominant. This results in the almost total disappearance of epiphylls. A similar phenomenon is occurring on Mauritius, where *Psidium cattleianum* and other species are invading upland climax forest, resulting in formerly species-rich areas becoming seriously depauperate (Pócs 1985). On the southern slopes of Kilimanjaro, only 10% of the former forest flora has survived under broadleaved plantation trees (Pócs 1985). On Kilimanjaro, the ericaceous belt is very bryophyte-rich; however, *Erica* is extensively used for fuel.

Recommendations

- 1. Communicate the existing knowledge of African bryophytes to conservation workers.**
- 2. Ensure that this document is used to support the case for conserving specific sites.** There are many very large nature reserves and national parks in Africa, but many of these are semi-arid, maintained for ‘big game’ and are not in the centres of greatest bryological diversity. The areas of

greatest bryological interest tend to be in wet montane forest, rather than in dry savannah. Some areas, however, such as Bwindi/Impenetrable Forest in Uganda, are of interest both for large mammals and bryophytes. Also, other national parks include bryologically rich habitats, such as Korup, Kahuzi-Biega, Bale, Virunga, Elgon, Aberberre, Mt Kenya, and Kilimanjaro.

3. **Ensure that the regional specialists make this document available to conservation workers in the relevant countries.**
4. **Highlight existing areas of highest bryophyte diversity** within the existing network of national parks and other protected areas
5. **Seek to create additional protected areas** in those localities where bryophyte diversity is high, and which are not currently within the existing protected area network. This is particularly important in restricted but poorly protected areas with a high degree of endemism, such as islands (e.g., Réunion Island) or isolated mountain massifs (e.g., Mt Mulanje, Malawi).
6. **Integrate bryophyte education into current education programmes.** Education integration of this type is currently underway in the villages around Bwindi National Park in Uganda and mirrors a similar project

completed recently in South America. The recent Darwin Initiative-funded project in Uganda included a bryophyte training course for Ugandan and Kenyan students.

7. **Ensure that conservation workers consider bryophytes in conservation programmes.**
8. **Emphasise the ecological importance and economic potential of bryophytes.**
9. **Support the production of a generic handbook of African bryophytes.** A project is currently underway, being coordinated by Martin Wigginton and Brian O'Shea (British Bryological Society – Tropical Bryology Group). This two-year programme is due to be completed in 2001. Project findings are to be reproduced and distributed with minimal expense so as to assist future African bryologists with their studies.
10. **Increase levels of local co-operation** as a means to effectively conserve natural resources.
11. **Continue survey work.** Current or recent work includes initiatives in Uganda, Equatorial Guinea, Lesotho and South Africa, Rwanda and Democratic Republic of Congo, and Malawi. However, these are all initiatives from the temperate regions: there are very few bryologists resident and active in Africa.

***Renauldia lycopodioides* Bizot ex Pócs**
Status: Endangered (EN) (B1, 2c,d)

Class: Bryopsida **Order:** Bryales **Family:** Pterobryaceae

Description and Biology: A spectacular moss creeping on tree branches. The stems are tail-like, usually little branched and hanging, arched in shape, and about 10cm long and 4mm thick. The leaves are ovate to panduriform, concave, with a short, often channeled apiculus. The capsules are yellow, almost sessile, and hang on branches.

Distribution and Habitat: This plant is found in moist, mossy elfin forest. It occurs only on trees, as a branch epiphyte. The sites are usually rich in other rare and interesting bryophytes, such as the Madagascan *Plagiochila drepanophylla* Sde-Lac. and the endemic *Neorutenbergia usagarae* (Dix.) Biz. et Pócs.

History and Outlook: This plant is endemic to Africa and was known for a long time only from one tree at its type locality of the Sagara Ridge, West Usambara Mountains, Tanzania. The type locality is along a path at the southern edge of the Forest Reserve of Sokoine University located close to Mazumbai Research Station. Outside this reserve, trees are often collected and used for building poles or other purposes, and the species is seriously threatened. This plant was also found in a similar habitat in the West Usambara Mountains, in Balangai West Forest Reserve, on the eastern ridge of Kilimandegge at 1,700m alt., and on the ridge leading to Kwagoroto Summit at 1,850–1,950m alt. All these localities fall within an area of 10km diameter, where large-scale deforestation is currently taking place. During the past 25 years, 50% of the forest was converted into agricultural land.

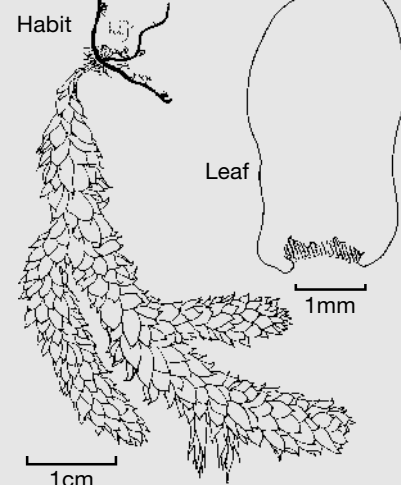
Recently, this species has been observed on two other mountains in the region: (a) the Ukaguru Mountains (Kilosa District) in the Mamiwa-Kisara (North) Forest Reserve where it is found in mossy elfin forest on the eastern part of Mamwira Ridge at 2,200m a.s.l. This habitat is endangered, as the forest reserve (both north and east slopes) is seriously encroached upon, perhaps due to the presence of a nearby working compound (Lovett and Pócs 1992); (b) the Uzungwe Mountains (Kilombero District). Here it is found in Mwanihana Forest Reserve in closed moist forest, at between 750 and 900m a.s.l., where the tree canopy is approximately 30m high. The species was collected by D.W. Thomas, 30 Aug. 1984, and described by B. Allen, 1990; illegal and high-intensity logging was taking place near this locality. This habitat is located in an area that is soon to form part of the Uzungwe National Park, therefore, the future protection of this species can hopefully be expected.

References: Bizot (1974), Kis (1985), Lovett and Pócs (1992), Msangi (1990).

Red Data sheet author: Text: T. Pócs

Figure 6.3.2.

Illustration: Drawn from the type specimen by G. Kis and T. Pócs.



6.4 Southern South America

Celina M. Matteri

Biodiversity, centres of diversity, and endemism

The southern half of South America contains a diverse range of vegetation types due to climatic and latitudinal variation. The most important vegetation types are protected to some extent by, among others, national parks and reserves, provincial reserves, World Heritage Sites, a few private reserves, Ramsar Sites, Biosphere Reserves, and cultural protected areas. Bryophytes and most other cryptogamic vegetation receive the same level of protection as vascular plant and animal species.

The southern part of this vast region is the most well known bryologically, most notably the areas of *Nothofagus* forest in Fuegia and Patagonia. This is a narrow belt of forests situated on both sides of the Andean cordillera. The steppe region to the east of the Andean mountains is a semi-desert, and has been highly eroded by overgrazing during the last 100 years. It is subsequently poor in bryophytes. The western forest region contains around 1,200 bryophyte species (about 60% mosses) and the rate of endemism is high. Several, mainly monotypic, moss genera are endemic to the region, such as *Cladomniopsis* (Ptychomniaceae), *Camptodontium* (Pottiaceae), *Atrichopsis* (Polytrichaceae), *Austrophilibertiella*, *Skottsbergia* (Ditrichaceae), *Schimperobryum* (Hookeriaceae), *Ancistrodes* (Meteoriaceae), *Neomeesia* (Meesiaceae), *Catagoniopsis* (Brachytheciaceae), and *Muscoflorschuetzia* (Buxbaumiaceae). Examples of endemic liverwort genera include *Cephalolobus*, *Stereocolea*, *Evansianthus*, *Grollea*, *Vetaforma*, *Pisanoa*, and *Perdusenia*.

The central and central-northern parts of the region have been subjected to much less bryological study. They contain a less diverse bryological flora due to intensive agriculture and cattle raising. About 40 moss genera, none of which are endemic, have been reported for the central region, mainly Pottiaceae, Bryaceae, Bartramiaceae,

Polytrichaceae, and Fissidentaceae. The central-northern area (the Chaco Dominion) is a semi-arid, subtropical steppe, with xerophilous deciduous forests (*Schinopsis*, *Prosopis*).

In the northwestern part of the region, again typified by rugged, mountainous terrain, the vegetation is strictly subtropical, with some pockets of transition between temperate and subtropical. This vegetation is under no immediate threat. Current bryological studies demonstrate high phytogeographical links between this vegetation and that in Bolivia, other Andean countries, and also southeastern Brazil. Bryological richness is high, mainly in the Yungas Province on the eastern slopes of the mountains, between 500 and 2,500m a.s.l.. Bryological richness is also high particularly between 1,500 and 2,500m a.s.l. in the upper montane forests of *Alnus acuminata*, which include the only conifer in the region, *Podocarpus parlatorei*. Several moss species are, at present, believed to be endemic, and many others from the Neotropics have their southern limit here.

Although Drehwald (1995) documented approximately 127 bryophyte epiphyte species (60% of which were mosses) from selected sites in Misiones Province, little is known of the soil, forest floor, or stream bed bryophyte flora in this

Figure 6.4.1. Regions in southern South America especially important for bryophyte conservation.

1. Northwestern Argentina, and adjacent Chilean and Bolivian lands; 2. Northern Argentina with south Paraguay and south Brazil; 3. Central Argentina; 4. Delta region in Argentina and Uruguay; 5. Central Andine region (37–39°S); 6. Sierra de la Ventana complex; 7. South Andine region; 8. Fuegian domain.

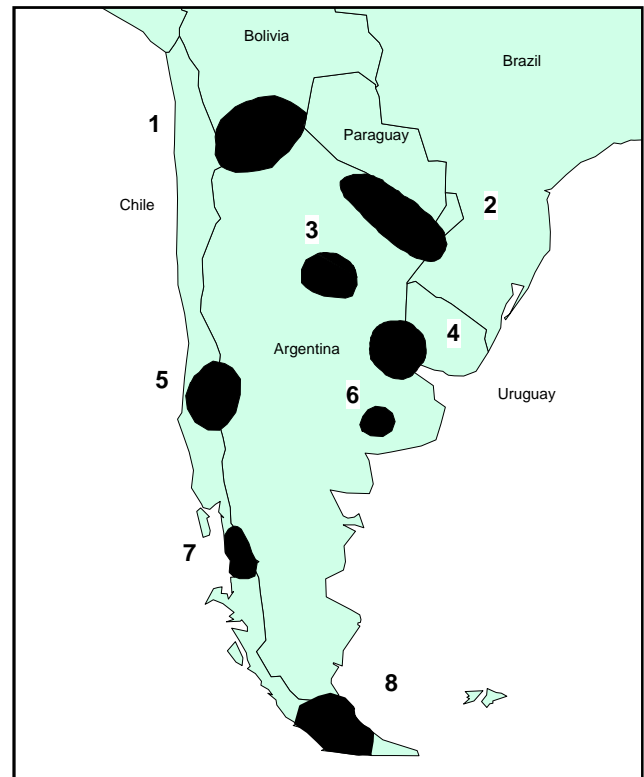


Table 6.4.1. Estimated* number of species, genera, and percentage of endemism in southern South America.

Group	Taxa (sp., subsp., var.)	Genera	% of Endemism
Mosses	1,965	284	15
Liverworts (Chile and Argentina)	652	158	60
Hornworts (Chile and Argentina)	17	5	unknown

Source: Matteri (pers.comm. 1998) for mosses and Hässel (1998) for liverworts and hornworts. * These figures will change with taxonomic revisions.

province. In the Argentinian corner of the region, tree ferns provide important habitats for many bryophyte species.

In the eastern-central part of the region, little is known of the littoral Argentinian-Uruguayan bryophyte flora. This is a generally flat, but extremely wet area with high oceanic influences, and it is a large delta region for the Paraná, Uruguay, and Río de la Plata rivers. Many northern bryophyte communities (mainly epiphytes) reach their southern limit at the mouths of these rivers. Approximately 100 moss species that have been reported from this region have phytogeographical links to SE and SW Brazil and to the solitary mountains in the southwest Buenos Aires province.

Current state of knowledge

The 1986 checklist of mosses for the region, comprising Argentina, Chile, and Uruguay, by D.M. Greene provides sound regional knowledge. However, an updated list is needed and a new checklist for this region is currently being prepared by C.M. Matteri. This will accompany a new list prepared by Hässel in 1998. Patagonian and Fuegian regions from Argentina and Chile have been the subject of more intensive investigation, and recent literature is comparatively large. Some of the more recent treatments summarising historical studies and checklists for the region are those for mosses by Matteri (1985) and those for liverworts by Hässel and Solari (1985). Malvinas moss flora has been revised by Matteri (1986), and the liverworts by Engel (1972). Kühnemann's works on Argentinian bryophyte flora (1938, 1949) are very much out of date, but his moss and liverwort checklists remain the only ones that cover the entire country. Mosses were partially listed for northwestern Argentina by Grassi (1976). In Chile, the bryophyte flora is relatively well documented by the regional checklists mentioned above (Greene 1986, Hässel 1998, Hässel and Solari 1985, Matteri 1985a). Mahu (1979) lists families and genera of mosses known from Chile, and Robinson (1975) summarised the moss flora of the Juan Fernandez Islands. Uruguay is also covered by the regional studies mentioned above, although there are few studies specifically for Uruguay. Two papers by Herter (1933a and b) focus on mosses in this region and provide useful lists. A list of liverworts by Hässel (1964) provides information on only 30 species known from Uruguay.

The general state of bryophyte knowledge in Latin America is comparatively poor and has been summarised by Matteri (1985). However, current literature on the conservation status of bryophytes and fungi is improving and has been presented in a paper by Gamundi and Matteri (1998) in the Proceedings of the VI Congreso Latinoamericano de Botánica, in Mar del Plata, Argentina. Due to incomplete knowledge of the bryophytes in this region, it is difficult to estimate the number of species that

might be threatened in unique microhabitats. However, where the ecosystems or habitats are threatened or seriously disturbed, bryophytes and many other cryptogams become vulnerable.

It is important to stress one key point related to the conservation of bryophytes "*in situ*" and local herbaria. This issue has been expressed at length elsewhere (Matteri 1985b) and is now acknowledged by at least some governments. In 1994, Argentina ratified the United Nations Convention on Biological Diversity (CBD) and, in so doing, assumed the premise that "states have sovereign rights on all their own biological resources". The first steps towards the design of the Argentinian National Strategy Plan were taken by the end of 1997 and early 1998, with the active participation of lower land plant specialists. During those meetings, the problem of the historical, as well as the current, one-way traffic of Argentinian plant specimens to overseas herbaria was raised. Accordingly, regional and provincial wildlife services were informed of official proceedings and are now implementing local regulations (in addition to the federal regulations already in force for all national parks and reserves) towards the conservation of resources i.e., against indiscriminate collecting and export of native plant material (including bryophytes).

To local cryptogamists, the biggest problem of this one-way traffic of plant specimens is that, recently, with very few exceptions, no material or type specimens were deposited in local herbaria. It is likely that the number of local bryophyte collections deposited in foreign herbaria well outnumber those deposited in local, national or regional herbaria.

Cryptogamic taxonomy, including bryology, has substantially advanced in more recent times. Most older local collections are available by regular loans and most importantly, several hundred specimens of recent local bryophyte material have become available to overseas colleagues through the distribution of herbarium specimens. Even fresh material is often provided when available. Moreover, several multinational botanical projects have recently produced very rich and full sets of bryophyte specimens deposited in central herbaria of the world. These current advancements have been achieved by the interactive work of local and overseas bryologists as a result of independent or joint projects. All those involved believe in the concepts of wilderness, and species and habitat protection worldwide because "conservation of biological diversity is a common interest of mankind".

Threats

Bryophytes are protected in national parks and reserves, and in a large number of private and provincial reserves. Adopting an ecosystem conservation approach, the most

threatened habitats are those in lowland valleys, lower montane forests, and bogs that are accessible for human use. Activities that result in the complete destruction of habitats pose serious threats to bryophytes. It may be that the most important cause of these activities is ignorance of what is being lost.

The lowland habitats (peat bogs and lower montane forests) are most vulnerable to alteration and exploitation by human activities e.g., urbanisation and burning for agriculture.

The already poor bryoflora in the relictual forests of the central and central-northern parts of the region is diminishing as a consequence of intensive agriculture and cattle raising.

The northeastern part of the region, though not critically threatened, may be termed as generally vulnerable and at risk because of increasing exploitation. Most of its bryophyte flora ranges into the Neotropical region. Unfortunately, no evidence exists as to whether or not the rich bryoflora in this area returns after deforestation.

Recommendations

1. **Train and encourage professional bryologists to investigate, survey, and describe the regional bryophyte flora.**

2. **Undertake surveys and explorations in the many currently undocumented areas.**
3. **Focus attention on habitat preferences and local distribution trends of plants.**
4. **Produce checklists of bryophytes** that would serve to increase the current knowledge base of bryophyte richness. A current checklist project is well underway for mosses.
5. **Inform those people who are involved in the implementation of protected areas** of the current situation of bryophyte conservation.
6. **Impress upon political figures that the current levels of protection afforded to bryophytes are inadequate** and require re-evaluation.
7. **Push for the establishment of new protected areas.** For example, Fuegian *Nothofagus pumilio* forests and *Sphagnum* bogs require urgent protection. This may be achieved by creating protected areas or enlarging those that currently exist.

In the central and central-northern regions, steps are being taken to protect forest stands of *Schinopsis balansae* (quebracho colorado) and *Prosopis* spp. (algarrobo). It is worth noting that this region contains only provincial reserves and no national parks.

Several long-standing proposals for national parks have not yet been implemented in the region. These proposals include the Aconquija-Cumbres Calchaquies (northwest Tucuman) and the area of Laguna del

***Skottsbergia paradoxa* M.A. Cardenas** **Status: Endangered (EN) (B1, 2c,d)**

Class: Bryopsida **Order:** Dicranales **Family:** Ditrichaceae

Description and Biology: This is a monotypic genus that grows in compact, small, short turfs. It is light green, with a conspicuous red setae. Fuegian plants grow up to 10cm in height and the leaves are approximately 2.5 to 3.5mm in length; the setae grow up to 3cm in length. South Georgian material is smaller in all aspects. They are usually fertile with abundant fruit. Asexual reproduction is unknown. The species is monoicous. The peristome structure is unusual and its evolutionary role should be investigated. It is asymmetrical and has nine short teeth and seven long teeth that seem smooth or finely granulose. It is conspicuously cross-barred and the spores, which are approximately 45–50µm in diameter, are granulate-verrucate (Matteri 1987).

Distribution and Habitat: The plant is endemic to the South Georgian-Fuegian region. It is distributed in Fuegian bogs amongst deciduous *Nothofagus* forests, and is unknown from evergreen forest bogs. The pH of Fuegian peat bogs ranges between 5.5 and 6.5, whilst the annual rainfall levels in deciduous forests range between 500–800mm (Matteri 1988). The species is hygrophytic, and can also be found on the wet soil of open peat bogs and marshes scattered amongst other mosses between 100 and 650m a.s.l.

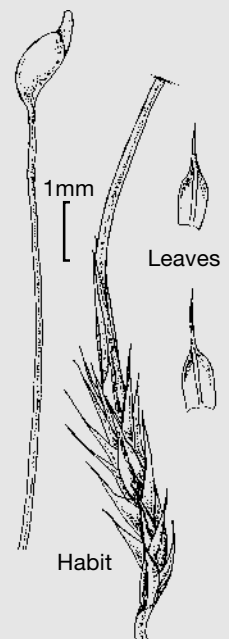
History and Outlook: Since 1950, it appears to have been collected only three times on the Fuegian Isla Grande. In view of its present distribution, the species may have had a larger distribution in Gondwanic times. The present sites are not protected on the Fuegian Island, as all sites are outside the national and provincial parks of Tierra del Fuego. The species is threatened by destruction of natural habitats. The Tierra Mayor peat bog (54°43'S 68°02'W.) and the area around the summit of Glaciar Le Martial (north of Ushuaia, 54°46'S 68° 29'W.) should receive protection.

References: Cardot (1908), Roivainen and Bartram (1937), Matteri (1987, 1988).

Red Data sheet author: C. M. Matteri

Figure 6.4.2.

Illustration: Celina Matteri.



Tesoro (southwest Tucuman), two sites that are critical if the upper montane forests are to be protected.

Areas in which tree ferns exist, especially those in the Paranense province, require urgent legal protection.

8. **Create awareness of bryophytes and their importance** as an important step in ensuring the conservation of the region. A perspective of local status and actions was recently presented by Matteri (1998), with general information on bryophytes, their role in nature and uses, and practical recommendations on how they should be protected.

6.5 Tropical America (incl. Mexico)

S. Rob Gradstein and Geert Raeymaekers, with contribution from Steven P. Churchill

Biodiversity, centres of diversity, and endemism

Tropical America (Neotropical region) is located between the tropic of Cancer and the tropic of Capricorn, stretching from Central Mexico and Cuba southwards to Bolivia and southeastern Brazil. The landscape of this region is extremely diverse and includes the hot, tropical lowland rainforests of the Amazon basin, the extensive cordilleran system of the Andes, where ice-capped peaks rise to over 6,000m, the savannahs and scrubby vegetation (“cerrado”) of the Brazilian Planalto, and the lush tropical islands of the Caribbean.

Due to the great variation in landscape and climate, tropical America has a very rich and highly diverse flora, and harbours approximately 4,000 species of bryophytes (Table 6.5.1) or almost one third of the world’s total bryophyte diversity. The Neotropics are also thought to contain the world’s principal centres of endemism, harbouring 78 endemic moss genera (Gradstein *et al.* 1999c) and over 50 endemic genera of liverworts (Schuster 1990). In comparison, only five liverwort genera are endemic to Europe and North America combined. Migration of species from North and South America in historical times, along the “cordilleran track” (Schuster 1983), has undoubtedly contributed greatly to the high diversity of the region. Two particularly important habitats in tropical America – rainforest and páramos – deserve attention.

Table 6.5.1. Neotropical bryophyte diversity.

Taxa	Families	Genera	Species
Mosses (1)	76	392	c.2,600
Liverworts (1)	41	190	c.1,350
Hornworts (2)	3	7	c.30
Total	120	589	c.3,980
Sources: Salazar Allen <i>et al.</i> 1996 (1), Gradstein 1999c (2).			

Rainforest

Lowland and montane rainforests are the principal habitat of bryophytes in the Neotropics. Some 50% of the neotropical mosses and more than 70% of the liverworts occur in these forests. Most of these species are epiphytes; few are terrestrial or grow on rocks. A small number of taxa, including some very interesting rare and threatened ones, occur as rheophytes in rivers in the rainforest areas.

Bryophytes restricted to virgin rainforest include some very rare endemics known only from very few collections, e.g., the liverwort genera *Haesselia*, *Dactylolejeunea*, *Phycolepidozia*, *Sphaerolejeunea* and *Vanaea*. In addition to more common moss genera, *Acritodon*, *Allioniellopsis*, *Ceuthotheca*, *Cygniella*, *Diploneuron*, *Fabronidium*, *Flabellidium*, *Florschuetziella*, *Holomitriopsis*, *Schroeterella*, *Sorapilla*, and *Steyermarkiella* are further examples of rare endemics restricted to virgin rainforest. The common taxa are the most useful to serve as indicators of undisturbed rainforest, and these are listed below. It appears that indicators of lowland forest are more numerous than those for montane forest, for reasons that are not entirely clear. The discrepancy is possibly explained by the much smaller area occupied by Neotropical, undisturbed montane forest; more than 90% of the Neotropical montane forest has now been destroyed, compared with about 10% of the area occupied by lowland rainforest.

Indicators of undisturbed lowland rainforest (below 500m a.s.l.):

Liverworts

Arachniopsis spp. (widespread)
Echinocolea asperrima (widespread, but nowhere common)
Fulfordianthus evansii (endemic to Central America)
Haplolejeunea cucullata (Guianas and southeastern Brazil)
Otigoniolejeunea spp. (Amazonia and Guianas)
Luteolejeunea herzogii (endemic to Chocó)
Leptolejeunea spp. (except the widespread *L. exocellata* and *L. elliptica*),
Marsupidium gradsteinii (endemic to Amazonia)
Potamolejeunea spp. (endemic to Amazonia)
Prionolejeunea spp. (widespread)
Rhaphidolejeunea polyrhiza (Amazonia and Guianas)
Schusterolejeunea inundata (Amazonia and Guianas)
Stictolejeunea balfourii (widespread)
Trachylejeunea spp. (mostly Amazonia and Guianas)
Zoopsidella spp. (widespread)

Mosses

Calymperes spp. (widespread)
Cyrtohypnum spp. (widespread)
Hydropogon fontinaloides (Amazon basin)
Hydropogonella gymnostoma (Amazon basin and Panama)
Lepidopilum polytrichoides and *L. surinamense* (uncommon)
Leucomium strumosum (widespread)

Macromitrium spp. (widespread)
Mniomalia viridis (uncommon)
Neckeropsis spp. (widespread)
Phyllophyllum tenuifolium (confined to 'tank' bromeliads)
Syrrhopodon spp. (widespread)
Taxithelium spp. (widespread)

Indicators of undisturbed submontane (= premontane) rainforest: (500–1,500m a.s.l.)

Liverworts

Calypogeia subgen. *Caracoma* spp. (northern S. America)
Coleura clavigera (Caribbean, Guianas)
Fuscocephaloziopsis spp. (mostly Chocó and Lesser Antilles)
Haesselia roraimensis (endemic to Guayana Highland)
Nowellia spp. (C. America and Caribbean)
Pallavicinia lyellii (Caribbean, C. America, and Chocó)
Physantholejeunea portoricensis (endemic to Caribbean)

Mosses

Amblytropis spp. (Central America and northern S. America)
Brymela spp. (not common, except *B. parkeriana* in the Guianas and northern Amazon)
Groutiella spp.
Isodrepanium lentulum (locally widespread)
Mesonodon spp. (northern S. America and southeast Brazil)
Pterobryaceae spp. (widespread)
Schliephackea prostata (Chocó)
Stenodictyon spp. (Central America and northern Andes)
Thamniopsis spp. (widespread)

Indicators of undisturbed montane rainforest (1,500–3,000m a.s.l.):

Liverworts

Athalamia spp. (central Andes)
Blepharolejeunea saccata (widespread, but nowhere common)
Echinocolea dilatata (Caribbean and C. America)
Jubula bogotensis (widespread, but nowhere common)
Trabacellula tumidula (endemic to Guayana Highland)

Mosses

Acidodontium spp. (primarily Andean)
Adelothecium bogotense (rather widespread)
Holomitrium spp. (rather frequent in canopy)
Macromitrium spp. (widespread)
Meteoridium remotifolium and *M. tenuissimum* (widespread)
Meteorium spp. (widespread)
Mittenothamnium spp. (widespread)
Neckera spp. (widespread)
Papillaria spp. (widespread)
Pilotrichella flexilis (widespread)
Porotrichum spp. (widespread)
Pyrrhobryum mnioides (widespread)

Páramos

Páramos are the cold and humid, high alpine regions of the Andes of northern South America. They extend from northern Peru to Venezuela and Colombia, and further northwards to Costa Rica. They occur from the treeline, between approximately 3,000 and 3,800m a.s.l. (depending on local climatic, edaphic, and human factors), to the perennial snowline at about 4,800m a.s.l. The Neotropical páramos are famous for their rich flora; between 3,000 and 4,000 species of vascular plants have been recorded, with an estimated 60% endemism; approximately 825 species of bryophytes exist (535 mosses, 290 liverworts), of which about 25% are endemic (Gradstein 1999).

This floristic richness is surprising because the area occupied by páramos is relatively small, c. 2% of the countries where they occur. Moreover, páramos are geologically very young, not having developed until the late Pliocene (c. 2–4 million years before present [B.P]), after the upheaval of the Andes. The rich flora is supposedly due to: (1) the great habitat variety in the páramos, ranging from very wet to rather dry; (2) the essentially discontinuous, island-type, present-day distribution of páramos; (3) the position of the páramos along the north-south running "cordilleran track", connecting the rich floras of North and South America and bordering the rich lower slopes of the equatorial Andes, thus allowing for immigration into the páramos of a great variety of taxa; most bryophytes of the páramos are examples of cold-temperate groups that have invaded the tropical alpine regions from higher latitudes; and (4) the long-term traditional human influence upon the ecosystem.

The cordilleran system of the American continent is unique. The absence of such a continuous pathway for migration in other parts of the tropics may be an important reason why the Neotropical páramo flora is richer in genera and species than that of other tropical high mountain regions.

Bryophytes characteristic of páramos include mostly terrestrial taxa, e.g., the liverwort families Acrobolbaceae (*Lethocolea*), Aneuraceae (*Riccardia*), Arnelliaceae (*Gongylanthus*), various Balantiopsaceae, Gymnomitriaceae, Jungermanniaceae, Lepidoziaceae, and Pallaviciniaceae (*Jensenia*), and the moss families Amblystegiaceae, Andreaeaceae (*Andreaea*), Batramiaceae (*Bartramia*, *Breutelia*, *Conostomum*, *Philonotis*), Dicranaceae (*Campylopus*, *Pilopogon*), Ditrichaceae, Hedwigiaceae, Polytrichaceae (*Pogonatum*, *Polytrichadelphus*, *Polytrichum*), Pottiaceae, Sphagnaceae and Splachnaceae. Arnelliaceae and Gymnomitriaceae occur exclusively in páramos and are lacking at lower elevations.

A checklist of the Neotropical páramo flora (Luteyn 1999) illustrates the richness of these habitats.

Centres of diversity and endemism

The only detailed description available of the bryophyte diversity within the Neotropical region is the classical treatment by Herzog (1926) in his *Geographie der Moose*. Although somewhat outdated, Herzog's work is still useful. Following Gradstein *et al.* (1999c), 10 subregions, each with a characteristic bryoflora, are found in the Neotropical region (Fig. 6.5.1). The number of bryophyte genera recorded in each subregion, and those that are endemic, can be found in Table 6.5.2.

It appears that the areas of highest diversity, in terms of total numbers of bryophyte genera, are in **Central America** (414 genera), the **Northern Andes** (413) and **Mexico** (409). Among these three subregions, **Northern Andes** (W. Venezuela, Colombia, Ecuador, N. Peru) has the highest level of endemism (11 genera) and might be considered the prime centre of biodiversity in the Neotropics. Almost 80% of the entire neotropical liverwort flora occurs in this area; seven liverwort genera are endemic and another eight are of extremely restricted distribution. Approximately 55% of Neotropical moss species (1,400 of 2,600) and four endemic moss genera occur in this area. The Northern Andes has also been noted for its richness of angiosperms and other organisms (Henderson *et al.* 1991). The area has been very heavily deforested; today less than 10% of virgin forests remain, compared to about 90% of the rainforests in Amazonia. The northern Andes is one of the world's principal "hot spots" and a priority area for conservation.

Lower levels of generic endemism are evident in **Mexico** and **Central America**. Interestingly, all endemic genera of these two subregions are mosses – no endemic liverwort genera have as yet been described from these areas. The greatest area of bryophyte richness in Central America is probably in Costa Rica, a country little larger than Denmark yet with over 1,000 species of mosses and liverworts. Species endemism in the region is low, probably no more than 2.5%. In comparison, Neotropical páramos have 10 times more endemic bryophyte species.

Southeastern Brazil (372 genera), the **Central Andes**, (370) and the **Caribbean** (348) rank intermediate with respect to generic richness. Among these, the **Central Andes** (Peru and Bolivia) stand out because of 12 endemic genera, the highest number recorded for any region in the Neotropics. As with Mexico and Central America, all endemic genera of the Central Andes are mosses. The majority of these are members of Pottiaceae and Grimmiaceae, moss families characteristic of relatively dry, harsh environments. This may reflect the extensive occurrence of semi-desert vegetation in the Central Andes.

The **Guayana Highland** (184 genera), **Amazonia** (178), the **Brazilian Planalto** (177), and the **Chocó** (152) are relatively low in generic richness. The **Guayana Highland**, comprising the famous sandstone table mountains of Venezuela and Guyana, is rich in endemic angiosperms. **Amazonia**, the greatest lowland rainforest area of the world, harbours important centres of generic endemism. These two areas contain six or seven endemic bryophyte genera

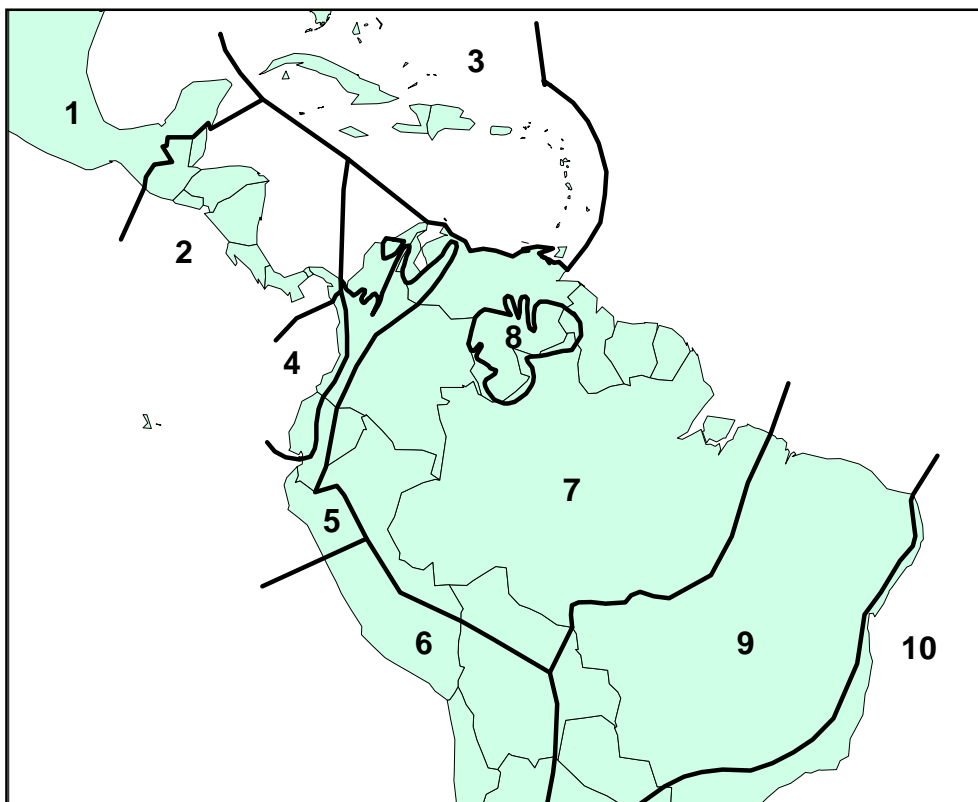


Figure 6.5.1. The 10 subregions of the Neotropics (from Gradstein *et al.* 1999c).
1. Mexico; 2. Central America; 3. Caribbean; 4. Chocó; 5. Northern Andes; 6. Central Andes; 7. Amazonia (including Orinoco basin and the Guianas); 8. Guayana Highland; 9. Brazilian Planalto; 10. Southeastern Brazil.

Table 6.5.2. Bryophyte diversity in 10 subregions of the Neotropics (see Fig. 6.5.1).				
Liverworts			Mosses	
Region	No. of genera	Endemic genera	No. of genera	Endemic genera
Mexico	124	none	285	<i>Acritodo</i> , <i>Anomobryopsis</i> , <i>Curviramea</i> , <i>Cygniella</i> , <i>Florschuetziella</i> , <i>Hymenolomopsis</i> , <i>Pringleella</i>
Central America	139	none	275	<i>Ceuthotheca</i> , <i>Fabronidium</i>
Caribbean	120	none	228	<i>Diploneuron</i> , <i>Hookeriopsis</i> , <i>Teniolophora</i>
Chocó	70	<i>Luteolejeunea</i>	82	none
Northern Andes	143	<i>Chaetocolea</i> , <i>Leptoscyphopsis</i> , <i>Myriocolea</i> , <i>Platycaulis</i> , <i>Pseudocephalozia</i> , <i>Rhodoplagiochila</i> , <i>Sphaerolejeunea</i>	270	<i>Allioniellopsis</i> , <i>Gradsteinia</i> , <i>Kingiobryum</i> , <i>Sphagnum</i> Sect. <i>Cuculliformes</i> , <i>Stenodismus</i>
Central Andes	105	none	265	<i>Aligrimmia</i> , <i>Coscinodontella</i> , <i>Flabellidium</i> , <i>Gertrudiella</i> , <i>Koponenia</i> , <i>Leptodontiella</i> , <i>Mandoniella</i> , <i>Polymerodon</i> , <i>Pseudohyophila</i> , <i>Shroeterella</i> , <i>Sphagnum</i> Sect. <i>Inretorta</i> , <i>Streptotrichum</i> , <i>Trachydontium</i>
Amazonia	87	<i>Cephalantholejeunea</i> , <i>Protocephalozia</i> , <i>Pteropsiella</i> , <i>Schusterolejeunea</i> , <i>Verdoonianthus</i>	91	<i>Colobodontium</i> , <i>Hydropogon</i>
Guayana Highland	89	<i>Haesselia</i> , <i>Vanaea</i> , <i>Odontoseris</i> , <i>Trabacellula</i>	95	<i>Holomitriopsis</i> , <i>Steyermarkiella</i>
Brazilian Planalto	61	none	116	<i>Moseniella</i>
Southeastern Brazil	130	<i>Pluvianthus</i> , <i>Vitalianthus</i>	242	<i>Cladostomum</i> , <i>Crumuscus</i> , <i>Itatiella</i> , <i>Moseniella</i> , <i>Paranapiacabaea</i>
Source: Gradstein <i>et al.</i> 1999c				

each, most of which are liverworts (see below). The relatively low bryophyte diversity in Amazonia and the Chocó as compared with the Andes has been commented on by several authors (e.g., Henderson *et al.* 1991), and is probably due to the lack of elevation variation in the Amazon and Chocó basins, areas consisting of only a single vegetation zone (lowland rainforest). In comparison, the elevation variation in the Andes ranges from 500 to 6,000m, and includes at least five different vegetation zones.

The relatively dry **Planalto** region of Brazil is interesting because of its very poor liverwort flora (61 genera, none of which are endemic). This is the lowest number recorded for any Neotropical subregion and may well be due to the relatively dry vegetation of the Planalto. Moss generic richness in the Planalto is about twice that of liverworts, which again may be due to the relatively dry climate in this area. Indeed, the moss/liverwort ratio is highest in Mexico and the Central Andes, both of which have extensive areas of dry vegetation.

In contrast, the Chocó (82 genera), Amazonia (91), and Guayana Highland (95) have the lowest numbers of moss genera in the Neotropics. These low numbers undoubtedly reflect the very wet climate of these subregions

and the occurrence of large areas of dense, moist forest, which is more favourable for liverworts. Liverwort diversity in these subregions is almost as high as moss diversity, and there are more endemic genera among liverworts than mosses. For a discussion of (low) moss diversity in the Guayana Highland see Buck (1989).

Current state of knowledge

There is a vast amount of literature on Neotropical bryophytes. Checklists exist for many countries and there are comprehensive moss floras for Mexico (Sharp *et al.* 1992), Guatemala (Bartram 1949), Colombia (Churchill and Linares 1995), Amazonian Ecuador (Churchill 1994), and the Guianas (Florschütz 1964, Florschütz-de Waard 1986, 1996). Moss floras for Central America (Allen 1994) and the Caribbean (Buck 1998), and monographs on a large number of neotropical families for Flora Neotropica are partially finished or in preparation. The main gap in the current literature, undoubtedly, is the lack of a comprehensive liverwort flora. Apart from the identification key for Puerto Rico (Gradstein 1989), there are no

identification keys to liverwort species. The manual of the leafy liverworts of Latin America by Fulford (1963–1976) has remained largely unfinished and is, in part, outdated. However, the *Guide to the Bryophytes of Tropical America* (Gradstein *et al.* 1999c) will allow for the identification of all the Neotropical moss and liverwort genera, and provide basic information on their habitats and distribution.

In spite of the vast number of publications, knowledge of the Neotropical bryoflora is still incomplete. Some areas have been explored much more intensively than others. The Central Andes (Peru and Bolivia), for example, is much less well known than the Northern Andes, and almost nothing is known about the supposedly poor bryoflora of the vast and dry Planalto of Brazil. Large parts of Amazonia are still bryological “*terra incognita*”, and the remote table mountains of the Guayana Highland, an excitingly beautiful area, rich in endemic taxa, remain basically unexplored, at least for liverworts.

Threats

Geographically, the five most critically threatened areas recognised are:

- **Southern Central America: Costa Rica and Panama.** This area has several Endangered species and seems to be the largest concentration of Endangered taxa in a single area: *Brymela tutezona* (Western Panama), *Calypogeia rhynchophylla* (Costa Rica), *Fulfordianthus evansii* (Caribbean coast of Central America) and *Nowellia reedii* (Costa Rica).
- **The Chocó and adjacent slopes of the western Cordillera of the northern Andes.** Several threatened species occur in this floristically very rich area, including *Drepanolejeunea spinosa* (EN in western Colombia), *Leptolejeunea tridentata* (globally CR), and *Sphaerolejeunea umbilicata* (globally CR) (western cordillera of the Andes, Colombia, Dept. Cauca), and *Spruceanthus theobromae* (globally CR) (coastal Ecuador, Prov. Los Rios). It should be noted that large parts of the Chocó and the northern Andes are still completely unknown bryologically. Much more fieldwork is needed to properly assess the flora of the area and the distribution of the taxa recorded as threatened.
- **Northern and Central Amazonia, including the adjacent slopes of the Guayana Highland and the Andes.** This is the Neotropical centre of endemism for lowland rainforest species, and 17 of the endemics recorded in this area have been identified as threatened. Since deforestation in this area has yet to reach alarming levels, the threatened Amazonian taxa are usually classified as Vulnerable or at least Lower Risk near threatened. Exceptions are the two endemic species of Ecuador, *Fissidens hydropogon* and *Myriocolea irrorata*,

which occur on the lower slopes of the Andes bordering Amazonia, in an area where the forest is under considerable pressure. Both species were discovered more than a century ago and have not been collected since. Intensive fieldwork in potentially suitable habitats is urgently needed to ascertain the continued existence of these unusual taxa.

- **Northern Caribbean: the Greater Antilles.** Five threatened species occur on the islands of the Greater Antilles. A particularly critical area is eastern Cuba, which has two threatened taxa: *Drepanolejeunea senticosa* (CR) and *Nowellia wrightii* (VU). It is also one of the few areas from which the rare *Neurolejeunea catenulata* has been collected in recent years.
- **Southeastern Brazil (“Mata Atlantica”).** The two areas of remnant rainforest along the Atlantic coast of Southeastern Brazil harbour two endemic liverwort genera and five threatened species, including at least one that is Endangered: *Drepanolejeunea aculeata*.

The main threat to tropical rainforest bryophytes as discussed by Gradstein (1992a), is the conversion of vast areas of forest into plantations and farmland. The bryophyte floras of plantations, and secondary and disturbed forests are impoverished, and differ from those of primary forest. Predictably, the destruction of the lowland and mountain rainforests has a major effect on the local bryophyte flora. In particular, shade epiphytes that occur in the understorey and lower canopy are not well adapted to desiccation and may be seriously affected by the disturbance (Gradstein 1992a,b). It appears that about 20% of the liverwort genera are restricted to virgin forest and seem to be unable to establish in secondary forest or plantations. They are likely to vanish when the forest is opened up.

Compared with rainforests, the páramo flora is probably less threatened. Nevertheless, there is increasing pressure from the local population currently using the lower portions of the páramos (up to 4,000m) for agriculture (cattle grazing, potato cultivation, and recently sheep farming) and afforestation to alter this habitat further. Species growing in zonal páramo vegetations (grass páramos, shrub páramos) seem to be the most threatened by human activities. Those growing in azonal vegetations, including bogs, mires, and river valleys, are also affected. In páramos, bryophytes form an important component of the vegetation and play a crucial role in its hydrology. Destruction of páramo vegetation may lead to the silting up of lakes and the flooding of rivers near large population centres. The rich Neotropical páramo flora certainly deserves more attention from conservationists. Efforts should be made to preserve as much of the species and habitat diversity of these unique tropic-alpine habitats as possible.

Despite the establishment of nature reserves, over-exploitation of the rainforests and intensive land use of páramos are causing increasing threats to the natural

vegetation. Often there is a lack of sufficient personnel and equipment to set up appropriate conservation programmes, to begin the necessary conservation actions, and to monitor threatened populations and habitats.

Action taken

A first list of 49 Red-Listed bryophyte species of tropical America was published by Gradstein (1992a). Almost all are rainforest species. The selection of the taxa was based on three criteria: 1) the species should be narrowly endemic or more widely distributed, but nowhere common; 2) the species should occur exclusively in undisturbed rainforest; 3) the taxonomic status and distribution of the species must have been verified by a specialist.

Because of the limitations imposed by these criteria, only a small portion of the Neotropical bryophyte species could be taken into consideration. The Neotropical taxa which have been studied critically, and whose distribution and habitats have been documented, are very few. Had all rainforest taxa been taken into account, the number of threatened species would undoubtedly have been much higher. It was estimated that about 10% of the total bryoflora of Neotropical rainforests, or about 150–200 species, are threatened.

Recommendations

1. **Recognise the following five areas as critical sites for conservation** (determined using the distribution of the Red-Listed species):

- Southern Central America: Costa Rica and Panama
- The Chocó and adjacent slopes of the western Cordillera of the Northern Andes
- Northern and central Amazonia, including the adjacent slopes of the Guayana Highland and the Andes
- Northern Caribbean: the Greater Antilles
- Southeastern Brazil (“Mata Atlantica”)

2. **Recognise that the Páramos of northern South America and Costa Rica is a major centre of bryophyte diversity and endemism** in the Neotropics, and deserves full conservation attention.
3. **Protect habitat to ensure both bryophyte species and community survival.** As indicated above, some forest species are able to survive in disturbed forests whilst others cannot, and are at risk. The establishment of small forest reserves can be adequate to protect bryophyte species, provided that the appropriate micro-habitats (climate, substrate) can be maintained. For example, large-scale forestry opens up the forest, promotes desiccation and light penetration, and leads to the disappearance of typical rainforest species. Therefore, large viable forest reserves, which ensure the rejuvenation of host trees and encompass different altitudinal zones – as the tropical bryophyte flora shows distinct altitudinal diversification (Van Reenen and Gradstein 1983) – should preferably be the target for the conservation of forest bryophytes.
4. **Consider the formulation of multi-variate programmes** when promoting bryophyte conservation in tropical America, including:
 - **Training and education:** In order to facilitate inventories and ecological research, there is an

***Spruceanthus theobromae* (Spruce) Gradst.** **Status: Critically Endangered (CR) (B1, 2c)**

Class: Hepaticopsida **Order:** Jungermanniales **Family:** Lejeuneaceae

Description and Biology: *Spruceanthus theobromae* is a rather robust leafy liverwort which forms loose, upright or hanging tufts on the bark of rainforest trees. The stems are up to 5cm long and have forked branching. The leaves are made up of narrowly elongated cells and have very small water sacs. Small, ovate underleaves are also evident. The plants are usually fertile and sporophytes arise from perianths with many (five to eight) folds.

Distribution and Habitat: Known only from coastal Ecuador, where it was collected four times in the Province Los Rios, between Quevedo and Guayaquil. The species has been found growing on bark of old cacao trees in periodically flooded habitats at the foot of the Andes, at about 300m a.s.l. The other species of this genus occur in Southeast Asia and Australia (Gradstein 1999b).

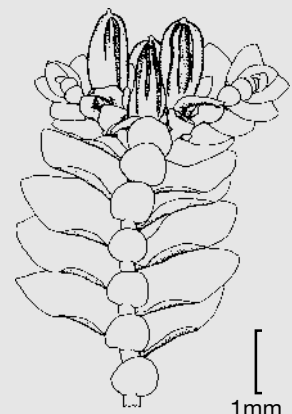
History and Outlook: *Spruceanthus theobromae* has been collected in the mid-19th century, in 1947, and in 1997 in the province of Los Rios, Ecuador. Since the 1960s, most of the region has been deforested, but the forest in the area of the Hacienda Clementina, where it was again collected in 1997, is still largely intact. However, it is currently growing in a critically endangered habitat. Its conservation is of considerable importance as the species is the only representative of *Spruceanthus* in the New World.

Reference: Gradstein 1999b.

Red Data sheet author: S. Rob Gradstein.

Figure 6.5.2.

Illustration: Mariette Aptroot-(Teeuwen).



urgent need to: 1) provide adequate training facilities for undergraduate and graduate students in tropical America; and 2) promote the appointment of bryophyte taxonomists to botanical research centres in the area.

- **Preparation of floras:** Several local floras are available for the identification of neotropical bryophytes, but there is no single flora for the neotropical species, and especially not for the liverworts. Preparation of such a (local) liverwort flora is urgently needed to promote bryophyte conservation in this region.
- **Bryological herbaria:** Herbaria are the botanical archives of biodiversity. They are crucial centres for taxonomical research, floristics, and ecology, and an important information source for all conservation actions. There is an urgent need to donate reference specimens or duplicates of collected material to these institutions, and to hire well-trained personnel to maintain and study the collections.
- **Promoting awareness:** Bryophytes are not well known to the general public. It is necessary to highlight their presence and their role in tropical ecosystems, and to raise awareness through the use of education programmes, e.g., visitor trails in national parks highlighting bryophytes, videos, press coverage of bryological symposia, and also popular, user-friendly, illustrated field guides, etc. Activities such as these should be promoted where possible.
- **Inventories and Red Lists:** Systematic collecting of bryophytes in tropical America started about 150 years ago. Areas that should receive priority for bryological inventories include large parts of the montane Chocó, the northern Andes, the eastern slopes of the Andes, portions of Amazonia, southeastern Brazil, and Central America. The liverwort flora of the central Andes also needs to be inventoried. Based on these inventories, national or regional Red Lists can be developed.
- **Centres of bryophyte diversity:** Recognising that conservation action should focus on important bryophyte areas, additional centres of diversity should be identified. These areas, if conserved, would safeguard not only the greatest number of species but also many evolutionary novelties.
- **Ecological research:** Bryophytes are an important component of tropical ecosystems. Nevertheless, very little ecological research, so important for the management of these areas, has been documented. There is an urgent need to undertake community and ecological succession research (canopy research and research regarding disturbance of ecosystems),

and hydro-ecological research of bryophytes in moist tropical forests.

- **Monitoring:** More and more bryophytes are being harvested in the wild for horticultural or other purposes e.g., nativity scenes and other Christmas decorations (Lewis 1988). So far, this exploitation has not yet resulted in a documented threat to specific species or genera in the Neotropical region, but there is a need to monitor bryophyte exploitation and to exchange information on this issue.
- **Integrate bryophyte conservation into other nature conservation efforts:** Bryophyte conservation should be incorporated into other conservation efforts, at least in the five critical regions described previously.

6.6 Europe (incl. Macaronesia)

Nick Hodgetts

Biodiversity, centres of diversity, and endemism

Europe is extremely varied and contains a wide range of bryological diversity. Most temperate and boreal habitat types are represented. Some habitats are important on an international scale e.g., bogs, oceanic woodlands, boreal forest. Out of a total of nearly 1,700 species, 406 (24.1%) are considered to be threatened (ECCB 1995).

Europe has perhaps been more disturbed by human activity than any other region. Consequently, natural habitats are very rare or absent, although there are extensive areas of 'semi-natural' habitat. In densely populated areas (e.g., parts of England and the Netherlands), semi-natural areas may be almost restricted to nature reserve 'islands' in a strongly anthropogenic landscape.

The total number of species found in Europe is high, compared to the total for North America. This is almost certainly because of the more complete state of bryological knowledge for Europe. However, new species continue to be described, particularly from relatively less well-known areas such as the Iberian Peninsula. Many countries have produced, or are producing, Red Lists for bryophytes (see below) and, while the data quality on which these are based is variable, they all contribute to a gradual refinement in our knowledge of the threatened species.

Table 6.6.1. Summary of bryophyte taxa in Europe.

	Total	Endemic
Species	c. 1,700	219
Genera	336	7
Families	99	0
No. of threatened species	406 (24%)	133 (60%)

Endemism and disjunction

The level of endemism of bryophytes in Europe is rather low, compared to the vascular plants. One way to explain this is that, compared to vascular plants, bryophytes tend to be more efficient at dispersal over a wider area because of the often very small diaspores, but their habitat-specificity often means that only a very small proportion of dispersed diaspores establish themselves successfully. This may often lead to a wide, but very sparse, distribution pattern in bryophytes. There are also, apparently, proportionally fewer endemic bryophytes than in tropical areas, perhaps because many tropical bryophytes are more specialised for a tropical climate and, therefore, more restricted to their immediate environment. Furthermore, the number of 'endemic' species in Europe will probably decrease as other parts of the world are more thoroughly explored, i.e., the ratio between documented European species and those of the other parts of the world will decrease as the same endemic species are discovered in different areas of the world.

The total number of bryophyte species endemic to Europe is 219 (13% of the total flora), of which 133 (60%) are threatened (ECCB 1995). There are no bryophyte families endemic to Europe, and only seven endemic genera: *Alophosia*, *Andoa*, *Nobregaea*, *Ochyraea*, *Pictus*, *Trochobryum* (all moss genera), and *Saccogyna* (a liverwort genus). There are four monotypic families in Europe (Disceliaceae, Oedipodiaceae, Schistostegaceae, and Catosciaceae) and about 50 monotypic genera (depending on the genus concept used).

However, as suggested above, disjunct distributions are a very noticeable feature of the European bryophyte flora, and must be taken into account when assessing conservation priorities. Disjunctions may arise because of natural processes, such as climate change, which leave widely-spaced relict populations. There are many examples of this in the oceanic-montane flora, such as the liverwort *Plagiochila carringtonii*, known from western Scotland and Ireland, the Faeroe Islands and Nepal. An example of a disjunct distribution within Europe is the liverwort *Jamesoniella undulifolia* (refer to map in ECCB 1995), which is very sparsely distributed over a wide area in *Sphagnum* mires. This may be, at least partly, because of widespread habitat destruction.

Evolutionary centres

There are several areas in Europe particularly important for bryophytes that appear to be evolutionary centres. Further information on European bryophyte habitats is provided in the Red Data Book (ECCB 1995).

The main evolutionary centre for bryophytes in Europe must be considered to be in the Macaronesian islands, due to their isolation. Although these islands contain strong elements from both Europe and Africa, as well as some from America, they also have an important endemic flora.

Of the 219 'European' endemics, 60 are Macaronesian endemics. Furthermore, most of these are likely to be genuine endemics, rather than simply species that have not yet been found elsewhere. Some genera, most notably *Echinodium*, have the islands as their evolutionary centre.

The Mediterranean area can also be regarded as an evolutionary centre because its semi-arid habitats are isolated to the north by increasing competition from vegetation used to a more amenable climate, and to the south by the extreme aridity of the Sahara Desert. Therefore, there is a great diversity of taxa, in genera such as *Riccia* for example, that are unique to the Mediterranean area. A little-known Mediterranean habitat that is proving rich in pioneer species occurs on the gypsum and salt-rich soils of southeastern Spain (see Appendix 3). Further east, towards the Asian border, steppe grassland also has its own characteristic suite of bryophytes.

The Alps are regarded as another evolutionary centre, as there are some genera which are clearly proliferating here (e.g., in the Leskeaceae). There are outlying alpine habitats to the north and west in Britain and Scandinavia, and to the east in the Carpathians. However, many alpine species are widespread on a global scale and many occur, for example, in the Himalaya.

Boreal, Arctic, and Atlantic areas are important centres of diversity. Most notably, Scandinavia is a centre of diversity for *Sphagnum*, with Britain and Ireland also being important. Scandinavia is isolated from other boreal and Arctic zones by more extreme Arctic vegetation, and sea. Towards and beyond the Arctic Circle, some groups increase in diversity. Species of mineral-rich fens, for example, that are rare elsewhere in Europe may become relatively widespread in the north (*Paludella squarrosa*, *Helodium blandowii*, etc.). Some genera, such as *Scapania*, also increase their diversity in the north taking advantage of harsh Arctic conditions that are intolerable for many other plants.

The well-known assemblages of oceanic species on the Atlantic coasts of Europe may better be regarded as representing a collection of relict species than actively evolving species. However, whatever their significance in evolutionary terms, they do represent a centre of bryological diversity and should, therefore, be regarded as a high conservation priority.

Current state of knowledge

Europe is the best-known part of the world for bryophytes. Most countries have checklists and those with one or more Red Lists are:

Austria: Grims 1986 (mosses), Saukel 1986 (hepatics)

Belgium: De Zuttere and Schumacker 1984

Czech Republic: Vána 1993; 1995

Estonia: Ingerpuu 1998

Finland: Rassi and Väisänen 1992
Germany: Ludwig *et al.* 1996
Hungary: Rajczy 1990
Iceland: Jóhannsson 1996
Italy: Cortini and Aleffi 1993
Latvia: Abolina 1994
Lithuania: Balevicius *et al.* 1992
Luxembourg: Werner 1987
Norway: Frisvoll and Blom 1997 (including a list of rare bryophytes in Svalbard)
Poland: Szweykowski 1986 (hepatics), Ochyra 1986 (mosses)
Russia incl. part of former USSR: Roshchevsky *et al.* 1982, Bardunov *et al.* 1984, Druzhinina 1984, Garushjants *et al.* 1989 and Konstantinova 1990
Slovakia: Kubinska *et al.* 1996
Slovenia: Martincic 1992 (mosses)
Spain and Portugal: Sérgio *et al.* 1994
Sweden: Hallingbäck 1998
Switzerland: Urmi *et al.* 1992
The Netherlands: Siebel *et al.* 1992
Ukraine: Anon. 1996

However, the state of knowledge is very variable, and new species are still being described. Britain is very well known (though new species continue to be found and old species are being separated taxonomically), while Greece is more poorly known than many tropical countries, having few resident bryologists and few visiting experts.

There are many species in Europe whose status remains obscure for various reasons. The European Red Data Book contains a long list of Insufficiently Known (K) species, which are thought to qualify for inclusion in the Red List, but are too poorly known to be sure. Also, newly described species must often be considered insufficiently known. Often their distribution can only be determined after bryologists have had the opportunity to look for them away from their type locality.

Threats

Threatened types

Table 6.6.2 shows numbers of species in the European Bryophyte Red Data Book (ECCB 1995) corresponding to habitat types (Hodgetts 1996). Many species have been scored as occurring in more than one habitat, so the sum of the totals is considerably more than the total number of threatened species in Europe.

Several interesting points can be drawn from this table. Montane rock habitats support the largest number of threatened species. This reflects the fact that bryologically important areas, such as high-altitude, base-rich rocks, have a rather restricted distribution in the mountains and that, although many areas are relatively remote and

inaccessible, many of the richest bryological areas are under threat. It is also striking that a very large number of threatened bryophytes occur in woodland habitats (including epiphytes and those growing on rotting wood). The importance of Macaronesian forests is emphasised.

Principle threats

The threats to bryophytes in Europe are many. Europe is one of the most densely populated areas of the world. Nearly all 'virgin' natural habitat has disappeared, to be replaced by post-agricultural and industrial revolution landscapes. Areas of 'semi-natural' vegetation remain, which, although usually essentially anthropogenic, contain vestiges of natural habitats. Organisms requiring large tracts of natural wilderness for their survival, such as large predators, are therefore either extinct or severely threatened. However, according to current knowledge, few bryophytes have become extinct. This is because the species and

Table 6.6.2. Number of threatened bryophyte species in Europe according to habitat

Habitat	No. of species
Montane cliffs, rocks, and grassland (basic)	69
Macaronesian laurel and juniper forest	66
Non-Atlantic woodland	44
Montane cliffs, rocks, and grassland (non-basic)	35
Rotting wood	34
Arctic tundra, rocks, waste ground, soil, fens, and swamps	34
Epiphytic (not necessarily woodland)	32
Atlantic forest and ravine woodland (non-Macaronesian)	32
Lowland rock exposures (basic)	22
Lowland rock exposures (non-basic)	22
Lowland grassland, quarries, waste ground, and soil (basic)	20
Lowland riverine and aquatic	19
Coastal grassland, rocks, and thin turf	19
Margins of lowland pools and reservoirs	15
Lowland grassland, quarries, waste ground, and soil (non-basic)	15
Boreal forest	14
Epiphyllous	14
Upland flushes and mountain streams	13
Upland heath and bog	12
Xeric mediterranean terrestrial habitats	12
Lowland heath and bog	11
Cultivated fields	9
Lowland fen	9
Snow patch	9
Heavy metal rich rocks and mine waste	4
Woodland paths (non-basic soil)	4
Steppe	3
Sea caves and dripping gullies in coastal cliffs	2
Thatch	2
Volcanic vents (non-Atlantic only)	2
Dunes	2
Unknown	10

communities are at a small scale. Although many species have declined markedly because of habitat destruction, it would be much more difficult to eradicate all possible sites for a bryophyte than for a wolf or bear. On the contrary, most species are capable of surviving in microhabitats in otherwise inhospitable surroundings, unlike many vascular plants or animals, which require larger areas. Some species are, however, so restricted in their habitat and range that they are under severe threat (e.g., mineral-rich fen species in central and southern Europe).

Habitat destruction

Historically, habitat destruction has been the most important threat. This is still a threat, through building programmes, afforestation with non-indigenous species, deforestation of natural and semi-natural woodland, tourist developments, etc. However, there are now wide areas of protected, semi-natural vegetation in Europe, and any attempt to encroach on these further is always fought very hard.

Pollution

Pollution is perhaps the most insidious and, therefore, the most serious threat to bryophytes in Europe because it can reach and destroy even the microhabitats. There are good examples in northern Russia, in particular, of large-scale pollution that has dramatically diminished biodiversity over large areas (e.g., the effects of the aluminium smelter in the Kola Peninsula). Eutrophication because of excessive use of fertilisers and slurry, and over-stocking is an important threat throughout Europe, threatening freshwater systems and wetlands.

Lack of information

Within the conservation movement in Europe, ignorance is sometimes a threat to bryophytes. For example, it has been known for nature reserve managers to dig up bryophyte-rich dune slacks to create ponds for natterjack toads. More commonly, it is ignorance of correct management procedures for bryophytes that is the problem, and many valuable bryophyte sites have been lost by being allowed to fall victim to scrub invasion, or over- or under-grazing. It is the duty of bryologists to disseminate their specialist knowledge to conservation authorities, so that bryophytes may be integrated into conservation programmes effectively.

Action taken

Most countries have some form of legislation relating to wildlife protection. In general, these take two forms: site protection and species protection. Site protection usually involves the identification of areas of importance, such as those containing high biodiversity, and provides for the management of these areas for their wildlife interest.

Species protection is usually based on a selected list of species. These species are not allowed to be collected.

Bryophytes are included on the lists of a few countries (Germany, The Netherlands, Belgium, Luxembourg, Great Britain, Switzerland (in part), Hungary, and the former Soviet Union), and several other countries are considering the addition of bryophytes to their lists of protected species. In some cases, the bryophytes that have been given protection are highly endangered species, but more usually they are widespread species that are exploited commercially (e.g., *Sphagnum*). Legislation of this sort is a double-edged sword: while it is clearly desirable to legislate for the conservation of species, a blanket ban on collection of rare species can be counter-productive, as collection is often necessary for identification. Whatever the legal situation in particular countries, bryologists must be responsible in collecting only small specimens of rare species if they are not to bring themselves into disrepute.

The habitats of protected species are also protected in some countries, such as Poland, Hungary, Spain, and a part of Austria. In several Swiss cantons, planning permission is required before the habitat of protected species can be altered. Many important bryophyte sites have been protected incidentally through designation of protected areas for other, usually habitat-related, reasons. In Spain, the concept of 'microsites' gives protection to small areas where threatened plants grow (e.g., a rock outcrop).

Species may also be given protection under international law. As mentioned above, it is incumbent on bryologists to ensure that bryophyte conservation is integrated into mainstream conservation programmes, and that bryophyte communities are taken into account when habitat conservation is considered. It is important to include species and bryophyte-rich habitats in appendices of international conventions, if only to raise their profile.

International law and the Bern Convention

The European Committee for the Conservation of Bryophytes (ECCB) was formed in 1990 to address bryophyte conservation in Europe. Its first act was to recommend the addition of a selection of species to Appendix I of The Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention). The following species were accepted for addition to the Convention:

Hornwort:

*Notothylas orbicularis** (Notothyladaceae)

Liverworts:

Cephalozia macounii (Cephaloziaceae)

*Frullania parvistipula** (Jabulaceae)

*Jungermannia handelii** (Jungermanniaceae)

*Mannia triandra** (Aytoniaceae)

*Marsupella profunda** (Gymnomitriaceae)
*Petalophyllum ralfsii** (Codoniaceae)
*Riccia breidlerii** (Ricciaceae)
*Riella helicophylla** (Riellaceae)
*Scapania massalongii** (Scapaniaceae)

Mosses:

*Atractylolcarpus alpinus** (Dicranaceae)
*Bruchia vogesiaca** (Dicranaceae)
*Bryoerythrophyllum machadoanum** (Pottiaceae)
*Buxbaumia viridis** (Buxbaumiaceae)
Cynodontium suecicum (Dicranaceae)
*Dichelyma capillaceum** (Fontinaliaceae)
*Dicranum viride** (Dicranaceae)
*Distichophyllum carinatum** (Hookeriaceae)
*Echinodium spinosum** (Echinodiaceae)
*Hamatocaulis vernicosus** (Amblystegiaceae)
*Meesia longiseta** (Meesiaceae)
*Orthotrichum rogeri** (Orthotricaceae)
*Pyramidula tetragona** (Funariaceae)
*Sphagnum pylaisii** (Sphagnaceae)
*Tayloria rudolphiana** (Splachnaceae)
*Thamnobryum fernandesii** (Neckeraceae)

*Species also added to the list of protected species in the European Community Directive on the conservation of natural habitats and of wild fauna and flora (i.e., those occurring in member states of the European Union; the two species not included occur outside the E.U.).

These species were the first lower plants to be listed under any international treaty or law. A panel of experts under the Council of Europe has been set up to review this list periodically. The European Community Directive was ratified in May 1992 and has several important aspects. It seeks to ensure the protection of selected threatened species and important sites where they are found. As far as bryophytes are concerned, all the species listed in the Bern Convention that occur within the European Union area require 'Special Areas of Conservation' to be designated for their protection.

An article in the European Community Directive deals with the commercial exploitation of species. This article now means that the exploitation of all *Sphagnum* species and *Leucobryum glaucum* should be monitored by member states, and measures should be taken to prevent exploitation from adversely affecting the status of these species.

Action Plans for individual species

Blanket protection for species is, however, not necessarily the best way of protecting bryophytes, as it can be counter-productive and stifle professional and amateur research. Action plans for individual species protection appear to offer a much more positive way forward, as they can be tailored to the requirements of individual species.

Bryophyte conservation should go forward as an integrated part of an overall biodiversity conservation strategy, rather than being marginalised. Following the 1992 Rio Biodiversity Convention, this is now widely recognised. For example, the UK response to the Rio Convention was to produce a UK Biodiversity Action Plan, which includes action plans for habitats and species, including many bryophytes. Bryophytes and other cryptogams are also taken into consideration in the UK Plant Conservation Strategy (Palmer 1995), along with vascular plants. Other countries have formulated their own responses to the Rio Convention. How effective the various approaches will be remains to be seen.

Red Data Book of European bryophytes

The ECCB has produced a Red Data Book of European bryophytes (ECCB 1995). This includes an introductory section, the European Bryophyte Red List, and a Site Register, which incorporates a selection of important bryophyte sites in Europe. A large number of threatened species [279 (73.2%)] occur in sites identified in the Site Register.

Networking in Europe

One of the main actions of the ECCB has been to organise a symposium on bryophyte conservation in Europe once every four years. The first, where the ECCB was formed and the recommendations for additions to Appendix 1 of the Bern Convention were made, was held in Uppsala in 1990. The follow-up symposium, held in Zürich in 1994, culminated in a number of resolutions for the conservation of bryophytes (listed in Appendix 4). The most recent (Trondheim 1998) concentrated on the scientific basis for bryophyte conservation.

Also at four-year intervals, alternating with the symposia, the ECCB arranges 'workshop' meetings to deal with specific issues. The first of these (Reading 1996) was concerned with application of the revised IUCN threat criteria and categories to bryophytes. As a result, guidelines recommending ways of interpreting the IUCN criteria for bryophytes were published (Hallingbäck *et al.* 1998), and have been officially adopted by the IUCN.

Planta Europa is an important recent initiative bringing together a large number of European statutory and non-statutory organisations for the benefit of plant conservation Europe-wide. Planta Europa was established at a conference in Hyères, France in 1995, which resulted in a number of important papers and resolutions. A second Planta Europa conference was held in Uppsala, Sweden in 1998. This conference was divided into 'workshop' sessions, one of which addressed the conservation of cryptogams. For bryophytes, the important outcome was that a number of specific cryptogam-related resolutions were passed, and cryptogams were also fully incorporated into many of the other conference resolutions (Appendix 5). Also, it is

now explicit that there should always be at least one cryptogamic botanist on the Planta Europa Steering Committee.

Darwin Initiative

Because there are currently many bryologists in Europe compared to very few in the tropics, European bryologists should play an important role in the conservation of tropical bryophytes. European bryologists can enthuse botanists in tropical universities to study bryophytes and impart their knowledge to them. Systems such as the Darwin Initiative, now under way in Britain as a result of the Biodiversity Convention in Rio, can be important in this respect. Far from bryophyte study being a handicap in obtaining funding, one of the criteria for Darwin Initiative funding is to study 'little-known' groups. This demonstrates that bryologists should be confident in applying for funding that addresses conservation of what others might think of as obscure organisms.

Recommendations

1. **Continue to support the production of the second edition of the Red Data Book (RDB) for Europe.** This edition will use the revised IUCN criteria and is being prepared by the ECCB. To this end, ECCB is utilising its extensive network of contacts in Europe to improve, as much as

possible, the level of information on internationally threatened species. It is planned to complete work on this volume in 2000/01. The second ECCB workshop meeting will be held in Portugal in 2000, and will concentrate on compiling the available information and finalising data sheets for the RDB.

2. **Explore those areas that have yet to be fully explored bryologically**, so that the current bryological dataset for these areas may be increased. These areas, identified by the ECCB, are concentrated in eastern and southern Europe and include Greece, Albania, and Romania. Western Russia and former Russian states also need to be explored bryologically. A recent paper by Söderström *et al.* (1998) has shown that several areas of Europe appear to be greatly under-recorded for liverworts, and the same is likely to be the case for the mosses. Future bryological field expeditions should concentrate on these areas. Bryological societies may be able to co-operate with the ECCB in organising such expeditions.
3. **Network.** It is critical that the bryological community, through the ECCB, maintains contact with organisations such as Planta Europa, IUCN, the Council of Europe, and the European Union. Realistically, the role of most bryologists is principally an advisory one. It is only through wider initiatives and larger, more powerful conservation organisations that *action* for the conservation of bryophytes can be

***Distichophyllum carinatum* Dixon and W.E.Nicholson** **Status: Endangered EN B1,2c**

Class: Bryopsida **Order:** Hookeriales **Family:** Hookeriaceae

Description and Biology: A tiny pleurocarpous moss growing in whitish-green carpets, sometimes tinged with brown colour; the shoots are vermiform and fragile; the leaves are concave and keeled, with a very fine nerve. Sporophytes have never been found.

Distribution and Habitats: Scattered localities in the European Alps (Austria, Germany, Switzerland), in central Honshu (Japan) and Mt Ormei (China). In total, it is known from less than 10 populations. It occurs on wet, shaded rocks with a pH of between 5.0 and 6.5, especially in wooded ravines. The habitat is not obviously threatened, but *D. carinatum* is probably an example of species very sensitive to subtle changes in habitat conditions due to the pollution of the atmosphere.

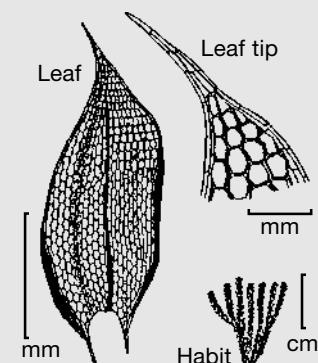
History and Outlook: *D. carinatum* is a species with a very disjunct distribution. It is known worldwide from less than 10 localities. In Europe, the species has been re-discovered at only two localities, despite repeated searches (Dr R. Lübenau-Nestle pers. comm. 1998). One of the sites was destroyed by road construction; the causes for the loss of the other populations are not known. In Japan, students of Prof. N. Kitagawa (pers. comm. 1994) successfully re-discovered the species in a "safe" site in central Honshu. Statutory protection, through the designation of nature reserves, is required for the sites of the known remaining populations of this species in Europe, Japan, and China. The sites also need regular monitoring to ensure survival of the species. If it increases in extent, transplanting it to some of the other safe localities should be considered. A small amount should be taken into cultivation for *ex situ* conservation. This species is included in Appendix I of the Bern Convention and on Annex 2 of the EC Habitats and Species Directive.

References: Futschig 1954, Noguchi 1991, Urmi 1984.

Red Data sheet authors: Ph. Martiny, E. Urmi, R. Lübenau-Nestle.

Figure 6.6.1. Redrawn from Mönkemeyer 1927.

Illustration: Mönkemeyer 1927, Futschig, 1954, Urmi 1984.



integrated with nature conservation generally. It is also important that national workers maintain an international perspective, so that individual countries can conserve the bryophytes and bryophyte habitats in those countries that are of international importance. Conservation organisations within these countries can also assist in communicating and harnessing biological expertise.

4. **Increase the employment of Action Plans for the conservation of “target species”.** While often bureaucratic and frustrating, they are also becoming successful at raising the profile of lesser-known groups such as bryophytes. It cannot be over-emphasised that bryologists need to continue to promote bryophytes as important parts of biodiversity, if they are not to be overlooked as “small and insignificant”.
5. **Educate the public on the importance of bryophytes and their roles within the ecosystem.** This can be achieved through the use of various media, including popular publications; such action already occurs in other European countries, for example Sweden. Future environmental education efforts may benefit from seeking advice from, and working with, countries with experience in this matter.
6. **Increase the extent to which bryophyte conservation is included in protected area management and other initiatives,** such as Important Plant Areas. Bryophyte conservation must be translated into effective management and protection protocols.
7. **Support the production of the paper on the various methods used to arrive at lists of “species of conservation concern”.** This initiative was suggested at the recent Trondheim conference and will be produced by the ECCB. A series is also planned on key European bryophyte sites, for use by conservation authorities.

6.7 North America

Wilfred B. Schofield

Biodiversity, centres of diversity and endemism

North America, extending from the tropics in Florida to the high Arctic in Canada and Greenland, is extraordinarily diverse in terms of climate, substrata, and vegetation. The vegetation includes tropical forest, temperate coniferous and deciduous forest, steppe and grassland, semi-desert, Arctic and alpine tundra, and Arctic rock deserts. There are also extensive wetlands, lakes, and watercourses.

In spite of considerable disturbance and destruction caused by human activity, extensive areas remain (especially in Canada and Alaska) where human disturbance has not

Table 6.7.1. Summary of bryophyte taxa in North America.

	Families	Genera	Species
Mosses	74	317	c.1,325
Liverworts	45	116	c.555
Hornworts	1	4	16

been extreme. Regrettably, the regions where bryodiversity is highest coincide with areas of concentrated human utilisation. Protection of these areas is arrested when political and commercial motives reject conservation of sites that affect financial considerations.

When the diversity of the environment is taken into account, and the multiplicity of historical circumstances considered in the development of the flora, the bryoflora is not extraordinarily large. The mosses include approximately 1,325 species in 317 genera belonging to 74 families. The liverworts contain c. 555 species in 116 genera belonging to 45 families. The hornworts include four genera and 16 species in one family. These estimates are conservative and are flawed by an attempt to reconcile variant opinions among researchers.

Among the mosses, 25 endemic species are known only from the type specimen or from three or four further localities. Non-endemics that are found in North America from fewer than five localities total 58 species. In the liverworts, 28 endemic species are known only from the type specimen or from three or four further localities. Rare non-endemic species, usually well represented elsewhere in the world, are represented by only 24 species in North America with few localities. Many of these are predominantly Neotropical. If this provides a reasonably accurate documentation of their presence, these species must be considered vulnerable and possibly in danger of extinction in North America. Indeed, several species may be extinct already. The endemic mosses *Neomacounia nitida* (collected in 1864) and *Weisia inoperculata* (in 1955) have not been collected since they were described, and the same is true for the endemic hepatics *Cylindrocolea andersonii*, *Fossombronina zygospora*, and *Cephaloziella brinkmanii*, and undoubtedly others.

Non-endemic species that may be extinct in North America include the mosses *Meiothecium tenerum* and *Micromitrium tenerum*, and the liverworts *Radula flaccida*, *Porella swartziana*, *Rectolejeunea pililoba*, *Cololejeunea subcristata*, and undoubtedly others. *Bartramia stricta*, for example, is known from numerous localities in California but, based on available collections, is extremely local in British Columbia, representing the only Canadian localities where it is considered Endangered (Belland 1997). *Andreaea megistospora*, on the other hand, is widespread in near-coastal British Columbia, but is extremely rare in the adjacent United States (Murray 1987).

Centres of endemism

Concentrated bryophyte endemism occurs in certain areas within North America. Five of these areas are outlined below (compare with Fig. 6.7.1).

- 1. The southern Appalachian Mountains of the United States** were first assessed by A.J. Sharp, who studied the flora in detail. The researchers H.L. Blomquist, L.E. Anderson, and R.M. Schuster, among others, considerably enriched the documentation and understanding of this area. Affinities are mainly with Southeast Asia or tropical America. Mosses in this area include *Bryum reedii*, *Diphyscium cumberlandianum*, *Fissidens clebchii*, *Mnium carolinianum*, and *Orthotrichum keeverae*, while the liverworts include *Bazzania nudicaulis*, *Diplophyllum andrewsii*, *Lophocolea appalachicola*, *Pellia megaspora*, *Riccardia jugata*, and *Plagiochila appalachiana*. The hornworts include *Anthoceros appalachianus* and *Megaceros aenigmaticus*. Many of these species are very restricted in their range and, by good fortune, many are found in national and state parks that afford them some protection.
- 2. The range of the broadleaf deciduous forest and the mixed forest of eastern North America** circumscribes an area of high bryophyte endemism in which a large proportion of the endemics show a very wide range. Again, parks help to protect this flora both in Canada and the United States. The endemic moss genera in this region include *Aphanorrhegma* (Funariaceae), *Brachelyma* (Fontinalaceae),

Bryoandersonia (Brachytheciaceae), and *Donrichardsia* (Amblystegiaceae) (Fig. 6.7.2), all of which are monotypic.

- 3. Near the Pacific coast of western North America** many of the bryophyte endemics range widely in the area circumscribed by southern British Columbia of Canada, extending southwards to northern California. Endemic bryophytes occur particularly in areas of high precipitation. In this area, at least 10 endemic genera are found, predominantly pleurocarpous: *Alsia* (Leucodontaceae), *Bryolawtonia* (Neckeraceae), *Dendroalsia* (Leucodontaceae), *Leucolepis* (Mniaceae), *Meiotrichum* (Polytrichaceae), *Trachybryum* (Brachytheciaceae), and *Tripterocladium* (Hypnaceae). Included in the liverworts is the endemic genus *Gyrothyra* in the monotypic family, Gyrothyraceae, *Geothallus* (Sphaerocarpaceae), and *Schofieldia* (Cephaloziaceae); all are highly distinctive monotypic genera with no close relatives.
- 4. Arctic western North America**, especially unglaciated areas of Alaska and Yukon, contains a number of endemic bryophytes. The endemic monotypic families Andreaebryaceae and Pseudoditrichaceae both occur here. The former is relatively widespread, but the latter appears to be known only from the type locality and has not been collected since the original collection of W.C. Steere, made in 1948.
- 5. The drier climatic portions of California and adjacent states** also demonstrate marked endemism. It is possible that these seeming endemics will be discovered in adjacent Mexico when it is more thoroughly explored

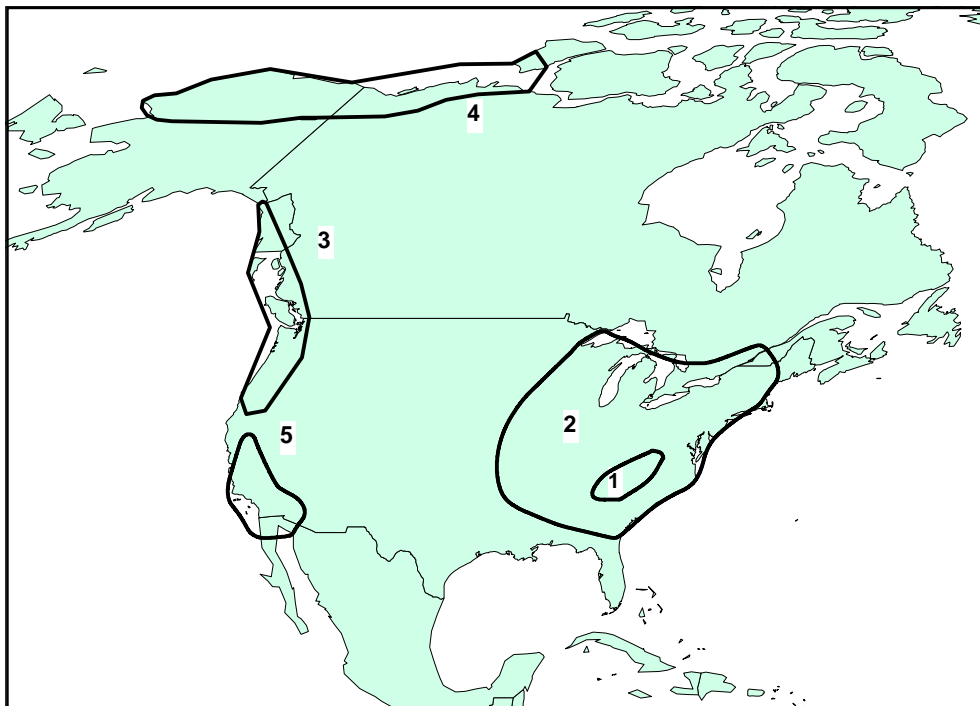
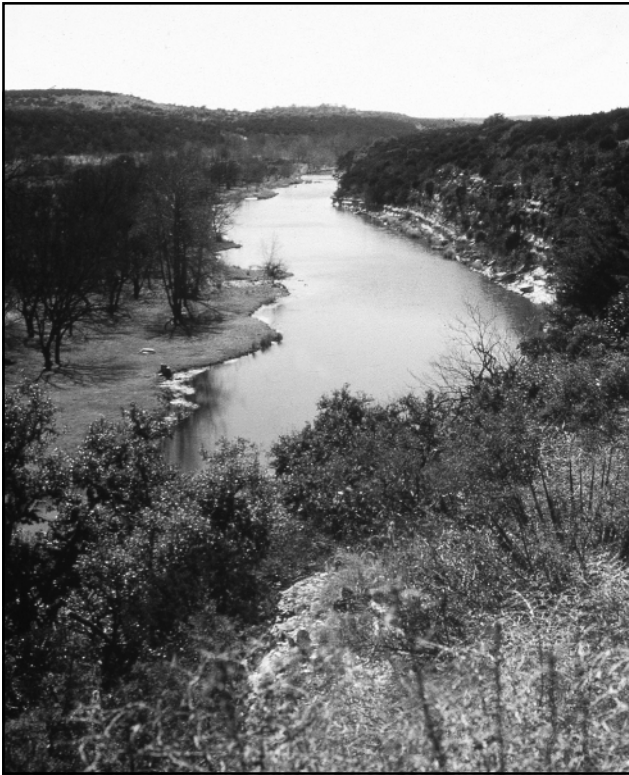


Figure 6.7.1. Map of North America showing some regions where phytogeographically significant bryophytes are concentrated.



Robert Wyatt

Figure 6.7.2. The only known locality (Edwards County, Texas) for the vulnerable moss *Donrichardsia macroneuron* (Grout) Crum and Anders.

bryologically. Many of the endemics are represented by a small number of collections, and much of the terrain where they were collected is under threat by human activities e.g., human settlement and agricultural expansion, all-terrain vehicle use, and mountain-biking.

Current state of knowledge

Checklists exist of the bryoflora of North America, and these have been compiled with considerable care. For eastern North America, recent manuals of liverworts (Schuster 1966–1992) and mosses (Crum and Anderson 1981) are available. For western North America, checklists are available for most states, provinces, and territories; detailed manuals are available for some areas, most notably those by Howe (1899) for the California liverworts, Lawton (1971) for the mosses of northwestern United States, and Flowers (1961, 1973) for the liverworts and mosses of Utah. Steere (1978) has provided an important annotated listing of the mosses of northern Alaska, and Steere and Inoue (1978) have provided an important annotated listing for the liverworts of the same region. For western North America, much of the bryoflora remains to be synthesised as well as discovered by field research. In Arctic North America the task is even greater.

Threats

Predictably, the activities of the human population are the prime source of habitat destruction or alteration. Deforestation is unquestionably a major contributor to the destruction of vast areas of bryophyte habitat. Its effects are most severe in the subtropical and temperate eastern North American deciduous forest; epiphytic species are particularly affected. When cliffs and watersheds are opened up as a result of clear-felling, a rich array of bryophytes are destroyed through desiccation. In the coniferous forests, it is the areas near watercourses and shaded cliffs that show the greatest diversity in bryophytes, thus the exposure of these sites to desiccation greatly accelerates restriction of the ranges of many bryophytes.

Increases in human populations, besides generating the practices that lead to forest removal for commercial purposes, also result in human settlement of and agricultural expansion into forest areas. In the process, bryophyte habitats are destroyed, and the ranges of some taxa are reduced or eliminated.

It is ironic that the establishment of parks sometimes leads to the rapid deterioration of the vegetation that they were intended to protect. It draws attention to the availability of the area for recreational purposes, and often attracts individuals whose thoughtless activities alter the habitats that favour the persistence of many bryophytes. Such behaviour is difficult to control; thus, although parks can be useful for habitat preservation, it is also necessary to preserve areas within them under an *ecological reserve classification*, not open to recreational use.

Wetlands are also vulnerable to human destruction or alteration through agricultural use, draining for housing development, and mining of peat resources. Changing the drainage patterns into and from such wetlands leads to the restriction or destruction of bryophyte habitats.

Flooding of extensive areas, especially for hydroelectric development, has already destroyed extensive areas in many parts of North America. Within the past 30 years, immense impoundments have been created in British Columbia and California, with the consequent submergence of extensive areas. Regrettably, there was no concerted effort to document the biological diversity of these areas before they were submerged. Air pollution, particularly acid rain, continues to influence forested and unforested terrain. Its effects on bryophyte distribution need to be assessed.

In conclusion, the situation does not encourage optimism. In times of financial instability the environment tends to deteriorate rapidly in spite of governmental assurance that legislation is being generated to prevent such deterioration. In spite of good intentions, the intensity of environmental destruction proceeds. The reduction of available experts who can assess destructive activities and suggest appropriate procedures to arrest the destruction is especially alarming. Government agencies are often aware of the problems, but

are unable to take action to stop them. The electorate is becoming increasingly conservative, and self-interest tends to overrule the common good. Thus, many small acts of destruction collectively produce major consequences.

Action taken

In North America, there are few instances of protecting rare and Endangered bryophytes. The Nature Conservancy of Oregon, largely through the efforts of John Christy, has purchased the only site where the moss *Limbella fryei* occurs for protection. It appears probable that the newly discovered site of the hepatic *Geothallus tuberosus* may be preserved through the efforts of its discoverer, William Doyle. No similar efforts in Canada are known, although in the national parks of eastern Canada special restrictions have been made concerning the sites of phytogeographically significant bryophytes. This research has been initiated by Parks Canada and carried out by René J. Belland of Edmonton. Although such trends are limited, they do indicate that the bryophytes are beginning to receive attention. With support from COSEWIC (Committee on the Status of Endangered Wildlife in Canada) a first listing of rare moss species in Canada has recently been assessed (Belland 1998).

Recommendations

1. **Change public attitude.** Members of the public generally become concerned only when the fate of a particular organism has a direct impact upon them. It is necessary to impress upon people that the extinction of ANY organism, including a bryophyte, is a warning that other extinctions will follow, which could directly affect them. This needs to be followed by governmental measures that reflect this change in attitude.
2. **Protect ecosystems, through the use of intelligent legislation, where rare or endangered species are known to occur.** Such legislation must not impede research; therefore, informed bryologists should be involved in formulating the legislation.
3. **Convince the public that such protection is for the common good.** Public awareness can be improved through publication of popular, accurate, and well-illustrated works that demonstrate the significance of bryophytes in the environment. Such publications should also demonstrate the intrinsic beauty of these plants.
4. **Preserve areas within national parks or reserves under an ecological reserve classification, not open to recreational use.**

Conservation Measures

The level of protection afforded to areas containing bryophytes varies considerably between continents and regions. For example, whilst the majority of habitats rich in bryophyte species are protected in Australia, only a very low percentage of the bryophyte habitats in The Netherlands and Denmark receive protection. In some parts of the world, local bryophyte floras are conserved through the establishment of large national parks and nature reserves that are designed to protect large animals and flowering plants. However, bryophytes cannot always be expected to receive protection because an area which supports high vertebrate and flowering plant diversity is established as a reserve; the regions where bryophyte diversity is highest do not always coincide with those of high vertebrate and flowering plant diversity. For example, the Camargue in France and the Serengeti National Park in Africa do not support very interesting bryophyte floras.

The conservation of endangered plants can be viewed as a five-step process:

1. Recording the distribution of rare and declining taxa.
2. Assessing their population trends and extinction risks.
3. Proposing conservation programmes.
4. Executing these programmes.
5. Evaluating the effectiveness of the programmes.

Eleven species action plans have recently been produced for bryophytes in Great Britain (including one for *Thamnobryum angustifolium*). In Sweden, a species action plan for *Dichelyma capillaceum* has also been recently published. All action plans provide useful information for *in situ* bryophyte conservation.

7.1 Habitat approach

7.1.1 Achieving habitat protection

Because of their low-growth habit, small size, and occurrence in “micro-sites”, bryophytes can often be protected simply and effectively by protecting their habitats (Pócs 1991, ECCB 1995, Hallingbäck 1995). In many countries, areas of natural vegetation have been set aside as parks or nature reserves and, if managed properly, these protected areas may serve as refugia for bryophytes. Preliminary data on the species density of bryophytes in a tropical rainforest (Gradstein 1992a)

suggests that small reserves could conserve many species, provided the “host” trees are capable of regeneration. The Rio Palenque Science Centre in coastal Ecuador, comprising 87ha of mature virgin rainforest surrounded by cultivated land, may serve as an example of a small reserve with a well-developed bryophyte flora (Gradstein 1992b). However, whether the bryophytes will survive in these small reserves or sites remains uncertain. According to Pócs (pers. comm. 1995), some species are disappearing from preserved forest fragments in East Africa due to local climate change and desiccation caused by large-scale forestry. The relationship between habitat area and species survival thus remains unclear with respect to bryophytes.

Whilst habitat area and species survival information is being gathered, bryophyte conservation must proceed using the best information at hand. Appropriate methods should be adopted, and high priority should be given to the conservation of remaining bryophyte vegetation. Despite this being a “blunt tool”, it is, for the time being, the best approach to the conservation of the bryophyte flora.

7.1.2 Habitat function approach to habitat protection

Adopting the “habitat function approach” may ensure habitats receive protection. For example, emphasising the water-holding capacity of cloud zone forests in Africa is likely to be the best method of ensuring bryophyte protection within this forest type. The resultant slow and steady release of water to the coffee plantations at lower altitudes is vital to their continuing productivity (Pócs 1980).

7.1.3 Funding habitat protection

Protecting habitats is usually extremely difficult without sound financial backing. Fundraising campaigns should be constructed in such a way that as many possible funders are attracted to bryophyte conservation. Fundraising campaigns must stress the importance of bryophytes in ecosystem functioning, and in ensuring human well-being.

If bryologists join forces with scientists from other taxonomic groups, bryophyte conservation then becomes a component of much larger and more charismatic projects for which it is much easier to obtain funding.

Ex situ conservation strategy

The following strategy is intended to act as a guide for conservation policy dealing with *ex situ* programmes. It does not represent an inflexible code of conduct. Each *ex situ* project should be rigorously reviewed on its individual merits. The IUCN/SSC Bryophyte Specialist Group can assist in suggesting priority species for *ex situ* conservation.

Ex situ storage and the cultivation of threatened bryophyte species are often the final options to ensure species survival. In certain cases, however, an *ex situ* conservation strategy can be a complementary management method applied in the early stages of bryophyte conservation. Because this approach to the management of living material could involve risks, the Species Survival Commission's Bryophyte Specialist Group must suggest a specific strategy for *ex situ* conservation. This strategy could help to justify *ex situ* activities, and assess the likelihood of success or failure. This strategy could also include methods for disseminating information among interested parties.

A. Aims and objectives

- The overall aim of *ex situ* conservation activities should be to improve the population size and viability of threatened species.
- If successful, at least part of the population should be re-introduced into the wild.
- Enhancement of the long-term chances of survival of a species is one objective that should be included in *ex situ* conservation projects.

B. Background research should involve

- An assessment of the taxonomic identity of individuals that are to be stored or cultivated.
- The identification of the causes of decline in order to ensure successful re-introductions into the wild.
- Pilot projects, using species that are not threatened, to test methods under a variety of conditions.
- Thorough research into previous *ex situ* experiments of the same or similar species.
- Contacting personnel with relevant expertise prior to, and during, the development of an *ex situ* protocol.

C. Species selection and collection

- Ideally, *ex situ* conservation measures should only be undertaken as a last resort, when there is no possibility for *in situ* protection.
- *Ex situ* conservation must never be regarded as an excuse to destroy naturally-occurring *in situ* populations.
- Specimen collection for *ex situ* activities must take place with the full permission and involvement of all relevant government agencies of the recipient and host country.
- The collection of individuals for *ex situ* conservation must not endanger the wild source population. It is important to use the smallest possible amount of plant material, and to never collect the last sample of any specimen of any population.

D. Storage, cultivation, re-introduction, and monitoring

- Storing and cultivating spores and living plant material are generally long-term projects that require long-term financial and political support. Adequate funding for all programme phases must be guaranteed beforehand.
- Effort must be made to re-introduce populations that have been stored or cultivated as *ex situ* for some time. This gives an indication of whether the *ex situ* procedure might damage or change the vitality of material.
- *Ex situ* conservation plans should include a monitoring programme. Monitoring the viability and the survival of *ex situ* species is important. Monitoring might be possible through the use of infrared photography and photosynthesis measurements.
- Intervention may be necessary if *ex situ* activities endanger the population; *ex situ* activities may then have to be altered or stopped to ensure species survival.
- Decisions for revising, rescheduling, or discontinuing programmes should be discussed when necessary.
- An evaluation of the cost-effectiveness and success of the re-introduction techniques is also necessary.

E. Other considerations

- Those institutions involved in *ex situ* conservation should produce a document describing the procedures and the protocols for any *ex situ* storage or cultivation project.
- Both the scientific community and conservation bodies dealing with endangered species must be informed of the results of *ex situ* conservation projects. The results should be published in an international journal. Results, both positive and negative, should be reported regularly in scientific and non-scientific literature.
- The benefits of the *ex situ* programme should be explained to the public through the mass media.
- If possible, local people should be involved.
- It is of the utmost importance that the project does not risk the health of any population of a globally Endangered species, nor increase the extinction risk for any species.
- Conservation education programmes should be developed for long-term *ex situ* storage projects. *Ex situ* techniques for bryophytes are fairly new and some have yet to be tested. In addition, fundamental knowledge of the biology of bryophytes is still incomplete, especially regarding the effects of *ex situ* handling.
- Individuals involved in long-term programmes should receive professional training.
- A multidisciplinary team with access to expert technical advice for all phases of the programme should be assembled.

7.2 Species approach

7.2.1 Species approach to habitat protection

Highlighting the plight of threatened species, and their reliance on specific habitats, is an approach that has been adopted by several countries in Europe to obtain habitat protection. Often Red List species have been used to justify conserving natural habitats. One advantage of this approach is that the present level of public awareness of threatened species is high; the majority of people find it easier to link the need for conservation to species rather than habitats.

7.2.2 Flagship and indicator species

In some countries, a “flagship charismatic species” approach can be used for bryophyte habitat conservation instead of, or parallel to, a threatened species approach (Hunter and Hutchinson 1994). This means focusing attention and efforts on protecting sites that support a particularly spectacular or enigmatic species (such as a tiger, a giant panda, or an orangutan) which can then be invoked to attract sponsorship and funding. This can, of course, only be effective if bryophytes and flagship species occupy the same habitat.

Highlighting the use of bryophytes as bio-indicators or as monitoring organisms may encourage the protection of other bryophyte species or bryophyte habitats, or both. The presence of epiphyllous liverworts, for example, can indicate a high atmospheric humidity in primary forests and, indirectly, the probable existence of pristine and highly diverse plant and animal communities (Pócs 1991). Thus, the quality of an ecosystem can, to some extent, be estimated by studying the composition of the local bryophyte flora.

7.2.3 Keystone species

The use of “keystone” species (Given 1994) may be another useful strategic approach. A keystone species is one on which many other species depend for their survival, the disappearance of which would, therefore, lead to the disappearance of a range of other species. This could be a tree species that usually function, as a substrate to threatened mosses and liverworts.

7.3 Legal instruments

Very few international legal instruments or conventions can be applied directly to bryophyte protection. A major principle of the 1992 United Nations Convention on Biological Diversity is to protect the natural habitats of species (Synge 1995). Those countries that have ratified this Convention must prepare and implement national strategies and conservation plans. Bryophytes should be included in the biodiversity strategy of each country, and Red Lists for plants have been used with some success as a tool to highlight bryophyte conservation in some European countries. However, compared to the resources that some countries direct to the protection of rare animal species, the funds allocated to bryophyte habitat protection are minimal. Recently, the Convention on the Conservation of European Wildlife and Natural Habitats, 1979 (The Berne Convention) has produced a list of bryophyte species that require protection. This list has been adopted by the European Union and is to receive protection as part of the Habitats Directive. There is now hope that, in Europe, bryophytes will be increasingly recognised as an important part of the environment and worthy of protection in their own right.

Recommendations

The following recommendations are based upon the information provided in the previous chapters of this Action Plan. Recommendations cover three specific areas:

1. Fieldwork and research.
2. Planning and development.
3. Increasing bryophyte awareness amongst conservation organisations and the general public.

1. Additional fieldwork and research is required to:

- establish which bryophyte sites require increased levels of protection;*
- determine which species and habitats are threatened;
- distinguish between species that are naturally rare, and those that are truly threatened;
- determine the impacts of anthropogenic disturbances (agriculture, forestry, and other forms of land use) on bryophytes, so that appropriate conservation measures can be implemented to minimise these impacts;
- establish the taxonomy, global distribution, and habitat preferences of bryophytes;
- determine which species are truly endemic;
- identify those species that are unable to survive in habitats that have been disturbed or altered by human activity; and
- develop a system that identifies threatened sites before the habitat is altered, and informs the relevant conservation authorities. This will involve partnerships between the statutory and voluntary sectors, and require the use of hot spot and habitat surveys, and satellite image analysis.

2. In order to ensure that bryophyte conservation is considered in governmental and non-governmental daily decision making:

- bryophyte conservation should be incorporated into current and future land-planning procedures and management practices;
- bryophyte conservation should be integrated into current economic or development activities, or both; and

- conservationists must develop the capacity to operate proactively with both government and non-government officials and departments *before* species and habitats are threatened with eradication or extinction, or both.

3. In order to increase bryophyte conservation awareness amongst conservation organisations and the general public:

- bryologists must increase their current level of communication with conservation bodies and provide them with further information (where available) on the distribution, biology, and ecology of bryophytes. More areas with particularly sensitive species, and those with important conservation value, must be reported by bryologists to the appropriate conservation agencies and political authorities;
- conservation organisations must supply bryologists with necessary information so that they may undertake effective research;
- both conservation organisations and bryologists should utilise current developments in information technology and communication systems to increase dialogue between one another;
- bryologists must communicate relevant bryophyte information, including that outlining the main threats, to appropriate education and environmental centres; *
- conservation campaigns that focus on areas where bryophytes are threatened must include bryologists; *
- the importance of bryophytes for humans and ecosystems must be emphasised; and
- general public awareness and interest can be raised through the publication of user-friendly and illustrated bryophyte manuals and field-guides.

* denotes priority projects

References

- Abolina, A. 1994. Latvijas retas un Aizsargajamas sunas. *Vides Aizsardziba Latvija* 6: 1–24. Riga.
- Adamek, W. 1976. Introductory report on oncostatic and therapeutic nature of the peat preparation in human neoplastic disease. Pp. 417–429 In: *Proc. 5th Intern. Peat Congress, Poznan, Poland. September 21–25, 1976. Vol.1. Peat and Peatlands in the Natural Environment Protection*. Wydawnictwa Czasopism Technicznych Not. Warsaw, Poland.
- Akeroyd, A. 1995. A Downtrodden Community. *Plant Talk*. 2: 3.
- Allen, B. 1994. Moss Flora of Central America. Part 1. *Monographs in Systematic Botany* 49: 1–242.
- Amakawa, T. 1963. New or little known Asiatic species of the family Jungermanniaceae I. *Journal of the Hattori Botanical Laboratory* 26: 20–26.
- Ando, H. 1983. Use of bryophytes in China 1. *Proceedings of the Bryological Society of Japan. Tokyo* 3: 104–106.
- Ando, H. and Matsuo, A. 1984. Applied Bryology. Pp. 133–224 In: Schultze-Motel W. (Ed.). *Advances in Bryology* 2. J. Cramer, Vaduz.
- Anonymous. 1988. *Tadzhikistan Red Data Book. The list of rare and threatened bryophyte species included in the SSR Red data Book*. Dushanbe, Donish.
- Anonymous. 1996. Bryophytes of the Red Book of Ukraine. 2nd Edition. In: Shelyak-Sosonka Y.R. *Chervona Kniga Ukrainy – Roslinnyy Svit [Red data book of Ukraine – Plant Kingdom]* Ukrainskaya Enciklopedia, Kiev.
- Argent, G.C.G. 1973. A taxonomic study of African Pterobryaceae and Meteoraceae. I. Pterobryaceae. *Journal of Bryology* 7: 353–378, 563–602.
- Aronsson, M., Hallingbäck, T. and Mattsson, J.-E. (Eds) 1995. *Rödlistade växter i Sverige 1995 (Swedish Red Data Book of Plants 1995)*. ArtDatabanken, Uppsala.
- Baillie, J. and Groombridge, B. (Eds). 1996. *1996 IUCN Red List of Threatened Animals*. IUCN, Gland, Switzerland.
- Balevicius, K. (Ed.) 1992. *Lietuvos raudonoji knyga [Red Data Book of Lithuania]*. Lietuvos Respublikos aplinkos apsaugos departamentas, Vilnius.
- Banerjee, R.D. 1974. *Studies on antibiotic activity of bryophytes and pteridophytes*. Ph.D. Thesis. University of Kalyani, Kalyani, India.
- Bardunov, L.V., Matskevitch, N.V. and Filin, V.R. 1984. *The USSR Red Data Book: rare and endangered plant and animal species*. 2. Krasnaja Kniga CCCP, Moscow.
- Bartram, E.B. 1939. Mosses of the Philippines. *Philippine Journal of Science*. Manila 68: 1–437.
- Bartram, E.B. 1949. Mosses of Guatemala. *Fieldiana, Botany* 25: 1–442.
- Beever, J., Allison, K.W. and Child, J. 1992. *The mosses of New Zealand*. 2nd Edition. University of Otago Press. Dunedin, New Zealand.
- Belland, R.J. 1997. Status report of the apple moss *Bartramia stricta* Brid., in Canada. COSEWIC Report.
- Belland, R.J. 1998. *The Rare Mosses of Canada – A review and first listing*. COSEWIC, Ottawa.
- Benson, C.S. 1986. Problems of air quality in local Arctic and sub-Arctic areas, and regional problems of Arctic haze. Pp. 69–84 In: Stonehouse, B. (Ed). *Arctic Air Pollution*. Cambridge University Press, Cambridge.
- Bentley, B.I. and Carpenter, E.J. 1984. Direct transfer or newly-fixed nitrogen from free-living epiphyllous microorganisms to their host plant. *Oecologia (Berlin)* 63: 52–56.
- Bisang, I. and Urmi, E. (Eds) 1995. Conservation of Bryophytes in Europe. *Cryptogamica helvetica* 18: 193.
- Bischler, H. 1962. The genus *Calypogeia* Raddi in Central and South America I. *Candollea* 18: 19–51.
- Bischler, H. 1964. Le genre *Drepanolejeunea* Steph. en Amérique Centrale et Méridionale. *Revue Bryologique et Lichénologique* 33: 15–179.
- Bischler, H. 1969. Le genre *Leptolejeunea* (Spruce) Steph. en Amérique. *Nova Hedwigia* 17: 265–462.
- Bischler, H. 1970. Les espèces du genre *Calypogeia* sur le continent africain et les îles africaines. *Revue Bryologique et Lichénologique* 37: 63–134.
- Bischler, H., Boisselier-Dubayle, M. C. and Pant, G. 1994. On *Aitchisoniella* Kash. (Marchantiales). *Cryptogamie, Bryologie et Lichénologie* 15: 103–110.
- Bizot, M. 1974. Enumeratio muscorum novarum. *Revue Bryologique et Lichénologique* 40: 101–138.
- Blom, H.H. and Holten J.I. 1988. *Plagiochila norvegica*, a new hepatic from West Norway. *Lindbergia* 14: 8–11.
- Bouman, A.C. and Dirkse, G.M. 1992. The genus *Radula* in Macaronesia. *Lindbergia* 16: 119–127.
- Bouman, A.C., Dirkse, G.M. and Yamada, K. 1988. *Radula jonesii* spec. nov. (Hepaticae) a new species from Tenerife. *Journal of Bryology* 15: 161–164.
- Bubier, J., Moore, T. and Juggins, S. 1995. Predicting methane emission from bryophyte distribution in northern Canadian peatlands. *Ecology* 76: 677–693.
- Buck, W.R. 1981. A re-interpretation of the Fabroniaceae, III: *Anacamptodon* and *Fabronidium* revisited, *Mamillariella*, *Helicodontiadelphus* and *Bryobartlettia* gen. nov. *Brittonia* 33: 473–481.

- Buck, W.R. 1989. Why are there so few mosses on tepui summits? Pp. 46–51. In: Herben, T. and McQueen, C.B. (Eds). *Proceedings of the Sixth Meeting of the Central and East European Bryological Working Group (CEBWG). Liblice, Czechoslovakia, 12–16 September, 1988. Prague.* One table.
- Buck, W.R. 1998. Pleurocarpous Mosses of the West Indies. *Memoirs of The New York Botanical Garden*. 82: 1–400.
- Bykov, B.A. 1979. On quantitative estimate of endemism. Boran. Mater. Gerb. Inst. *Botanicheskije Materialy Gerbariya Botanicheskogo Instituta Botaniki Akademii Nauk Kazakhskoi SSR AlmaAta* 11: 3–8.
- Bykov, M.F. 1981. In: Bijashev, G.S. and Bajtenov, M.S. (Eds) *Red Data Book of Kazakh SSR. Rare and endangered species of animals and plants. Part 2. Plants.* Nauka, Alma-Ata. 260pp
- Campbell, D.H. 1896a. A new California liverwort. *Botanical Gazette* 21: 9–13.
- Campbell, D.H. 1896b. The development of *Geothallus tuberosus* Campbell. *Annals of Botany* 10: 489–510.
- Cardot, J. 1905. Deux genres nouveaux de mousses acrocarpes. *Revue Bryologique. Caen*. 32: 45–47.
- Cardot, J. 1908. La flore bryologique des Terres Magellaniques, de la Géorgie du Sud et de l'Antarctide. *Wissenschaftliche Ergebnisse der Schwedischen Sudpolar-Expedition 1901–1903 unter Leitung von Dr. Otto Nordenskjöld* 4(8): 298.
- Casas, C., Brugués, M., Cros, R. M. and Sérgio, C. 1989. *Cartografia de Briòfits Península Ibérica i les Illes Balears, Canàries, Açores i Madeira* [Bryophyte cartography of the Iberian Peninsula, Balearic and Canary Islands, Azores and Madeira] Fasc. II: pp. 51–100. Institut d'Estudis Catalans, Barcelona.
- Caughley, G. 1994. Directions in conservation biology. *Journal of Animal Ecology* 63: 215–244.
- Chang, K.-C. and C. Gao 1984. Plantae novae hepaticarum sinarum. *Bulletin of Botanical Research* 4(3): 83–99.
- Christy, J.A. and Wagner, D.H. 1996. *Guide for the identification of rare, threatened or sensitive bryophytes in the range of the northern spotted owl, Western Washington, Western Oregon, and Northwestern California.* Bureau of Land Management, Oregon-Washington State Office, Portland, Oregon.
- Churchill, S.P. 1985. The systematics and biogeography of *Scouleria* Hook. (Musci: Scouleriaceae). *Lindbergia* 11(1): 59–71.
- Churchill, S.P. 1986. A revision of *Echinodium* Jur. (Echinodiaceae: Hypnobryales). *Journal of Bryology* 14: 117–133.
- Churchill, S.P. 1987. Systematics and biogeography of *Jaffueliobryum* (Grimmiaceae). *Memoirs of the New York Botanical Garden* 45: 691–708.
- Churchill, S.P. 1992. Clarification and review of *Lepidopilum affine* and *L. grevilleanum* (Callicostaceae). *Brittonia* 44: 350–355.
- Churchill, S.P. 1994. The Mosses of Amazonian Ecuador. Dept. of Systematic Botany, University of Aarhus. *AAU Reports* 35: 1–211.
- Churchill, S.P. and E. L. Linares C. 1995. *Prodromus Bryologiae Novo-Granatensis. Biblioteca 'José Jeronimo Triana'* 12: pp. 1–924. Santafé de Bogotá, Colombia.
- Clymo, R. S. 1970. The growth of *Sphagnum*: methods of measurement. *Journal of Ecology* 58: 13–49.
- Coker, P.D. 1967. The effects of sulphur dioxide pollution on bark epiphytes. *Trans. Brit. Bryol. Soc.* 5: 341–347.
- Corley, M.F.V. and Crundwell, A.C. 1991. Additions and amendments to the mosses of Europe. *Journal of Bryology* 16: 337–356.
- Corley, M.F.V., Crundwell, A.C., Düll, R., Hill, M.O. and Smith, A.J.E. 1981. Mosses of Europe and the Azores; an annotated list of species, with synonyms from the recent literature. *Journal of Bryology* 11: 609–689.
- Cortini, C. and Aleffi, M. 1993. Lista rossa delle briofite d'Italia. Pp. 559–637 In: Conti, F., Manzi, A. and Pedrotti, F. *Libro rosso delle piante d'Italia.* W.W.F., Roma.
- Crum, H.A. and Anderson, L.E. 1981. *Mosses of Eastern North America.* Two volumes. Columbia Univ. Press, New York. 1328pp.
- Crundwell, A.C., Greven, H.C. and Stern, R. C. 1994. Some additions to the bryophyte flora of the Azores. *J. Bryol.* 18: 329–337.
- D'Hennezel, F. and Coupal, B. 1972. Peat moss: A natural absorbant for oil spills. *CIM Bull.* 65 (717): 51–53.
- Damsholt, K. and Hallingbäck, T. 1987. *Riccia gothica*, a new species of hepaticae from Sweden. *Lindbergia* 12: 100–102.
- DäSSLER, H.G. and Ranft, H. 1969. Das Verhalten von Flechten und Moosen unter Einfluss einer Schwefeldioxid-begasung. *Flora, Abt. B*, 1958. Pp. 454–461.
- De Zuttere, Ph. and Schumacker, R. 1984. Bryophytes nouvelles, méconnues, rares, menacées ou disparues de Belgique. *Ministère de la Région Wallonne Travaux*. 13: 160+1pp. Nine figures and 40 maps.
- Delgadillo, M.C. 1994. Endemism in the Neotropical moss flora. *Biotropica* 26(1): 12–16.
- Ding, H. 1982. *Medicinal spore-bearing plants of China.* Shanghai Scientific Publisher, Shanghai. 409pp.
- Dirkse, G.M., Bouman, A.C. and Losada-Lima, A. 1993. Bryophytes of the Canary Islands, an annotated checklist. *Cryptogamie, Bryologie-Lichénologie* 14: 1–47.
- Dixon, H.N. 1935. A contribution to the moss flora of Borneo. *Journal of the Linnean Society. Botany* 50: 57–140.

- Doyle, W.T. 1962. The morphology and affinities of the liverwort *Geothallus*. *University of California Publications, Botany* 33: 185–268.
- Doyle, W.T. 1998. Liverworts and Hornworts of the Santa Rosa Plateau Ecological Reserve, Riverside County, California. *Evansia* 15: 122–124.
- Drehwald, U. 1995. Epiphytische Pflanzengesellschaften in NO-Argentinien. *Dissertationes Botanicae*, Bd. 250. Anh. J. Cramer, Berlin. 175pp.
- Druzhinina, O.A. 1984. Mochoobrasnye [Bryophytes]. Pp. 23–24 In: Bardonov, L.V., Matskevitch, N.V. and Filin, V.R. *USSR Red Data Book. Part 2*. All-Unios Research Inst. of Nature Conservation and Reserves. Sadki-Znamenskoye, Moscow.
- During, H. J. 1992. Ecological classifications of bryophytes and lichens. Pp. 1–31 In: Bates, J. W. and Farmer, A. M. (Eds). *Bryophytes and lichens in a changing environment*. Clarendon Press, Oxford.
- ECCB. 1995. *Red Data Book of European Bryophytes*. European Committee for Conservation of Bryophytes (ECCB), Trondheim.
- Eddy, E. 1977. Sphagnales of tropical Asia. *Bulletin of the British Museum (Natural History). Botany* 5: 1–445.
- Eldridge D.J. 1993. Cryptogam cover and soil surface condition: effects on hydrology on a semiarid woodland soil. *Arid Soil Research and Rehabilitation* 7 (3): 203–217.
- Empain, A., Lambinon, J., Mouvet, C. and Kirchmann, R. 1980. Utilisation des bryophytes aquatiques et subaquatiques comme indicateurs biologiques de la qualité des eaux courantes. Pp. 195–223 In: P. Pessen. *La Pollution des eaux continentales: incidence sur les biocénoses aquatiques*. Gauthier-Villars, Paris. Fifteen figures and two tables.
- Engel, J.J. 1972. Falkland Island Hepaticae and Anthocerotae: a taxonomic and phytogeographic study. Mich. St. Univ. Ph.D Thesis. Ann Arbor. (issued 1978). 608pp.
- Enroth, J. 1994. A taxonomic monograph of the genus *Pinnatella* (Neckeraceae, Bryopsida). *Acta Botanica Fennica* 151: 1–90.
- Enroth, J. 1995. Commentary on the moss genus *Flabellidium* (Brachytheciaceae). *Fragmenta Floristica Geobotanica* 40: 743–747.
- Enroth, J. and R. E. Magill 1994. *Neckeropsis pocsii* (Neckeraceae, Musci), a new species from Comoro Islands. *Bryologist* 97: 171–173.
- Florschütz, P.A. 1964. Musci (Part I). *Flora of Suriname VI*. E.J. Brill, Leiden. Pp. 1–272.
- Florschütz-de Waard, J. 1986. Musci (Part II). *Flora of Suriname VI*. E.J. Brill, Leiden. Pp. 273–361.
- Florschütz-de Waard, J. 1996. Musci (Part III). *Flora of the Guianas* (Flora of Suriname VI). Kew Gardens, U.K.
- Flowers, S. 1957. Ethnobotany of the Gosiute Indians of Utah. *Bryologists* 60: 11–14.
- Flowers, S. 1961. *The Hepaticae of Utah*. University of Utah Biol. Ser. 12 (2): 1–89. Plates 1–18.
- Flowers, S. 1973. *Mosses: Utah and the West*. Brigham Young University Press, Provo, Utah. xii + 567pp.
- Francez, A. and Vasander, H. 1995. Peat accumulation and peat decomposition after human disturbance in French and Finnish mires. *Acta Oecologica* 16: 599–608.
- Frisvoll, A.A. and Blom, H.H. 1992. Trua moser i Norge med Svalbard; raud liste. *Nina Utredning* 42: 1–55.
- Frisvoll, A.A. and Blom, H.H. 1997. Trua moser i Noreg med Svalbard. Førebelse ark. *NTNU, Vit.-mus., Bot. Notat* 1997(3): 1–170.
- Frisvoll, A.A., Elvebakk, A. Flatberg, K.I. and Ökland, R. H. 1995. Checklist of Norwegian bryophytes. Latin and Norwegian nomenclature. *NINA Temahefte* 4: 1–104.
- Frye, T.C. and Clark, L. 1937. *Hepaticae of North America*. Publications in Biology Part I, Vol. 6, No. 1 (University of Washington). The Press, Washington. 162pp.
- Fulford, M. 1963–1976. Manual of the Leafy Hepaticae of Latin America. Parts I–IV. *Memoirs of the New York Botanical Garden* 11(1): 1–172, 1963; 11(2): 173–276, 1966; 11(3): 277–392, 1968; 11(4): 395–535, 1976.
- Fulford, M. and Sharp, A. J. 1990. The leafy Hepaticae of Mexico: one hundred and twenty-seven years after C. M. Gottsche. *Memoirs of the New York Botanical Garden* 63: 1–86.
- Futschig, J. 1954. *Distichophyllum carinatum* Dixon et Nicholson in den Allgäuer Alpen. *Berichte der Bayerischen Botanischen Gesellschaft zur Erforschung der Heimischen Flora* 30: 15–18.
- Gamundi, I.J. and Matteri, C.M. 1998. La problemática de la conservación en las criptógamas avasculares. In: Bacigalupo, N. and Fortunato, R. (Eds). *Proceedings of the VI Congreso Latinoamericano de Botánica 1994*. St. Louis, USA. Monogr. Systematic Botany Miss. Bot. Garden 68: 287–299. Gao, C. and Chang, K. C. 1981. *Flora hepaticarum Chinae boreali-orientalis*. Science Publisher, Peking. 220pp.
- Gao, C. and T. Cao. 1988. A study of *Trichocolea* Dum., *Trichocoleopsis* Okam. and *Netotrichocolea* Hatt. (Hepaticae) in China. *Investigatio et studium naturae* 8: 24–37.
- Gärdenfors, U. 1996. Application of IUCN Red List Categories on a Regional Scale. Pp. 63–70 In: Baillie, J. and Groombridge, B. (Eds) *1996 IUCN Red List of Threatened Animals*. IUCN, Cambridge.
- Gärdenfors, U., Rodríguez, J.P., Hilton-Taylor, C., Hyslop, C., Mace, G., Molur, S. and Poss, S. 1999. Draft Guidelines for the Application of IUCN Red List Criteria at National and Regional Levels. *Species* 31–32: 58–70.

- Garushjants, K.J., Druzhinia, O.A., Mamedova, E.T., Matskevich, N.V., Novak, O.G., Petrova, M.M., Semansko, A.J. and Usacheva, I.S. 1989. *List of species of cryptogam plant and fungi which are recommended for the new USSR Red Datas Book*. Sovremennye problemy Krasnoj knigi SSSR, Moscow.
- Geissler, P. and Greene, S.W. (Eds) 1982. Bryophyte taxonomy methods, practices and floristic exploration. *Proceedings of the International Association of Bryology Taxonomy Workshop Meeting, Genève 27 Aug – 2 Sept 1979*. J. Cramer, Vaduz.
- Given, D.R. (Ed.) 1994. *Principles and Practice of Plant Conservation*. Chapman and Hall, London. 281pp.
- Glenny, D. 1998. A revised checklist of New Zealand liverworts and hornworts. *Tuhinga* 10: 119–149.
- Glime, J.M. and Saxena, D. 1991. *Uses of bryophytes*. Today and Tomorrow's Printers and Publishers, New Delhi.
- Gradstein, S.R. 1974. Studies on Lejeuneaceae subfam. Ptychanthoideae (Hepaticae) II. Two remarkable species of *Caudalejeunea*: *C. grolleana* spec. nov. and *C. cristiloba* (Steph.) comb. nov. *Acta Botanica Neerlandica* 23: 333–343.
- Gradstein, S.R. 1989. A key to the Hepaticae and Anthocerotae of Puerto Rico and the Virgin Islands. *Bryologist* 92: 329–348.
- Gradstein, S.R. 1991. Diversity and distribution of Asian Lejeuneaceae subfamily Ptychanthoideae. *Tropical Bryology* 4: 1–16.
- Gradstein, S.R. 1992a. The vanishing tropical rain forest as an environment for bryophytes and lichens. Pp. 234–258 In: Bates, J. W. and Farmer, A. M. (Eds). *Bryophytes and lichens in a changing environment*. Clarendon Press, Oxford.
- Gradstein, S.R. 1992b. Threatened bryophytes of the neotropical rain forest: a status report. *Tropical Bryology* 6: 83–93.
- Gradstein, S.R. 1992c. On *Thysananthus*, *Dendrolejeunea*, and *Fulfordianthus* gen. nov. *Bryologist* 95: 42–51.
- Gradstein, S.R. 1994. Lejeuneaceae: Ptychantheae, Brachiolejeuneae. *Flora Neotropica Monograph* 62: 1–225.
- Gradstein, S.R. 1999a. Checklist of páramo plants: Hepatics. Pp. 65–73 In: Luteyn, J.L. (Ed.). *Páramos: A checklist of plant diversity, geographical distribution, and botanical literature*. *Memoirs of the New York Botanical Garden*. 84: New York Botanical Garden, New York.
- Gradstein, S.R. 1999b. On the rediscovery of *Spruceanthus theobromae* (Lejeuneaceae, Hepaticae), an endangered bryophyte of cacao trees in western Ecuador. *Bryobrothera* 5: 81–86.
- Gradstein, S.R. and van Beek, J. 1985. A revision of the genus *Symbiezidium* Trevis. *Beihefte zur Nova Hedwigia* 80: 221–249.
- Gradstein, S.R., Churchill, S.P. and Salazar Allen, N. 1999c. A Guide to the Bryophytes of Tropical America. *Memoirs of the New York Botanical Garden*. 86. New York Botanical Garden, New York.
- Grassi, M.M. 1976. Notas de Clase Bryophyta II. Parte Especial. *Miscelanea* 55: 193–255.
- Greene, D.M. 1986. *A conspectus of the mosses of Antarctica, South Georgia, the Falkland Islands and Southern South America*. Brit. Ant. Survey, Cambridge. Pp. 1–314.
- Greven, H.C. 1992. *Changes in the Dutch bryophyte flora and air pollution*. Diss. Bot. J. Cramer, Berlin, Germany.
- Greven, H.C. 1993. Proposal for a red data list of European *Grimmia* species. *Cryptogamie, Bryologie Lichénologie* 14: 401–404.
- Grims, F. 1986. Rote Liste gefährdeter Laubmoose (*Musci*) Oesterreichs. Pp. 138–151 In: Nikfelt, H. (Ed.). Rote Liste gefährdeter Pflanzen Oesterreichs. *Grüne Reihe, Bundesminist. Gesundh. and Umweltschutz* 5. Wien, Germany.
- Grolle, R. 1966. Die Lebermoose Nepals. Khumbu Himal. *Ergebnisse des Forschungsunternehmens Nepal Himalaya* 1: 262–298.
- Grolle, R. 1968. Monographie der Gattung *Nowellia*. *Journal of the Hattori Botanical Laboratory* 31: 20–49.
- Grolle, R. 1971. Jamesoniella und Verwandte. *Feddes Report*. 82: 1–100.
- Grolle, R. 1983. Hepatics of Europe including the Azores: an annotated list of species, with synonyms from the recent literature. *Journal of Bryology* 12: 403–459.
- Grolle, R. 1985. *Cololejeunea schaeferi* spec. nov., ein verkanntes Lebermoos in Makaronesien. *Journal of Bryology* 13: 487–495.
- Grolle, R. 1995. Catalogue of the Hepaticae and Anthocerotae of the East African Islands. An Annotated Catalogue. *Bryophytorum Bibliotheca. Lahre, Vaduz*. 48: 1–178.
- Grolle, R. and Gradstein, S. R. 1988. *Haesselia*, a new genus of Cephaloziaceae (Hepaticae) from Mt Roraima, Guyana. *Journal of the Hattori Botanical Laboratory* 64: 327–334.
- Grolle, R. and Persson, H. 1966. Die Gattung *Tylimanthus* auf den Atlantischen Inseln. *Svensk Botanisk Tidskrift* 60: 164–174.
- Guerra, J., Martinez, J.J. and Ros, R.M. 1992. On the degree of adaptation of the moss flora and vegetation in gypsiferous zones of the south-east Iberian Peninsula. *Journal of Bryology* 17: 133–142.
- Hallingbäck, T. 1991. Mossor som indikerar skyddsvärd skog [Bryophytes indicating high nature conservation values in Swedish woodland sites]. *Svensk Botanisk Tidskrift Utgifven af Svenska Botaniska Foreningen Stockholm* 85: 321–332.
- Hallingbäck, T. 1995. The practice of bryophyte conservation. *Cryptogamica Helvetica. Geneva, Teufen* 18: 119–130.

- Hallingbäck, T. 1998. Rödlistade mossor i Sverige – ArtFakta. [Swedish Red Data Book of Bryophytes]. Swedish Threatened Species Unit, SLU, Uppsala. 328pp.
- Hallingbäck, T., Hodgetts, N., Raeymaekers, G., Schumacker, R., Sérgio, C., Söderström, L., Stewart, N. and Våða, J. 1998. Guidelines for application of the revised IUCN threat categories to bryophytes. *Lindbergia* 23: 6–12.
- Hasegawa, J. 1980. Taxonomical studies on Asian Anthocerotae II. Some Asian species of *Dendroceros*. *Journal of the Hattori Botanical Laboratory* 47: 287–309.
- Hässel, G.G. 1964. Nota sobre la flora briológica del Uruguay (Hepáticas). *Revista del Museo Argentino de Ciencias Naturales “Bernardino Rivadavia” e Instituto Nacional de Investigación de la Ciencias Naturales: Ciencias Botánicas* (2): 141–160.
- Hässel, G.G. 1998. Avances en taxonomía de Hepatophyta y Anthocerothophyta Austrosudamericanas. Proceedings of the VI Congreso Latinoamericano de Botánica 1994. *Monographs in Systematic Botany from the Missouri Botanical Garden* 68: 87–100.
- Hässel, G.G. and Solari, S.S. 1985. Catálogo de las hepáticas. Pp. 299–342 In: Boelcke, O., Moore D. M. and Roig F.A. (Eds). *Transecta botánica de la Patagonia Austral*. CONICET, Buenos Aires.
- Hattori, S. 1968. Résultats des expéditions scientifiques genevoises au Népal en 1952 et 1954 (partie botanique) 20. Hepaticae. *Candollea* 23: 275–285.
- Hattori, S. 1972. *Frullania tamarici*-complex and the species concept. *Journal of the Hattori Botanical Laboratory* 35: 202–251.
- Hattori, S. 1975. Anthocerotae and Hepaticae. Pp. 206–242 In: Ohashi, H. (Ed.). *Flora of Eastern Himalaya. Third Report*. Bulletin University Museum, University of Tokyo, Japan.
- Hattori, S., Sharp, A. J., Mizutani, M. and Iwatsuki, Z. 1968. *Takakia ceratophylla* and *T. lepidozoides* of Pacific North America and a short history of the genus. *Miscellanea Bryologica et Lichenologica* 4: 137–149.
- Haynes, C.C. 1910. *Sphaerocarpus hians* sp. nov., with a revision of the genus and illustrations of the species. *Bulletin of the Torrey Botanical Club* 37: 215–230.
- Hedenäs, L. 1992. Flora of Madeiran pleurocarpous mosses (Isobryales, Hypnobryales, Hookeriales). *Bryophytorum Bibliotheca. Lahre, Vaduz* 44: 1–165.
- Henderson, A., Churchill, S.P. and Luteyn, J.L. 1991. Neotropical Plant Diversity. *Nature* 351: 21–22.
- Herter, G. 1933a. Florula Uruguayas plantae avasculares. Pp. 7–84 In: Herter, G. (Ed.). *Ostenia*. W.G. Herter, Montevideo.
- Herter, G. 1933b. Las Plantas Uruguayas de E. Gibert. Nomenclator Gibertianus II. Pp. 153–171 In: Herter, G. (Ed.). *Ostenia*. W.G. Herter, Montevideo.
- Herzog, T. 1926. *Geographie der Moose*. G. Fischer, Jena.
- Herzog, T. 1938. *Sphaerolejeunea*, eine neue Gattung der Lejeuneaceae Schizostipae. *Annales Bryologici* 11: 86–89.
- Herzog, T. 1952. *Personiella* Herz. nov. gen. Hepaticarum. *Arkiv for Botanik Utgivet av k. Svenska Vetenskapsakademien* 2(4): 265–269.
- Hewson, H.J. 1982. Vandiemeniaceae: a new family in Metzgeriales. *Journal of the Hattori Botanical Laboratory* 52: 163–165.
- Hill, M.O., Collins, B. and Edwards, B. 1998. *Plagiochila norvegica* (Hepaticae) in southern England, newly recorded for the British Isles. *Journal of Bryology* 20: 121–126.
- Hill, M.O., Preston, C.D. and Smith, A.J.E. 1991. *Atlas of the bryophytes of Britain and Ireland. Vol. 1. Liverworts (Hepaticae and Anthocerotae)*. Harley Books, Colchester. 351pp.
- Hirota, J. 1981. *Bonkei: Tray landscapes*. Kodansha International, Tokyo. 128pp.
- Hodgetts, N.G. 1992. Measures to protect Bryophytes in Great Britain. *Biological Conservation* 59: 259–264.
- Hodgetts, N.G. 1996. Threatened Bryophytes in Europe. *Anales del Instituto de Biología de la Universidad Nacional Autónoma de México, Serie Botánica* 67(1): 183–200.
- Hodgetts, N.G. and Blockeel, T.L. 1992. *Thamnobryum cataractarum*, a new species from Yorkshire, with observation on *T. angustifolium* and *T. fernandesii*. *Journal of Bryology* 17: 251–262.
- Hodgetts, N.G. and Stark, G. 1995. A bryophyte site register for Britain conservation and protected sites database at JNCC and the occurrence of threatened species on nature reserves. *Cryptogamica Helvetica. Geneva, Teufen* 18: 135–143.
- Hofstede, R.J.M., Wolf, J.H.D. and Benzing D.H. 1993. Epiphytic biomass and nutrient status of a Colombian upper montane rain forest. *Selbyana* 14: 37–45.
- Holdgate, M.W. 1991. Conservation in a world context. Pp. 1–26 In: Spellerberg I.F., Goldsmith F.B., and Morris M.G. (Eds). *The Scientific Management of Temperate Communities*. Blackwell Science, Southampton.
- Hong, W.S. 1987. The distribution of western North American Hepaticae. Endemic taxa and taxa with a North Pacific arc distribution. *Bryologist* 90: 344–361.
- Howe, M.A. 1899. The Hepaticae and Anthocerotae of California. *Memoirs of the Torrey Botanical Club* 7: 1–208.
- Hunter, M.L. and Hutchinson, A. 1994. The Virtues and Shortcomings of Parochialism: Conserving Species that are Locally Rare, but Globally Common. *Conservation Biology* 8: 1163–1165.
- Hürlimann, H. 1978. Hepaticae aus dem gebiete des südlichen Pazifik. VI. *Bauhinia* 6: 293–305.

- Hyvönen, J., Koponen, T. and Norris, D.H. 1987. Human influence on the moss flora of tropical rain forest in Papua New Guinea. *Symposia Biologica Hungarica. Budapest* 35: 621–629.
- Ignatov, M.S. and Czerdantseva, V.Y. 1995. The families Cryphaeaceae, Leucodontaceae and Leptodontaceae (Musci) in Russia. *Arctoa* 4: 65–104.
- Ingerpuu, N. 1998. Samblad, *Bryophyta*. Pp. 37–48 In: *Eesti Punane Raamat. Ohustatud seened, taimed ja loomad [Red Data Book of Estonia. Threatened Fungi, Plants and Animals]*. Lilleleht, V. (Ed.). Eesti Teaduste Akadeemia. Looduskaitse Komisjon, Tartu.
- Inoue, H. 1974. *Illustrations of Japanese Hepaticae I*. Tsukiji Shokan Publ. Co. Tokyo, Japan.
- Inoue, H. 1987. Notes on the Plagiochilaceae, XIV. New species of *Plagiochila* (Dum.) Dum. from the neotropics. Pp. 95–105 In: Inoue, H. (Ed.). *Studies on Cryptogams in Southern Peru*. Tokai Univ. Press, Tokyo.
- Ireland, R.R. 1974. *Neomacounia*, a new genus in the Neckeraceae (Musci) from Canada. *Bryologist* 77: 453–459.
- Ishikawa, I. 1974. Bryophytes in Japanese gardens (2) *Hikobia* 7: 65–78.
- Isomura, K., Higuchi, M., Shibata, H., Tsukada, H., Iwashima K. and Sugiyama, H. 1993. Distribution of radioactive caesiums in mosses and application of mosses for monitoring of radioactive caesiums. *Radioisotopes* 42: 157–163.
- IUCN 1978. *The IUCN Plant Red Data Book*. IUCN, Richmond.
- IUCN 1994. *IUCN Red List Categories*. IUCN, Gland.
- Iwatsuki, Z. 1986. A peculiar New Caledonian *Sphagnum* with rhizoids. *Bryologist* 89: 20–22.
- Jeglum, J.K. 1971. Plant indicators of pH and water level in peatlands at Candle Lake, Saskatchewan. *Canadian Journal of Botany* 49: 1661–1676.
- Jelenc, F. 1950. Muscinées de l'Afrique du Nord (suite). *Bulletin de la Société de Géographie et d'Archéologie de la Province d'Oran* 73: 59–89.
- Jóhannsson, B. 1983. A list of Icelandic bryophyte species. *Acta Naturalist. Islandica* 30: 1–29.
- Jóhannsson, B. 1996. Mosar. Pp. 49–69 In: Válisti I, Plöntur. *Náttúrufræðistofnun Íslands. Red Data List (1) Plants*. Icelandic Natural History Institute, Reykjavík. Pp. 1–82.
- Jones, E.W. 1974. African Hepatics XXVI. The *Lejeunea eckloniana* complex. *J. Bryology* 8: 77–92.
- Jones, E.W. 1981. African Hepatics XXXII. *Journal of Bryology* 11: 311–323.
- Jones, E.W. and Rose, F. 1975. *Plagiochila atlantica* F. Rose, sp. nov. *Journal of Bryology* 8: 417–422.
- Jovet-Ast, S. 1984. *Riccia* (subg. *Viridisquamata*) caroliniana Ne-Thalang, espèce endémique rélictuelle d'Australie. *Cryptogamie, Bryologie, Lichénologie* 5: 389–402.
- Jovet-Ast, S. 1987. Vers une classification phylogénétique des espèces du genre *Riccia*. *Bryologist* 90: 321–330.
- Karczmarz, K. 1960. The bryological characteristics of the Polish loess area. *Annales Universitatis Mariae Curie – Skłodowska. Sect.3:Biologia. Supplement. Lublin, Poland* 15: 185–209.
- Kashyap, S.R. 1929. *Liverworts of the western Himalayas and the Panjab Plain*, part 1. Lahore, 123 + 10pp.
- Keats, J. 1820. 'Ode to a nightingale'.
- Kis, G. 1985. *Mosses of South-East tropical Africa. An annotated list with distributional data*. Inst. Ecol. Bot. Hung. Acad. Sci., Vacratot. 170pp.
- Kitagawa, N. 1966. A revision of the family Lophoziaceae of Japan and its adjacent regions. II. *Journal of the Hattori Botanical Laboratory* 29: 101–149.
- Konstantinova, N.A. 1990. [Rare and endangered plant and animal species of the Murmansk region.] *Redkie nuzhdajushchiesja v ochrane rastenija i rhivotnye Murmanskoi oblasti*. Pp. 14–23, 84–87 In: L.F. Zhdanova. *Murmanskoe Knizhnoe Izdatelstvo*. Publisher unknown. Murmansk. 189pp.
- Konstantinova, N.A. and Czernjadieva, I.V. 1995. De hepaticis in regione fluxus medii fl. Sob (Ural polaris) obviis notula. *Novosti Sistematiki Vysshikh Nizshikh Rastenii. Kiev* 30: 110–121.
- Konstantinova, N.A. and Potemkin, A.D. 1994. Studies on *Scapania sphaerifera* (Hepaticae). *Annales Botanici Fennici* 31: 121–126.
- Konstantinova, N.A. and Potemkin, A.D. 1996. Liverworts of the Russian Arctic: an annotated checklist and bibliography. *Arctoa* 6: 125–150.
- Koponen, A. 1992. European-Asiatic connections in *Tayloria* (Splachnaceae, Musci). *Bryobrothera* 1: 57–62.
- Koponen, T. 1992. Endangered bryophytes on a global scale. *Biological Conservation* 59: 255–258.
- Kubinska, A, Janovicova, K. and Peciar, V. 1996. The list of extinct, missing and threatened bryophytes (Bryophyta) of Slovakia (1st version). *Biologia Bratislava* 51(4): 373–380.
- Kühnemann, O. 1938. Catálogo de los Musgos argentinos. *Lilloa* 2: 37–183.
- Kühnemann, O. 1949. Catálogo de las Hepáticas argentinas. *Lilloa* 19: 319–375.
- Lai, M.-j. 1999. The disjunctive distribution of the genus *Scapophyllum speciosum* (Jungermanniaceae, Hepaticae). *Bryobrothera* 5: 131–132.
- Lawton, E. 1971. *Moss Flora of the Pacific Northwest*. Hattori Botanical Laboratory, Nichinan, Japan. xiii + 362 pp. plates 1–195. Lee, J., Brooks, R.R. and Reeves, R.D. 1977. Chromium accumulating bryophyte from new Caledonia. *Bryologist* 80: 203–205.
- Lee, J., Brooks, R.R. and Reeves, R.D. 1977. Chromium accumulating bryophyte from New Caledonia. *Bryologist* 80: 203–205.

- Lewinsky, J. 1992. *Orthotrichum truncato-dentatum*, a species known only from extinct habitats. *Bryologist* 95: 218–220.
- Lewis, M. 1988. Use of Bryophytes as Decorations for Nativity Scenes in La Paz, Bolivia. *Bryological Times; Newsletter of the International Association of Bryologists. Utrecht, Penicuik* 46: 8–9.
- Long, D.G. and Grolle, R. 1990. Hepaticae of Bhutan II. *Journal of the Hattori Botanical Library* 68: 381–440.
- Longton, R.E. 1988. *Biology of polar bryophytes and lichens. Studies in polar research*. Cambridge University Press, Cambridge.
- Longton, R.E. 1992. The role of bryophytes and lichens in terrestrial ecosystems. Pp. 234–258 In: Bates, J. W. and Farmer, A. M. (Eds). *Bryophytes and lichens in a changing environment*. Clarendon Press, Oxford.
- Lovett, J.C. and Pócs, T. 1992. *Assessment of the Condition of the Catchment Forest Reserves*. Dar es Salaam, 362 pp. (report).
- Ludwig, G., Düll, R., Philippi, G., Ahrens, M., Caspari, S., Koperski, M., Lütt, S., Schulz, F. and Schwab, G. 1996. Rote Liste der Moose (Anthocerophyta et Bryophyta) Deutschlands. *Schr.-R. f. Vegetationskde. H.* 28. 189–306.
- Lutelyn, J.L. (Ed.) 1999. Páramos: A checklist of plant diversity, geographical distribution, and botanical literature. *Memoirs of the New York Botanical Garden* 84. New York Botanical Garden. New York.
- Löve, A. and Löve, D. 1953. Studies on *Bryoxiphium*. *Bryologist* 56: 183–199.
- Magill, R.E. 1981. *Flora of Southern Africa. Bryophyta*. Part. 1, Mosses. Fascicle 1, Sphagnales to Grimmiaceae. Botanical Research Institute, Department of Agriculture and Fisheries, South Africa.
- Mahu, M. 1979. Familias y géneros de musgos chilenos. *Bryologist* 82(4): 513–524.
- Major, J. 1988. Endemism: a botanical perspective. Pp. 117–146 In: Myers, A.A. and Giller, P. S. (Eds). *Analytical Biogeography. An integrated approach to the study of animal and plant distributions*. Chapman and Hall, London.
- Mäkinen, A. 1987. Use of *Hylocomium splendens* for regional and local heavy metal monitoring around a coal-fired power plant in southern Finland. *Symposia Biologica Hungarica. Budapest* 35: 777–794.
- Martincic, A. 1992. Rdeci seznam ogrozenih listnatih mahov (Musci) v Sloveniji (Red List of threatened mosses in Slovenia) In: *Varasto Narave* 18: 1–190. Ljubljana.
- Maschke, J. 1981. Moose als Bioindikatoren von Schwermetall Immissionen. *Bryophytorum Bibliotheca* 22. Cramer, Vaduz. 492pp.
- Matteri, C.M. 1985a. Catálogo de los musgos. Pp. 265–298 In: Boelcke, O., Moore, D. M. and Roig, F. A. (Eds). *Transecta botánica de la Patagonia Austral*. CONICET, Buenos Aires.
- Matteri, C.M. 1985b. Current State of Latin American Bryology. *Journal of the Hattori Botanical Laboratory* 59: 481–486.
- Matteri, C.M. 1986. Los Musci (Bryophyta) de las Islas Malvinas, su habitat y distribución. *Nova Hedwigia* 43(1–2): 159–189.
- Matteri, C.M. 1987. Las esporas recientes de los Musei (Bryophytes) de las tuberas de Sphagnum de Tierra del Fuego, Argentina. *Bol., Instituto de Geociencias, Universidade de Sao Paulo* 17: 109–119.
- Matteri, C.M. 1988. Distribution maps of mosses from Tierra del Fuego, Argentina. 1. *Lindbergia* 14(3): 176–178.
- Matteri, C.M. 1998. Diversidad briológica (o de cómo y por qué proteger los musgos). *Ciencia Hoy* 46(8): 30–36.
- McAdam, S.V. and Smith, A.J.E. 1981. *Brachythecium appleyardiae* sp. nov. in southwest England. *J. Bryology* 11: 591–598.
- Merrill, G.L.S. 1992. *Ozobryum ogalalense* (Pottiaceae), a new moss genus and species from the American Great Plains. *Novon* 2: 255–258.
- Meyer, F.K. and Grolle, R. 1963. Eine neue Frullania-Art aus Albanien. *Feddes Repertorium* 68: 101–107.
- Miller, H.A., Whittier, H.O. and Whittier, B.A. 1983. *Prodromus Florae Hepaticarum Polynesiae*. J. Cramer, Vaduz.
- Mizutani, M. and K.C. Chang 1986. A preliminary study of Chinese Lepidoziaceae flora. *Journal of the Hattori Botanical Laboratory* 60: 419–437.
- Mönkemeyer, W. 1927. De Laubmoose Europas. In: *Rabenhorst Kryptogamen-Flora von Deutschland, Österreich und der Schweiz. IV. Band, Ergänzungsband*. 960 pp.
- Morales, M.I. 1991. Las Hepáticas comunicadas para Costa Rica. *Tropical Bryology* 4: 25–57.
- Morat, P. 1984. Floristic relationships of New Caledonian rain forest phanerogams. Pp. 71–128 In: Radovsky, F.J. Raven, P.H. and Sohmer, S.H. (Eds). *Biogeography of the tropical Pacific*. Honolulu, Hawaii: Assoc. System. Bernice P. Bishop Museum, special pub. 72. 221pp.
- Msangi, T.H. 1990. Management of nature reserves and catchment forests in the Usambaras. Pp. 13–19 In: Hedberg, I. and Persson, E. (Eds). *Research for Conservation of Catchment Forests. Proceedings from a workshop held in Morogoro, Tanzania, March 13–17, 1989*: Reprocentralen, HSC, Uppsala 1990. (mimeographed).
- Murray, B.M. 1987. *Andreaea scholfieldiana* and *A. megistospora*, species novae, and taxonomic criteria for Sect. *Nerviae* (Andreaopsida). *Bryologist* 90: 15–26.
- Müller, K. 1951–1958. Die Lebermoose Europas. In: Dr. L. Rabenhorst's Kryptogamenflora. Band 6, 3. Auflage. Leipzig. 1365pp.
- Na-Thalang, O. 1980. A revision of the genus *Riccia* (Hepaticae) in Australia. *Brunonia* 3: 61–140.

- Nicholson, W.E., Herzog, T. and Verdoorn, F. 1930. Hepaticae. In: H. Handel-Mazzetti, *Symbolae Sinicae* 5: 1–60.
- Niebor, E. and Richardson, D.H.S. 1980. The replacement of the non descript term “heavy metals” by a biologically and chemically significant classification of metal ions. *Environmental Pollution* 113–26.
- Noguchi, A. 1991. *Illustrated Moss Flora of Japan*, Part 4. The Hattori Botanical Laboratory, Obi, Nichinan-shi, Miyazaki-ken, Japan.
- O’Shea, B.J. 1995. Checklist of the mosses of sub-Saharan Africa. *Tropical Bryology* 10: 91–198.
- O’Shea, B.J. 1997. The mosses of sub-Saharan Africa. 2. Endemism and biodiversity. *Tropical Bryology* 13: 75–85.
- Ochyra, R. 1986a. List of threatened mosses in Poland. Pp. 117–128 In: Zazycky K. and Wojewoda W. (Ed.), *List of threatened plants in Poland*. Warsaw, Polska Akad. Nauk.
- Ochyra, R. 1986b. *Sciaromiadelphus* A. Abr. and I. Abra. The relationship between extant and fossil moss specimens. *Journal of the Hattori Botanical Laboratory* 61: 309–332.
- Ochyra, R. 1991. *Crassiphyllum* (Thamnobryaceae), a new moss genus from Madeira. *Fragmenta Floristica Geobotanica* 36: 71–79.
- Ochyra, R., Schmidt, C. and Bültmann, H. 1998. *Gradsteinia torrenticola*, a new aquatic moss species from Tenerife. *Journal of Bryology* 20: 403–409.
- Orbán, S. 1976. *Riccia gougetiana* Mant. és más érdekes Riccia-fajok a Hortobágyon. *Bot. Közlem.* 62: 197–201.
- Palmer, M. 1995. *A UK Plant Conservation Strategy: A strategic framework for the conservation of the native flora of Great Britain and Northern Ireland*. JNCC, Peterborough.
- Pant, G. and Tewari S.D. 1995. Additional, up to date notes on Red List monotypic endemic liverwort taxa of Kumaon (Western Himalaya). *Bryological Times; Newsletter of the International Association of Bryologists*. Utrecht, *Penicuik* 83/84: 7.
- Pant, G., Tewari, S.D. and Joshi, S. 1992. An assessment of vanishing rare bryophytes in Kumaun Himalaya – Thalloid liverworts. *Bryological Times; Newsletter of the International Association of Bryologists*. Utrecht, *Penicuik* 68/69: 8–10.
- Pant, G., Tewari, S.D. and Joshi, S. 1994. Vanishing greenery in Kumaon Himalaya: observations on bryoflora. *Geophytology* 23: 253–257.
- Paton, J.A. 1976. *Ditrichum cornubicum*, a new moss from Cornwall. *Journal of Bryology* 9: 171–175.
- Paton, J.A. 1984. *Cephaloziella nicholsoni* Douin and Schiffn. distinguished from *C. massalongi* (Spruce) K. Müll. *Journal of Bryology* 13: 1–8.
- Peciar, V. 1987. Súčasný stav bryoflóry na Slovensku a aktuálne problémy jej ochrany. *Biológia (Bratislava)* 42: 69–77.
- Pellow, R. 1991. Data management for conservation. Pp. 505–522 In: Spellerberg I. F., Goldsmith F.B., and M.G. Morris. *The Scientific Management of Temperate Communities*. Blackwell Science, Southampton. 566pp.
- Perin, F. 1962. Woodland mosses – A little-used growing medium. *American Orchid Society Bulletin* 31: 988.
- Persson, H. 1955. Remarks on the *Porella pinnata* group. *Archivum Societatis Zoologicae Botanicae Fennicae “Vanamo”* 9, suppl.: 225–231.
- Piippo, S. 1986. Bryophytes from Frieda River, East and West Sepik Provinces, Papua New Guinea. II. Hepaticae. *Annales Botanici Fennici* 23: 1–10.
- Piippo, S. 1990. Annotated catalogue of Chinese Hepaticae and Anthocerotae. *Journal of the Hattori Botanical Laboratory* 68: 1–192.
- Pócs, T. 1980. The epiphytic biomass and its effect on the water balance of two rain forest types in the Uluguru Mountains (Tanzania, East Africa). *Acta Botanica Academiae Scientiarum Hungaricae*. Budapest 26: 143–167.
- Pócs, T. 1985. East African Bryophytes, VII. The hepaticae of the Usambara rain forest project expedition, 1982. *Acta Botanica Hungarica* 31: 113–133.
- Pócs, T. 1991. The significance of lower plants in the conservation of Mount Kilimanjaro. Pp. 24–36 In: Newmark, W. D. (Ed.) *The Conservation of Mount Kilimanjaro*. IUCN, Nairobi.
- Pócs, T. 1995. East African Bryophytes, XIV. Hepaticae from the Indian Ocean Islands. *Fragmenta Floristica et Geobotanica* 40: 251–277.
- Poots, V.J.P., Mckay, G. and Healy, J.J. 1976. The removal of acid dye from effluent using natural absorbents I. *Peat Water Res.* 10: 1061–1066.
- Pospisil, V. 1975. Die Bedeutung der Moose *Pterogoneurum subsessile* (Brid.) Jur. und *P. ovatum* (Hedw.) Dix. als Indikatoren der Klimagebiete in der Tschechoslowakei. *Casopis Moravského Musea v Brně. Vědy Přírodní. Acta Musei Moraviae. Scientiae Naturales* 60: 125–146.
- Prance, G.T. 1991. Rates of loss of biological diversity: a global view. Pp. 27–44 In: Spellerberg, I. F. Goldsmith, F.B. and Morris. M.G. *The Scientific Management of Temperate Communities*. Blackwell Science, Southampton. 566pp.
- Pursell, R., Bruggeman, M.A. and Allen, B.H. 1988. A taxonomic revision of *Fissidens* subgenus *Sarawakia*. *Bryologist* 91: 202–213.
- Pursell, R.A. and Reese, W.D. 1982. The mosses reported from New Caledonia. *Journal of the Hattori Botanical Laboratory* 53: 449–482.
- Rabinowitz, D. 1981. Seven forms of rarity. Pp. 205–217 In: Synge, H. (Ed.). *The Biological Aspect of Rare Plant Conservation*. Wiley, Chichester.

- Rajczy, M. 1990. Mohák-Bryophyta. Pp. 322–325 In: Rakonczai, Z. *Vörös könyv (The Red Book of Hungary)*. Akadémiai Kiado, Budapest.
- Rao, D.N. 1982. Response of bryophytes to air pollution. Pp. 445–471 In: Smiths, A.J.E. (Ed.) *Bryophyte Ecology*. Chapman and Hall, London and New York.
- Rassi, P. and Väisänen R. 1992. *Threatened Animals and Plants in Finland*. Ministry of Environment, Helsinki.
- Redfearn, P. L., Jr., Tan, B. C., and He, S. 1996. A newly updated and annotated checklist of Chinese mosses. *Journal of the Hattori Botanical Laboratory*. 79: 163–357.
- Rhoades, F. 1995. Nonvascular epiphytes in forest canopies: worldwide distribution, abundance, and ecological roles. Pp. 353–408 In: Lowman, M.D. and Nadkarni, N.M. (Eds). *Forest Canopies*. Academic Press, San Diego.
- Richards, P.W. 1984. The ecology of tropical forest bryophytes. Chapt. 21. Pp. 1233–1270 In: Schuster, R.M. (Ed.). *New Manual of Bryology, Vol. II*. The Hattori Botanical Laboratory, Nichinan, Japan.
- Richardson, D.H.S. 1981. *The Biology of Mosses*. Blackwell, London.
- Robinson, H. 1975. The Mosses of the Juan Fernandez Islands. *Smithsonian Contribution to Botany* 27: 1–88.
- Roivainen, H. and Bartram, E.B. 1937. Bryological investigations in Tierra del Fuego. I. Sphagnaceae–Dicranaceae. *Annales Botanici Societatis Zoologicae-Botanicae Fennicae Vanamo* 9(2): 1–56.
- Roshchinsky, M. P. et al. (Eds) 1982. *Rare and protection demanding plants and animals of Komi*. ASSR, Syktyvkar. Pp. 1–123. In Russian.
- Rozmey, Z. and Kwiatkowski, A. 1976. The absorption of waste waters on the peats. Pp. 372–378 In: *Proc. 5th Internat. Peat Congr. Poznan, Poland, September 21–25, 1976, Vol. 1 Peat and Peatlands in the Natural Environment Protection*. Wydawnictwa Czasopism Technicznych Not. Warsaw, Poland.
- Ruel, M., Chornet, S., Coupal, B., Aitcin, P. and Cossette, M. 1977. Industrial utilisation of peat moss. Pp. 221–246 In: Radforth, N.W. and Brawner, C.O. (Eds). *Muskeg and the Northern Environment of Canada*. University of Toronto Press, Toronto, Canada.
- Salazar Allen, N., Gradstein, S.R. and Churchill, S.P. 1996. Bryophytes Non-woody Biodiversity Indicators: A Guide to the Bryophytes of Tropical America. A report. *Anales del Instituto de Biología de la Universidad Nacional Autónoma de México. Serie Botanica* 67: 59–65.
- Sastre-D.J., I. and Tan, B. 1995. Problems of bryophyte conservation in the tropics: a discussion, with case examples from Puerto Rico and the Philippines. *Caribbean Journal of Science* 31: 200–206.
- Saukel, J. 1986. Rote Liste gefährdeter Lebermoose (*Hepaticae*) Oesterreichs. Pp. 152–159 In: Nikfelt H. (Ed.). *Rote Liste gefährdeter Pflanzen Oesterreichs*. Grüne Reihe, Bundesminist. Gesundh. and Umweltschutz 5. Wien, Germany.
- Schuster, R.M. 1966. On *Phycolepidozia*, a new, highly reduced genus of Jungermanniales of questionable affinity. *Bulletin of the Torrey Botanical Club* 93: 437–449.
- Schuster, R.M. 1966–1992. *The Hepaticae and Anthocerotae of North America East of the Hundredth Meridian Vol I–VI*. Columbia Univ. Press, New York and London.
- Schuster, R.M. 1970. New Lejeuneaceae from Dominica and Jamaica. *Bulletin of the Torrey Botanical Club* 97: 336–352.
- Schuster, R.M. 1983. Phytogeography of the Bryophytes. Chapt. 10, Pp. 463–626 In: Schuster, R.M. (Ed.). *New Manual of Bryology, Vol. I*. The Hattori Botanical Laboratory, Nichinan, Japan.
- Schuster, R.M. 1990. Origins of Neotropical Leafy Hepaticae. *Tropical Bryology* 2: 239–264.
- Schuster, R.M. 1998. On the genus *Scaphophyllum* (Jungermanniaceae). *Bryologist* 101: 428–434.
- Schuster, R.M. and Konstantinova, N.A. 1996. Studies on the distribution of critical Arctic/subarctic Hepaticae with special reference to taxa found in Russia. *Lindbergia* 21: 26–48.
- SEPA 1996. *Action Plan on Biological Diversity*. Swedish Environmental Protection Agency (SEPA) Report 4567. SEPA, Stockholm.
- Sérgio, C. and Perold, S. M. 1992. A new species of *Riccia* L. from the island of Madeira, *Riccia atlantica* sp. *Journal of Bryology* 17: 127–132.
- Sérgio, C., Casas, C., Brugués, M. and Cros, R.M. 1994. *Lista Vermelha dos Briófitos da Península Ibérica* (Red list of bryophytes of the Iberian Peninsula). IUCN, Lisboa.
- Sérgio, C., Schumacker, R., Fontinha, S. and Sim-Sim, M. 1992. Evaluation of status of bryophyte flora of Madeira with reference to endemic and threatened European species. *Biological Conservation* 59: 223–231.
- Shacklette, H.T. 1984. The use of aquatic bryophytes in prospecting. *J. Geochem. Expl.* 21: 89–93.
- Sharp, J., Crum, H., and Eckel, P. M. (Eds.) 1992. The Moss Flora of Mexico. *Memoirs of the New York Botanical Garden* 69: 1–1113.
- Shelyak-Sosonka, Y.R. 1996. *Chervona Kniga Ukrainy – Rosliniy Svit [Red Data Book of Ukraine – Plant Kingdom]*. Ukrainsky Enciklopedia, Kiev. 608pp.
- Shin, T. 1970. Flora of the hepaticae in the Ryukyu Archipelago. parts 2 and 3: Enumeration of the species on Okinawa Islands and Sakishima Islands. *Science Reports of Kanazawa University; Biology* 19: 29–50.

- Siebel, H.N., Aptroot, A., Dirkse, G.M., van Dobben, H.M., van Melick and Touw, A. 1992. Rode Lijst van in Nederland verdwenen en bedreigde mossen en korstmossen. *Gorteria* 18: 1–20.
- Sjögren, E. 1975. Epiphyllous bryophytes of Madeira. *Svensk Botanisk Tidskrift Utgifven af Svenska Botaniska Foreningen Stockholm* 69: 217–288.
- Sjögren, E. 1978. Bryophyte vegetation in the Azores Islands. *Memórias da Sociedade Broteriana* 26: 1–283.
- Sjögren, E. 1997. Epiphyllous bryophytes in the Azores Islands. *Arquipélago Life and Marine Sciences* 15A: 1–49.
- Smith, D.K. and Davidson P. G. 1993. Antheridia and sporophytes in *Takakia ceratophylla* (Mitt.) Grolle: evidence for reclassification among the mosses. *Journal of the Hattori Botanical Laboratory* 73: 263–271.
- Söderström, L. 1988. The occurrence of epixylic bryophyte and lichen species in an old natural and a managed forest stand in northeast Sweden. *Biological Conservation* 45: 169–178.
- Söderström, L. and Herben, T. 1997. Dynamics of bryophyte metapopulations. *Advances in Bryology* 6: 205–240.
- Söderström, L., Hallingbäck, T., Hodgetts, N., Raeymaekers, G. Schumacker, R. Sérgio, C., Stewart, N. and Váňa, J. 1998. State of knowledge of the bryoflora of Europe as illustrated by the hepatic flora. *Lindbergia* 23: 28–32.
- Spjut, R.W., Cassady, J.M., McCloud, T., Suffness, M., Norris, D. H., Cragg, G. M., Edson, C. F. 1988. Variation in cytotoxicity and antitumor activity among samples of the moss *Claopodium crispifolium* (Thuidiaceae). *Economic Botany* 42(1): 62–72.
- Spjut, R.W., Suffness, M., Cragg, G.M. and Norris, D.H. 1986. Mosses, liverworts and hornworts screened for antitumor agents. *Economic Botany* 40 (3): 310–338.
- Spruce, R. 1884. Hepaticae Amazonicae et Andinae. *Transactions and Proceedings of the Botanical Society of Edinburgh* 15: 1–588.
- Steere, W.C. 1978. *The Mosses of Arctic Alaska*. Vaduz, Cramer.
- Steere, W.C. and Inoue, H. 1978. The hepaticae of Arctic. *Journal of the Hattori Botanical Laboratory* 44: 251–345.
- Synge, H. 1995. The Biodiversity Convention explained. Part 1. *Plant Talk* March 95: 14–15.
- Szweykowsky, J. 1986. List of threatened liverworts in Poland. Nauk: Pp. 107–115 In: Zazycky K. and Wojewoda W. (Eds). *List of threatened Plants in Poland*. Warszawa, Polska Akad.
- Tan, B.C. and Iwatsuki, Z. 1996. Hot spots of mosses in East Asia. *Anales del Instituto de Biología de la Universidad Nacional Autónoma de México. Serie Botanica* 67(1): 159–167.
- Tan, B.C. and Iwatsuki, Z. 1999. Four hot spots of moss diversity in Malesia. *Bryobrothera* 5: 247–252.
- Tan, B.C., Geissler, P. and Hallingbäck, T. 1994. Towards a world red list of bryophytes. *Bryological Times; Newsletter of the International Association of Bryologists. Utrecht, Penicuik* 77: 3–6; 78: 4–5.
- Tan, B.C., Sastre-de Jesús, I. and Pócs, T. 1991. Tropical bryology in peril: a survey. *Bryological Times; Newsletter of the International Association of Bryologists. Utrecht, Penicuik* 64: 1–6.
- Tangley, L. 1988. Research priorities for conservation. *BioScience* 38: 444–448.
- Taoda, H. 1972. Mapping of atmospheric pollution in Tokyo based upon epiphytic bryophytes. *Japanese Journal of Ecology* 22: 125–133.
- Tóth, Z. 1987. A phytogeographic review of *Tortula Hedw. Sect. Rurales* De Not. (*Pottiaceae*, Musci) in Hungary. *Acta Botanica Hungarica* 33: 249–278.
- Touw, A. 1978. The mosses reported from Borneo. *Journal of the Hattori Botanical Laboratory* 44: 147–176.
- Udar, R. and Srivastava, S. C. 1983a. Reproductive biology and some Indian liverworts. *Phytomorphology* 33: 37–46.
- Udar, R. and Srivastava, S. C. 1983b. Rare and endangered liverworts of India. Pp. 303–312 In: Jain, S. K. and Rao, R. R. (Eds), *An Assessment of Threatened Plants of India* (Proceedings of Seminar, September 14–17, 1981). Kumaon University, Naini Tal. Howrah.
- Urmi, E. 1984. Zur Moosflora des Alpenraumes. *Botanica Helvetica* 94: 177–188.
- Urmi, E. (Ed.) 1992. Die gefährdeten und selten Moose der Schweiz. – Ser. Rote Liste (ed. Bundesamt für Umwelt, Wald und Landschaft, BUWAL) – EDMZ, Bern. 56pp.
- Urmi, E., Schubiger-Bossard, C., Schnyder, N., Müller, N., Lienhard, L., Hofmann, H., and Bisang, I. 1996. Artenschutzkonzept für die Moose der Schweiz. *Schriftenreihe Umwelt* 265. Bundesamt für Umwelt, Wald und Landschaft (BUWAL), Bern.
- van der Wijk, R. 1959. *Index Muscorum. Regnum Vegetabile Vol. 15*. Utrecht.
- van Reenen, G.B.A. and Gradstein, S.R. 1983. A transect analysis of the bryophyte vegetation along an altitudinal gradient on the Sierra Nevada de Santa Marta, Colombia. *Acta Botanica Neerlandica* 32: 163–172.
- Váňa, J. 1970. Eine neue Lebermoosart aus Neukaledonien. *Österreichische Botanische Zeitschrift* 118: 233–236.
- Váňa, J. 1973. Studien über die Jungermannioideae (Hepaticae). 1. Allgemeine Charakteristik. *Folia Geobotanica and Phytotaxonomica* 8: 181–208.
- Váňa, J. 1986. *Ochyraea tatrensis* gen. et spec. nov., a remarkable pleurocarpous moss from Czechoslovakia. *Journal of Bryology* 14: 261–267.
- Váňa, J. 1992a. Endangered bryophytes in Czechoslovakia, causes and present status. *Biological Conservation* 59: 215–218.

- Váňa, J. 1992b. Phytogeographically important hepatics from the Altai Mts (Russia). *Novitates Botanicae ex Universitate Carolina* 7: 27–32.
- Váňa, J. 1993. Preliminary list of threatened bryophytes in the Czech Republic. I. Liverworts (Hepaticophyta) and hornworts (Anthocerotophyta). *Preslia* 65: 193–199.
- Váňa, J. 1995. Preliminary list of threatened bryophytes in the Czech Republic. II. Mosses (Bryophyta). *Preslia* 67: 173–180.
- Váňa, J. and Inoue, H. 1983. Studies in Taiwan Hepaticae V. Jungermanniaceae. *Bulletin of the National Science Museum, Tokyo, Ser. B*, 9: 125–142.
- Vanden Berghen, C. 1976. Frullaniaceae (Hepaticae) africanae. *Bulletin du Jardin Botanique National de Belgique* 46: 1–220.
- Vanden Berghen, C. 1984. Le genre *Caudalejeunea* (Steph.) Schiffn. (Lejeuneaceae, Hepaticae) en Afrique. *Cryptogamie, Bryologie, Lichénologie* 5: 99–109.
- Vohra, J.N. 1987. Some rare and endemic mosses from India. In: Sharma, M.R and Gupta, B.K. (Eds). *Recent Advances in Plant Sciences*. Bishen Singh Mahendra Pal Singh, Dehra Dun, India.
- WCMC 1992. *Global Biodiversity, Status of the Earth's Living Resources*. Chapman & Hall. London.
- Weibull, H. and Söderström, L. 1995. Red data listed hepatics of Scandinavia in a regional and worldwide perspective – a preliminary study. *Cryptogamica Helvetica. Geneva, Teufen* 18: 57–66.
- Welch, W. 1948. Mosses and their uses. *Proceedings of the Indian Academy of Science* 58: 31–46.
- Werner, J. 1987. Liste rouge des bryophytes du Grand-Duché de Luxembourg. *Travaux Scientifiques du Musée National d'Histoire Naturelle de Luxembourg* 11: 1–43.
- Wigginton, M.J. and Grolle, R. 1996. Catalogue of the Hepaticae and Anthocerotae of Sub-Saharan Africa. *Bryophytorum Bibliotheca* 50: 1–267. J.Cramer, Berlin-Stuttgart, Germany.
- Wigglesworth, G. 1929. A new Californian species of *Sphaerocarpus*. *University of California Publications, Botany* 16: 129–137.
- Wolery, M.G. and Doyle, W.T. 1969. The distribution of *Geothallus tuberosus*. *Bryologist* 72: 413–417.
- Wu, P.C. 1977. *Rhodobryum giganteum* (Schwaegr.) Par. can be used for curing cardiovascular disease. *Acta Phytotaxonomica Sinica* 15: 93.
- Wyatt, R. and Stoneburner, A. 1980. Distribution and phenetic affinities of *Donrichardsia*, an endemic moss from the Edwards Plateau of Texas. *Bryologist* 83: 512–520.
- Yamada, K. 1995. *Radula carringtonii* (Hepaticae, Radulaceae) new to the New World. *Fragmenta Floristica et Geobotanica* 40: 123–126.
- Yamada, K. and Choe, D.-M. 1997. A checklist of Hepaticae and Anthocerotae in the Korean Peninsula. *Journal of the Hattori Botanical Laboratory* 81: 281–306.
- Yamaguchi, T., Seppelt, R. D., Iwatsuki, Z. and Buchanan, A.M. 1990. *Sphagnum* (sect. *Buchanania*) *leucobryoides* sect. et sp. nov. from Tasmania. *Journal of Bryology* 16: 45–54.
- Zhu, R.-L. 1995. Notes on some species of the genus *Cololejeunea* (Lejeuneaceae, Hepaticae) in China. *Journal of the Hattori Botanical Laboratory* 78: 83–109.
- Zhu, R.-L., Hu, R.-L. and Ma, Y.-J. 1994. Some comments on rare and endangered liverworts in mainland China. *Arctoa* 3: 7–12.

Glossary

- Antheridium** – globose or cylindrical structure containing the male sex organ.
- Apiculus** – a short, abrupt point.
- Archegonium** – flask-shaped structure containing female sex-organ.
- Autoicous** – having antheridia and archegonia born close to each other in the same plant.
- Calcicolous** – an organism confined to calcium-rich substrate.
- Calcifuge** – an organism intolerant of calcium in high concentrations.
- Complanate** – flattened or compressed, such as leaves that have been flattened into approximately one plane.
- Corticolous** – growing on tree bark.
- Costa** – the nerve or midrib of a leaf, always more than one cell thick.
- Dioicous** – unisexual; with antheridia and archegonia on different plants. The dioicous condition in Bryophytes is analogous to the dioecious condition in vascular plants (as opposed to monoicous; cf. autoicous).
- Diploid** – having two sets of chromosomes (2n), characteristic of the sporophyte generation. Compare “Haploid”.
- Edaphic factors** – environmental conditions that are determined by the physical, chemical, and biological characteristics of the substrate.
- Elater** – elongate sterile cell, usually hygroscopic and admixed among the spores.
- Elfin forest** – high elevation forest of warm moist regions. Also called cloud forest.
- Endemic** – confined to a given region e.g., an island or a country.
- Ephemeral** – a plant with a short lifecycle, having several generations in one year.
- Epiphyll** – growing on leaves.
- Epiphytic** – a bryophyte attached to a plant (often a tree); the bryophyte does not grow parasitically on the plant, but merely uses it for substrate.
- Filiform** – slender and elongate, filamentous, thread-like.
- Fugitive** – ephemeral species with high reproductive effort and small spores, occurring preferentially in habitats that occur unpredictably and are suitable for a very short time only.
- Fusiform** – spindle-shaped; narrow (more than three times as long as wide) and tapered at both ends.
- Gamete** – sexual male or female cells.
- Gametophyte** – a phase of the Bryophyte lifecycle that has haploid nuclei. During this phase gametes are produced (cf. Sporophytes).
- Gemmae** – an organ of vegetative reproduction consisting of a small group of cells that easily become detached from the parent and develop into a new bryophyte plant.
- Granulate** – a surface finely papillose.
- Haploid** – a state represented by a single set of chromosomes (n) characteristic of the gametophytic generation. Compare “Diploid”.
- Hepatics (liverworts)** – a term used to describe plants of the Division Hepaticopsida.
- Hygrophytic** – marsh plants existing in moist habitats, though not in habitats inundated by water.
- Juniper forest** – forest dominated by Juniper bushes or trees.
- Laurus forest** – forest dominated by *Laurus* spp. trees.
- Lax** – loose; referring to both large thin-walled cells, and the nature and spacing of leaves on the plant stem. Also refers to the nature and spacing of leaves on the stems of plants in a tuft.
- Loess** – A sedimentary deposit of fine-grained, yellowish earth rich in calcium carbonate.
- Lianas** – climbing plants found in tropical forests with long, woody, rope-like stems.
- Mesic** – moist.
- Midrib** – nerve or costa of a leaf, always more than one cell thick.
- Monoicous** – bisexual; with antheridia and archegonia on the same plant, including autoicous, synoicous, paroicous, and polyoicous. The monoicous condition in Bryophytes is analogous to the monoecious condition in vascular plants. (as opposed to dioicous; cf. autoicous).
- Monotypic** – with only one species.
- Multicellular** – consisting of many cells.
- Nerve** – cf. costa or midrib.
- Panduriform** – shaped like the body of a violin; obovate with a median, rounded sinus on either side.
- Papillae** – cell ornamentation, a solid microscopic protuberance.
- Perianth** – among bryophytes, perianth is the leaf protecting the “flower” and enclosing the arkegon, and later the sporogon, during development.
- Peristome** – a single or double ring of teeth at mouth of spore capsule.
- Plasmolysis** – the shrinking of the cytoplasm away from the wall of a living cell due to the loss of water through osmosis.
- Pleurocarpous** – bryophytes with inflorescences (“flowers”) on short side branches.
- Pluriplicate** – having several longitudinal folds or ridges.
- Pottiaceous** – referring to family Pottiaceae.
- Protonema** – the juvenile stage that precedes the formation of gametophyte.

Pseudopodium / Pseudopodia – elongated stalk bearing either an archegonium or gemmae.

Rheophyte – plants adapted to flowing water.

Rhizoid – filamentous structure that anchor the plant to the substrate.

Saxicolous – growing on or among rocks.

Seta / Setae – the stalk of the spore capsule.

Shuttle species – species with large spores, adapted to microhabitats that disappear predictably at varying rates but reappear frequently within the same community.

Spermatozoids – sexual male cells.

Spherical – round or globular in shape.

Sporangium – the part of the sporophyte which contains the spores.

Sporophyte – a phase of the bryophyte lifecycle that has diploid nuclei. During this phase spores are produced (cf. gametophytes).

Tank bromeliads – belonging to the plant family Bromeliaceae (a large group of over 2,500 described species of Neotropical origin). Most tank bromeliads are epiphytes that grow in tree crowns, and are known to harbour many bryophytes mainly because they accumulate water in their leaf axils.

Thallose – composed of a flat plate of tissue.

Vermiform – long, narrow, and wavy in shape.

Verrucate – that has a rough surface.

Vicariant / Vicarious – closely related species derived from a common ancestral population divided by geographic isolation.

Xerophilous – thriving in dry habitats.

Guidelines for Application of the 1994 IUCN Red List Categories of Threats to Bryophytes

Hallingbäck, T., Hodgetts, N., Raeymaekers, G., Schumacker, R., Sérgio, C., Söderström, L., Stewart, N., and Váða, J.

The new IUCN Red List categories of threat include many numerical thresholds that require quantitative data. Since such data are rare for bryophytes, the evaluation against the threat categories must often be inferred from the available data. The most relevant data that can be used for bryophytes are population decline, present distribution and total population size, number of locations, and estimated loss of relevant habitats over the last 10 years or three generations. For assessing species at a regional level, evidence of an inflow of propagules from outside the Red List region is discussed. The use of the terms “individual”, “fragmentation”, “location”, and “generation time” is also discussed.

Summary of threat categories and criteria

A summary is given below of the 1994 IUCN Red List Categories of threat and qualifying criteria with an indication of how they are best applied to bryophytes. This system is complex and offers a range of alternatives for identifying the status of threatened species. A species is required to fulfil **a minimum of one criterion** (of criteria A to E) to qualify for any of the threatened categories on the Red List. Species are tested against all the categories and criteria, working “downwards” through the threat categories (starting with *Extinct*) until the appropriate category for that species is found. The species is allocated to the “highest” category that it fits. In other words, if a species is determined as *Critically Endangered* using criterion B but only *Endangered* using criterion C, its status is *Critically Endangered*. Decline may be measured as a reduction in the number of “individuals” observed or, in the absence of this information, inferred from distribution data.

Problems of scale

The guidelines are intended for global Red Lists, as well as Red Lists for smaller regions. Numbers of individuals, locations, or squares are not related to the size of the area for which a Red List is made. This, however, leads to confusion. Gärdenfors (1996) and Gärdenfors *et al.* (1999)

recently proposed guidelines on how to apply the IUCN system on a regional scale. He clearly showed that size of the Red List region, as such, does not make any difference in the system. The IUCN category system judges the risk of extinction of a population within a given geographical region. This region can be the world or a small country. The risk that a species, which, for example, is considered to have declined by 50%, or to consist of less than 10 individuals, or to be restricted to fewer than five locations, will become extinct is independent of the total size of the region. A higher *percentage* of the species stock will probably be Red Listed in smaller countries. This is because smaller countries generally house smaller populations and smaller populations are more prone to extinction, but not because the thresholds of the criteria are wrong or should be different on different geographical scales. One exception is if an inflow of diaspores from outside the Red List region is counteracting the extinction risk of the population (rescue effects). The smaller the country, the higher the probability of such a flow.

If there is no reason to believe that an inflow of propagules occurs or if the species is endemic, the criteria are applicable with those numbers given in the IUCN Red List booklet (IUCN, 1994). However, if new individuals disperse into the region from surrounding regions, the species is probably less prone to extinction and must therefore be “downgraded” to the next appropriate threat category in the IUCN system. Gärdenfors (1996) and Gärdenfors *et al.* (1999) stressed that the scale problem is “more pronounced in countries surrounded by other countries than those surrounded by sea or other barriers preventing dispersal.” If a downgrading takes place, this movement should be indicated by giving the category first met by the IUCN criteria within parentheses. This process was supported by participants of an IUCN workshop held in England in 1997. Thus, the same thresholds should be used in Luxembourg, Great Britain, and Europe, as well as at the global level, although a downgrading step must take place in countries where the species is healthy and not threatened just outside the country border.

According to Gärdenfors (1996) and Gärdenfors *et al.* (1999), those species which are considered extinct in the red-listed region, but not globally, should be listed as Regionally Extinct (RE).

Mature individual

What constitutes a mature individual bryophyte is not always clear and, without genetic studies of each unit, a reliable estimation of the number of different genetic individuals is impossible. It is recommended that authors of all investigations and Red Lists that use the term “individual” define the way they have used it. The sort of individual within which all the shoots are connected to one another is also often difficult to determine without extensive destruction of populations. However, it is possible to use a pragmatic definition of an individual, in the case of those species that have a growth form that makes it easy to separate colonies or stands. For example, a single tuft of *Ulota* or a single discrete patch of *Brachythecium* can be regarded as a mature individual.

Fragmentation

In bryophytes, information on the effects of isolation of subpopulations is lacking. However, in general, those taxa with a large production of small diaspores are considered probably more easily spread (cf. Söderström and Herben 1997) and hence not so vulnerable to isolation through fragmentation of their habitats. Species that produce only small numbers of diaspores (or none at all), or only large ones, are less efficient at long distance dispersal and the subpopulations may be considered more easily isolated if the population has become fragmented.

If the natural habitats have been fragmented, (for example, old-growth forests and rich fens), this can be used as indirect evidence for fragmentation of populations in species with poor dispersal ability. The IUCN system under criterion C uses “number of individuals of the largest subpopulation” as an estimation of fragmentation. This is not applicable to bryophytes since it is not normally possible to count individuals.

For practical reasons, we recommend that, in most circumstances, a minimum distance greater than 50km between sub-populations of species without spore dispersal can indicate severe fragmentation, and a distance of between 100km and 1,000km for species with spores (this distance will be shorter for species with low production and large spores, and longer for those with high production and small spores).

Location

Another difficulty is the definition of a location. The IUCN definition of a location is: “Location defines a geographically or ecologically distinct area in which a single event (e.g., pollution) will soon affect all individuals

of the taxon present. A location usually, but not always, contains all or part of a subpopulation of the taxon, and is typically a small proportion of the taxon’s total distribution.” The IUCN term “Location” in this study was regarded as what botanists usually call a “site” or “locality” (Georgina Mace, pers. comm.). The only guideline that it is possible to offer on this matter is to choose “locations” that are sensible and appropriate for the data available. Areas with good data are likely to have smaller “locations” than those with poor data. We recommend that all authors that use the term “location” define the way they use it.

Generation time

For the estimation of rates of decline either a time span of 10 years or a span of three generations (whichever is longest) should be used. The IUCN system defines “generation” as the “average age of parents in the population”. The “average age” is impossible to estimate for most bryophytes since age can vary between a few years and several thousands for most perennial species, depending on environmental conditions and disturbance dynamics increasing mortality.

For practical reasons, “parents” should be individuals which have started to produce spores. Individuals with only asexual reproduction cannot, we think, be classified as true “parents”. We believe that “generation time” can be useful for some perennial “slow” species, which take a very long time to produce spores for the first time and where we can see a retreat or a recovery, or both, only after many years. Note that the 1996 IUCN Red List of Threatened Animals recommends a maximum length of 25 years for one generation (Baillie and Groombridge 1996). For species never found with sporophytes in the region we recommend using 25 years as a generation length. For those which produce sporophytes only now and then, the generation length has to be linked to life strategy type (as defined by During 1992): “short” for typical colonisers and fugitives, “medium” for short-lived shuttles, and “long” for perennial stayers.

Therefore, we strongly recommend that “length of generation” be considered (but not in all cases) and always used with common sense. We suggest the following definitions based on the differences in potential life span of the gametophyte:

- “short” (colonists fugitives) = 1–5 years generation time (e.g., *Pottia* spp.)
- “medium” (pioneer colonists, short-lived shuttle) = 6–10 years generation time (e.g. *Orthotrichum* spp.)
- “long” (long-lived shuttles—perennial stayers) = 11–25 years generation time (e.g., *Hylocomium splendens*)

Definitions of the Red List Categories

Be aware that the synopsis given below includes only part of the original text about the Red List Categories. We, therefore, strongly recommend all those who want to adopt the 1994 IUCN Red List Categories to study the original publication (see Appendix 7 for full text) very carefully.

Extinct (EX)

IUCN definition: “A taxon is *Extinct* when there is no reasonable doubt that the last individual has died.” For bryophytes, this means, in theory, that no living material of the taxon exists in the world. See the comment under the next category (EW).

Extinct in the wild (EW)

IUCN definition: “A taxon is *Extinct in the wild* when it is known only to survive in cultivation, in captivity or as a naturalised population (or populations) well outside the past range.” Since bryophytes have a very high regenerative potential, this implies that no living material should exist in the wild.

To interpret these categories reasonably for bryophytes, EX and EW need additional definition. For the purposes of the European Bryophyte Red List (ECCB 1995), extinct (including EW) is defined as:

“Taxa for which all known localities have been checked repeatedly in the last 30 years without success, or taxa listed as extinct or vanished in all available Red Lists, if the total area of distribution is covered by Red Lists.”

At a workshop held in Reading, U.K. (workshop on bryophyte conservation in Europe; 1 August 1996), it was agreed to extend the threshold to 50 years. It must, however, be stressed that all known localities should have been carefully checked. For short-lived species with ephemeral gametophytes, the localities must be searched at the appropriate time of year and preferably over several years, in order to take account of possible population fluctuations and survival of the species by a diaspore bank only. When applied on a regional level, those species which are considered extinct in the red-listed region, but not globally, should be listed Regionally Extinct (RE) (Gärdenfors 1996, Gärdenfors *et al.* 1999).

Critically Endangered (CR), Endangered (EN), and Vulnerable (VU)

IUCN definitions:

“A taxon is *Critically Endangered* when it is facing an extremely high risk of extinction in the wild in the immediate future, as defined by any of the criteria (A to E).”

“A taxon is *Endangered* when it is not *Critically Endangered* but is facing a very high risk of extinction in

the wild in the near future, as defined by any of the criteria (A to E).”

“A taxon is *Vulnerable* when it is not *Critically Endangered* or *Endangered* but is facing a high risk of extinction in the wild in the medium-term future, as defined by any of the criteria (A to E).”

Only IUCN Red List Criteria A to D are indicated below, for the purposes of evaluating bryophytes. It is not possible to use Criterion E – “Quantitative analysis showing the probability of extinction in the wild is at least 50% within 10 years or 3 generations, whichever is the longer (CR); at least 20% within 20 years or 5 generations, whichever is the longer (EN); at least 10% within 100 years (VU)” – whilst no Population Viability Analysis (PVA) or equivalent relevant data are available. However, it may be possible to use it in the future, following more research on bryophyte extinction processes and threats.

A. Large decline

Major population decline observed, estimated, inferred or suspected in the last 10 years or three generations, whichever is the longer (A1), OR projected or suspected to be met within the next 10 years or three generations, whichever is the longer (A2), based on:

- a) direct observation (for A1 only)
- b) an index of abundance appropriate for the taxon
- c) a decline in area of occupancy and/or quality of habitat
- d) actual or potential levels of exploitation
- e) the effects of introduced taxa, hybridisation, pathogens, pollutants, competitors, or parasites.

≥80% decline = CR

≥50% decline = EN

≥20% decline = VU

B. Restricted area of occupancy, few localities, and decline

To qualify under this criterion, a species must occupy a restricted area **and** have few localities **and** have a “continuing decline observed, inferred or projected” in any of the following:

- b) area of occupancy
- c) area, extent and/or quality of habitat
- d) number of locations or subpopulations
- e) number of mature individuals

For bryophytes, the area of occupancy has been interpreted as the number of grid squares in which a species has been recorded. The IUCN classification of “severely fragmented” for species with small subpopulations which are all more or less isolated can also be used for bryophytes. Extreme fluctuations, used in the IUCN criteria, have not

been used here as there is seldom any information on the dynamics of bryophyte populations. However, when they are known, fluctuations can be included in the evaluation. Investigation into the fluctuations of listed species should be a principal objective before a final estimate can be made of the chances of their survival.

- Recently recorded within an area smaller than 10km² **and** found in only one locality **and** in decline = CR
- Recently recorded in five or fewer 10km x 10km squares **and** found in no more than five localities/severely fragmented **and** in decline = EN
- Recently recorded in twenty or fewer 10km x 10km squares **and** found in ten or fewer localities/severely fragmented **and** in decline = VU

In the event that a species occurs in, for example, three 10km x 10km squares and six localities, thus apparently falling between two threat categories, the species falls into the “lower” category (i.e., *Vulnerable*).

C. Small population and decline

Small population:

- fewer than 250 mature individuals = CR
 - fewer than 2,500 mature individuals = EN
 - fewer than 10,000 mature individuals = VU
- together with **either**:

C1. Large decline:

- at least 25% in three years or one generation = CR
 - at least 20% in five years or two generations = EN
 - at least 10% in 10 years or three generations = VU
- or**:

C2. Continuing decline and restricted to a single population **or** continuing decline and:

- no subpopulation estimated to contain more than 50 mature individuals = CR
- no subpopulation estimated to contain more than 250 mature individuals = EN
- no subpopulation estimated to contain more than 1,000 mature individuals = VU

D. Very small or restricted populations

- Fewer than 50 mature individuals = CR
- Fewer than 250 mature individuals = EN
- Fewer than 1,000 mature individuals (sub-criterion D1) **or** an area of occupancy less than five 5x5km squares **or** four or fewer localities (sub-criterion D2) = VU

Data Deficient (DD)

Species with insufficient data to categorise them and which could be listed as any category, including Lower Risk, when they are better known. *Data Deficient* species should be listed on an appended list. Listing taxa in this category indicates that more information is required.

Lower risk (LR)

A taxon belongs to the Lower Risk category when it has been evaluated but does not satisfy the criteria for any of the categories CR, EN or VU. This category does not include species thought to be significantly under-recorded. The LR category is divided into three: *least concern* (lc), *conservation dependent* (cd) and *near threatened* (nt). Taxa in the last subcategory are close to qualifying for VU. Be aware of the importance of the LR/nt species as any of them could rapidly become threatened and they should therefore be re-evaluated at appropriate intervals. A list of LR/nt species includes many that are close to qualifying for VU, and should therefore always be included in an appendix to a Red List. The LR/cd category is probably not applicable to bryophytes since conservation programmes are rarely directed specifically at bryophyte species. The LR/lc category includes the majority of common, non-threatened species.

Not Evaluated (NE)

This final category includes species that have not yet been evaluated against the IUCN criteria. It should not be confused with *Data Deficient*. All taxa in the categories CR, EN, VU are classified as threatened while those in DD could be either “threatened” or Lower Risk. The following remark from IUCN 1994 (preamble 5) is most important:

“Listing in the categories of *Not Evaluated* and *Data Deficient* indicates that no assessment of extinction risk has been made, though for different reasons. Until such time as an assessment is made, species listed in these categories should not be treated as if they were non-threatened, and it may be appropriate (especially for *Data Deficient* forms) to give them the same degree of protection as threatened taxa, at least until their status can be evaluated.”

Examples

The examples below give the reasons why species do or do not qualify for status in specified Red Lists under each of the criteria A to E, for different regions or all the world.

Jamesoniella undulifolia

Status: VU (B1, 2abcd) (Great Britain).

- A. Not applicable. Declined, but decline occurred more than 10 years ago.
- B. Applicable. Declined from about 10 localities in eight 10km x 10km squares to two localities in two 10km x 10km squares: *Endangered*.
- C. Not applicable. No detailed information available on population size.
- D. Not applicable. No detailed information available on population size; the fact that it occurs in fewer than

four localities would qualify it as *Vulnerable* if it did not already qualify as *Endangered*.

- E. Not applicable. No quantitative analysis of extinction probability is at hand.

Distichophyllum carinatum

Status: CR (B1, 2abed; C2a; D) (Europe).

- A. Not applicable. Declined, but detailed figures for decline during the past ten years are not available.
B. Applicable. Declined from six localities in four 10km x 10km squares to one locality in one 10km x 10km square: *Critically Endangered*.
C. Applicable. Certainly fewer than 250, and probably fewer than 50 “mature individuals”, and continuing decline: *Critically Endangered*.
D. Applicable. Probably fewer than 50 “mature individuals”: *Critically Endangered*.
E. Not applicable. No quantitative analysis of extinction probability is at hand.

Grimmia unicolor

Status: VU (D2) (Great Britain).

- A. Not applicable. No decline observed.
B. Not applicable. No decline observed.
C. Not applicable. No decline observed.
D. Applicable. No information on number of individuals (D1), but occurs in fewer than four localities (D2): *Vulnerable*.
E. Not applicable. No quantitative analysis of extinction probability is at hand.

Ochyraea tatrensis

Status: CR (D) (Global).

- A. Not applicable. No decline observed.
B. Not applicable. No decline observed.
C. Not applicable. No decline observed.
D. Applicable. Known only from a single locality with fewer than 50 mature individuals (sub-criterion D1): *Critically Endangered*.
E. Not applicable. No quantitative analysis of extinction probability is at hand.

Rhynchostegium rotundifolium

Status: CR (D) (Great Britain).

- A. Not applicable. No decline observed.
B. Not applicable. No decline observed.
C. Not applicable. No decline observed.
D. Applicable. Almost certainly fewer than 50 “mature individuals”.
E. Not applicable. No quantitative analysis of extinction probability is at hand.

Bryum lawersianum

Status: EX (Great Britain, Europe)

This endemic species has not been seen since 1924, in spite

of repeated searching. Evaluation against criteria A–E is, therefore, unnecessary (herbarium specimens are assumed to be dead!)

Orthotrichum gymnostomum

Status: LR/nt (Sweden).

- A. Not applicable. No decline observed.
B. Not applicable. No decline observed.
C. Not applicable. No decline observed.
D. Applicable. No information on number of individuals (D1), but occurs within more than four 5x5km squares and at more than four localities.
E. Not applicable. No quantitative analysis of extinction probability is at hand.

This species, which is an epiphyte on aspen (*Populus tremula*), does not qualify for the Swedish Red List. However, it may become *Vulnerable* in the near future unless appropriate conservation action is taken to improve the air quality and the proportion of aspen trees in Swedish woodlands, and is thus considered “near threatened” LR/nt.

Pterogonium gracile

Status: CR (C2a; D) (Sweden).

- A. Applicable. Suspected to have declined more than 20% but less than 50% in the last three generations (appr. 75 years) and therefore would meet *Vulnerable* if it did not meet *Critically Endangered* under criteria C and D.
B. Not applicable. Recorded recently in 17 sites in 15 10km x 10km squares, the population is not severely fragmented.
C. Applicable. Certainly fewer than 250, and probably fewer than 50 “mature individuals”, and continuing decline: *Critically Endangered*.
D. Applicable. Probably fewer than 50 “mature individuals”: *Critically Endangered*.
E. Not applicable. No quantitative analysis of extinction probability is at hand.

Discussion

Compared to the previous system, the 1994 IUCN Red List Categories and Criteria have many numerical thresholds that require quantitative data. For example, population size, decline over the last 10 years, generation time, and number of mature individuals. Since bryologists usually lack data with which to conduct PVAs, are seldom able to count individuals or measure “generation length” (*sensu* IUCN 1994), and seldom have information about bryophyte total population sizes, some of the criteria are often not applicable or are inappropriate when dealing with bryophytes.

The most relevant data that can be used for bryophytes are:

- Population decline over the last 10 years and three generations (criteria A, C)

- Decline in habitat quality (criteria A, B)
- Present distribution i.e. area of occupancy, counted as number of grid squares (B, D)
- Number of locations (B, D)
- Number of individuals in total population and in all subpopulations (to estimate the degree of fragmentation) (C).
- Evidence of inflow of propagules from outside the Red List region in regional listing (Downgrading)

We believe that most of the four criteria A–D can be applied to bryophyte species that have been relatively well monographed, or studied on a worldwide basis. However, our global overview of bryophyte distribution is very poor, mainly because of the lack of bryologists.

The preamble to the revised categories (IUCN 1994) emphasises the importance of attempting to allocate a Red List status to even relatively poorly known species by estimating and extrapolating the current or potential threats into the future, using the precautionary principle. This is important for the assessment of bryophytes since it enables us to use indirect factors such as habitat destruction and air pollution. Without this consideration, most bryophyte species would be categorised as *Data Deficient*

because bryophytes, in general, are less known compared to vascular plants and vertebrates. However, taxa that are likely to be overlooked *should* usually be placed in the *Data Deficient* category.

Decline in habitat quality can be very useful if up-to-date information about the population status of the species is lacking. The problem is to collate the up-to-date information about destruction of the habitat for all known sites for a taxon. While bryologists usually know the taxa well, they seldom have access to appropriate data on recent habitat destruction, creeping degradation, or air pollution throughout the range of a taxon.

As stressed in the preamble to the categories (IUCN 1994), Red List threat categories alone are *not* sufficient to determine priorities for conservation. A system of assessing priorities for action should also include other factors, such as international responsibilities, taxonomic uniqueness, logistics, chances of success, and perhaps costs.

Acknowledgement

We thank Ulf Gärdenfors for valuable comments on the manuscript.

The 2000 IUCN World Red List of Bryophytes

(available at <<http://www.dha.slu.se/guest/WorldBryo.htm>>)

Ben Tan, Patricia Geissler (†), Tomas Hallingbäck, and Lars Söderström

Introduction

The World Red List of Bryophytes currently includes 92 species. This list is only a small subset of globally threatened species. It has been constructed to provide the public with general information as to which bryophytes are threatened with extinction.

Method

The selection of species was based on the following three criteria:

1. The species must be threatened worldwide.
2. The species must be confined to a threatened habitat.
3. The species must have a narrow distribution range.

The list of candidates was first presented for public comment via the bryological listserver (BRYONET¹) on the Internet. We received several responses, many of which contained information on the local geography of the threatened species, information for which we are most thankful. We then assessed each species against the IUCN Red List Criteria (IUCN 1994), using the guidelines presented in Hallingbäck *et al.* (see Appendix 1).

Discussion

Selecting species for a World Red List of Bryophytes is a difficult task. Sound threat assessments are difficult to determine. For example establishing the threats to European and Macaronesian species, where the actual distribution should be relatively well known, is not easy. For many other regions, particularly tropical areas, the bryophyte flora is even less well known. Where recent literature still reports large regions of presence, with many localities within the distribution area, the species were provisionally categorised as Lower Risk (near threatened) i.e., those not considered to be threatened at present and not included in this Appendix. Similarly, all taxa that have been taxonomically queried are not yet included or were considered as Data Deficient (DD). Information on these

Lower Risk and Data Deficient species can be provided upon request.

Several of the species not included on the World Red List are taxa whose current range or distribution is difficult to determine worldwide. Others are inconspicuous ruderal species of disturbed sites whose habitats do not appear to be threatened by human activities. Many are simply rare, local endemics whose habitat threat has not been observed or identified, but not rare enough to apply criteria D. Some species have recently been described and, therefore, their total range and habitat threats require assessment.

The List

MOSSES (MUSCI)

Acritodon nephophilus H. Rob.

Family: Sematophyllaceae.

Distribution: Mexico (less than five localities in Oaxaca State).

Habitat: On tree bark in forested ravines in cloud forest belt, 3,000–3,200m a.s.l.

Threat: Known only from one small region, which is heavily disturbed and where large areas of forest have been felled recently.

Source: C. Delgadillo pers. comm.

IUCN: There are less than five localities and the population is suspected to have declined because its habitat has been severely destroyed by human activity. It, therefore, meets the IUCN criteria for Endangered based on the small area of occupancy (less than 500km²), the less than five localities, and the decline in the quality of its habitat resulting from high level of exploitation by humans. – EN (B1,2c).

Archidium elatum Dixon and Sainsbury

Family: Archidiaceae.

Distribution: New Zealand (north Auckland). Known from less than five localities.

Habitat: On coastal rock.

Threat: Human activities.

Source: A. Fife pers. comm.

IUCN: The known area of occupancy is less than 500km², known to exist at no more than five localities, and the species' habitats seem to be declining in extent and quality. It, therefore, meets the IUCN criteria for Endangered

1. To join BRYONET please contact Prof. Janice M. Glime (jmglime@mtu.edu).

based on the small fragmented area and the decline of habitat quality. – EN (B1,2c).

Aschisma kansanum A.L. Andrews

Family: Pottiaceae.

Distribution: USA (from three counties in Kansas).

Habitat: Known from an unusual habitat of quartz pebbles in sandy Pleistocene gravel, covered partly by the persistent protonema of this species.

Threat: Because of its rarity, the populations are now severely threatened by over-collection and also by cattle grazing in the area.

Source: Crum and Anderson 1981, Smith-Merrill pers. comm.

IUCN: The species seems to have a very restricted distribution. It, therefore, meets the IUCN criteria for Vulnerable, based on an estimation that the number of localities are fewer than five. – VU (D2).

Brymela tutezona Crosby and B.H. Allen

Family: Hookeriaceae.

Distribution: Panama (Cerro Arizona, Veraquas Province). Not known outside the type locality.

Habitat: Epiphytic in tree crowns in elfin cloud forest.

Threat: Rapid deforestation.

Source: Gradstein 1992a,b.

IUCN: The known area of occupancy is less than 10km² and deforestation is continuing. It, therefore, meets the IUCN criteria for Critically Endangered based on the small fragmented area, the only known locality, and the decline of habitat quality. – CR (B1,2c).

Bryoxiphium madeirense A. Löve and D. Löve

Family: Bryoxiphiaceae.

Distribution: Portugal (Madeira). There are less than five known recent localities for the species.

Habitat: On moist and dripping volcanic rocks, in shaded streams in *Laurus* forest.

Threat: Habitat threatened by the recent logging and clearing of *Laurus* forest for agricultural development and pasture land.

Source: Löve and Löve 1953, ECCB 1995.

IUCN: The known area of occupancy is less than 500km² and the species' habitat seems to be declining in quantity and quality. It, therefore, meets the IUCN criteria for Endangered based on the small fragmented area, the less than five localities, the decline of habitat quality, and the declining number of locations. – EN (B1,2cd).

Distichophyllum carinatum Dixon and W.E. Nicholson

Family: Hookeriaceae.

Distribution: Known only from four localities. Germany (two sites in Bayern), Austria (RE), Switzerland (RE), Japan (one site in Honshu), and China (one site in Sichuan).

Habitat: On wet cliffs in wooded ravines, and on tree trunks in deciduous forest in mountains.

Threat: Seems to be very sensitive to subtle changes of habitat conditions; for example, changes caused by air pollution.

Source: Urmi 1984, Noguchi 1991, R. Lübenau pers. comm., H. Deguchi pers. comm.

IUCN: The known area of occupancy is less than 500km² and the species' habitats seem to be declining. It, therefore, meets the IUCN criteria for Endangered based on the small area, the less than five localities, and the decline of habitat quality and number of locations. – EN (B1,2c).

Ditrichum cornubicum Paton

Family: Ditrichaceae.

Distribution: Great Britain (Cornwall). Known from only one locality.

Habitat: The species is known from copper mine waste in three granite areas, but has disappeared from one. Plants grow on compacted, well-drained peaty, loamy, or gravelly soil where the vegetation is sparse and open.

Threat: In recent years, the population is known to have disappeared from one of the three original sites. Habitat is threatened by encroachment of rank vegetation and excessive human disturbance, for example vehicular activity.

Source: Paton 1976, ECCB 1995.

IUCN: The known area of occupancy is less than 500km² and the species' habitat seems to be declining. It, therefore, meets the IUCN criteria for Endangered based on the small fragmented area, the less than five localities, and the decline of habitat quality. – EN (B1,2c).

Donrichardsia macroneuron (Grout) H.A. Crum and L.E. Anderson

Family: Amblystegiaceae.

Distribution: USA (Edwards County, Texas). Only one locality remains.

Habitat: Growing on boulders in calcareous spring water.

Threat: The calcareous spring habitat is unusual and is easily degraded by settlements, dam constructions, and water pollution.

Source: Wyatt and Stoneburner 1980.

IUCN: The species seems to have a very restricted distribution. It, therefore, meets the IUCN criteria for Vulnerable based on an estimation that the number of localities is less than five. – VU (D2).

Echinodium renauldii (M.A. Cárdenas) Broth.

Family: Echinodiaceae.

Distribution: Portugal (Azores). Less than 10 known localities on five islands.

Habitat: On rocks in forested, deeply shaded ravines and craters above 500m. The species is also known from a Pliocene fossil from the Canary Islands.

Threat: Because of changes in land policy the *Laurel* forest habitat is threatened by logging.

Source: Churchill 1986, ECCB 1995, Sjögren 1997.

IUCN: The species has a very restricted distribution and seems to have declined. It, therefore, meets the IUCN criteria for Vulnerable based on an estimate that the present number of localities is less than 10, the area of occupancy is less than 2,000km², and the population is declining because of declining habitat quality. – VU (B1, 2cd)

Echinodium setigerum (Mitt.) Jur.

Family: Echinodiaceae.

Distribution: Portugal (NW Madeira). Confined to less than five localities.

Habitat: On stones in deep and narrow valleys, among shading ferns.

Threat: Confined to localities where the natural forest habitat is potentially threatened by changing land uses.

Source: Hedenäs 1992.

IUCN: The species seems to have a very restricted distribution area. It, therefore, meets the IUCN criteria for Vulnerable based on an estimation that the number of localities is less than five. – VU (D2).

Fissidens hydropogon Spruce ex Mitt.

Family: Fissidentaceae.

Distribution: Amazonian Ecuador (southeastern area at the foot of the Andes, along Rio Bombonasa). Known only from the type collected in 1857.

Habitat: Submerged in flowing rivers in rainforest.

Threat: The forest in the area has been disturbed.

Source: Pursell *et al.* 1988, R. Pursell pers. comm.

IUCN: The known area of occupancy is less than 10km² and the species' habitat seems to be declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small fragmented area, the only known locality, and the decline of habitat quality. – CR (B1,2c).

Flabellidium spinosum Herzog

Family: Brachytheciaceae.

Distribution: Bolivia (Santa Cruz Cordillera). Known only from the type collection made in 1911.

Habitat: Epiphytic.

Threat: The forest of the type locality and vicinity has been logged and cultivated over the years.

Source: Enroth 1995, idem pers. comm.

IUCN: We consider that there is no reasonable doubt that the last locality for this species has been destroyed and that the last individual has died. – EX.

Gradsteinia torrenticola Ochyra, C.Schmidt, and Bültmann

Family: Amblystegiaceae.

Distribution: Spain (Known only from a single locality on Tenerife in the Canary Islands).

Habitat: Grows submerged on rocks in a waterfall.

Threat: A change in waterflow or pollution of the river is a potential threat.

Source: Ochyra *et al.* 1998.

IUCN: The species seems to have a very restricted distribution. It, therefore, meets the IUCN criteria for Vulnerable based on an estimation that the number of localities is less than five. – VU (D2).

Hypodontopsis apiculata Z. Iwats. and Nog.

Family: Rhachithecaceae.

Distribution: Japan (Honshu). Less than 10 localities are known. It has disappeared from at least one of these (the type locality) by cutting of host trees. The others are only small colonies.

Habitat: Restricted habitat on the bark of *Cryptomeria japonica* (it may occasionally also grow on the bark of pines; *Pinus* sp.) in gardens of Buddhist temples, Shinto shrines, and old castles.

Threat: The subpopulation at the type locality has disappeared because the trees have been felled or damaged by typhoons. At the remaining sites the growth is threatened by tree removal, most of the sites being very close to human settlements.

Source: Z. Iwatsuki pers. comm.

IUCN: The area of occupancy is currently less than 2,000km², occurring in less than 10 localities, and the quality of its main habitat has continuously declined, mainly because of human activities. It, therefore, meets the IUCN criteria for Vulnerable based on a decline of suitable trees, high level of human exploitation, and heavy air pollution. – VU (B1,2c).

Jaffuelobryum arsenei (Thér.) Thér.

Family: Grimmiaceae.

Distribution: Mexico (States of Querétaro and Zacatecas). Four localities. One of the sites in Zacatecas may have been destroyed by human interference. The other three are situated close to urban developments.

Habitat: On soil-covered rocks in dry lands.

Threat: Habitats are threatened by farmland expansion and housing.

Source: Churchill 1987, Claudio Delgadillo pers. comm.

IUCN: The known area of occupancy is today less than 500km² and the species' habitat seems to be declining. It, therefore, meets the IUCN criteria for Endangered based on the small fragmented area, the less than five localities, the decline of habitat quality, and the declining number of locations. – EN (B1,2cd).

Lepidopilum grevilleanum Mitt.

Family: Daltoniaceae.

Distribution: Ecuador (western coastal region of the Andean foothills). Known only from two localities.

Habitat: On trees in humid premontane forests.

Threat: The massive deforestation in western Ecuador may account, in part, for the rarity or even possible extinction of this species. According to Churchill (1992), this very conspicuous species is likely to be collected even by non-bryologists.

Source: Churchill 1992.

IUCN: The known area of occupancy is less than 10km² and the species' habitat seems to be declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small fragmented area, the decline of habitat quality, and the declining number of locations. – CR (B1,2cd).

***Leucoperichaetium eremophilum* Magill**

Family: Grimmiaceae.

Distribution: Namibia (Witpütz). Known only from the type collection.

Habitat: On quartzite outcrops in dwarf succulent shrublands.

Threat: The small locality is surrounded by diamond mines. The threat is resulting from these mining activities that may be on the increase.

Source: Magill 1981, C. Hilton-Taylor pers. comm.

IUCN: The species seems to have a very restricted distribution. It, therefore, meets the IUCN criteria for Vulnerable based on an estimation that the number of localities is less than five. – VU (D2).

***Limbella fryei* (R.S. Williams) Ochyra.**

Family: Pterobryaceae.

Distribution: USA (coastal Oregon, Sutton Lake Swamp Preserve). Known from two localities, but has been found again recently at only one of these. It has been extensively looked for in the region, but no new locality has been found.

Habitat: Near a road adjacent to a lake on wet, rotten wood, leaf litter, etc.

Threat: Housing developments, water pollution, earthquake-related subsidence, and human-induced changes in hydrology are the primary threats (Christy and Wagner 1996).

Source: W. B. Schofield pers. comm.

IUCN: The known area of occupancy is less than 10km² and the species' habitat seems to be declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small fragmented area, the only locality, and the decline of habitat quality. – CR (B1,2c).

***Mamillariella geniculata* Laz.**

Family: Leskeaceae.

Distribution: Russian Federation (Russian Far East near Khabarovsk). Known only from between five and seven localities. However, fewer than five of these are recent.

Habitat: In mixed deciduous forest.

Threat: The forests in the Russian Far East are today seriously threatened by on-going economic development in the region.

Source: Buck 1981, M.S. Ignatov pers. comm.

IUCN: The known area of occupancy is less than 500km² and the species' habitat seems to be declining. It, therefore, meets the IUCN criteria for Endangered based on the small fragmented area, the decline of habitat quality, and the declining number of locations. – EN (B1,2cd).

***Merrillibryum fabronioides* Broth.**

Family: Fabroniaceae.

Distribution: Philippines (mountains of northern Luzon). Known from less than five localities. All of the records are old, but Tan, based on his knowledge of the area (pers. comm.), believes it must still be present in at least some localities.

Habitat: Epiphytic on trees in montane mossy forests.

Threat: Habitat has been disturbed for decades by agricultural expansion, logging, and mining operations.

Source: Gradstein 1992a, B. C. Tan pers. comm.

IUCN: The known area of occupancy is less than 500km² and the species' habitat seems to be declining. It, therefore, meets the IUCN criteria for Endangered based on the small fragmented area, the less than five localities, the decline of habitat quality, and the declining number of locations. – EN (B1,2cd).

***Mitrobryum koelzii* H. Rob.**

Family: Dicranaceae.

Distribution: India (Uttar Pradesh). First reported in 1968 from the type and later from one other collection in the area at 3,300m a.s.l.

Habitat: On forest soil.

Threat: Habitat threatened by human activities.

Source: Vohra 1987.

IUCN: The known area of occupancy is less than 500km² and the species' habitat seems to be declining. It, therefore, meets the IUCN criteria for Endangered based on the small fragmented area, the less than five localities, the decline of habitat quality, and the declining number of locations. – EN (B1,2cd).

***Neckeropsis pocsii* Enroth and Magill**

Family: Neckeraceae.

Distribution: Comoros (Mayotte). Only one locality.

Habitat: On boulders in mesic evergreen forest.

Threat: The species is threatened by excessive logging.

Source: Enroth and Magill 1994; T. Pócs pers. comm.

IUCN: The known area of occupancy is today less than 10km² and the species' habitat seems to be declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small area, the only locality, and the decline in habitat quality due to logging. – CR (B1,2c).

***Neomacounia nitida* (Lindb.) Ireland**

Family: Neckeraceae.

Distribution: Canada (Ontario, Hastings County). Known only from the type and two other collections made in the same general locality between 1862 and 1864.

Habitat: On elms in a swamp.

Threat: Extinct

Source: Ireland 1974.

IUCN: The known localities were not rediscovered during several expeditions by bryologists since 1864, including fieldwork in the 1970s. The species may, therefore, be considered Extinct – EX.

Ochyraea tatrensis Váňa

Family: Hypnobartlettaceae.

Distribution: Slovakia (Nízke Tatry Mountains). Known only from two localities, but has vanished from one of these recently.

Habitat: On granite stones in streams at subalpine elevation.

Threat: Habitat threatened by human activities.

Source: J. Váňa pers. comm., J. Váňa 1976.

IUCN: The species seems to have a very restricted population size. It, therefore, meets the IUCN criteria for Critically Endangered based on an estimation that the number of individuals are fewer than 50. – CR (D).

Orthodontopsis bardunovii Ignatov and B.C. Tan

Family: Bryaceae.

Distribution: Russian Federation (Siberia in Altai Mountains and Western Sayan Mountains). Known only from a few localities.

Habitat: On rotten old logs in *Pinus-Larix* forest.

Threat: The species seems unable to survive outside the fast disappearing old-growth forest.

Source: M.S. Ignatov pers. comm.

IUCN: The known area of occupancy is less than 500km² and the species' habitat seems to be declining. It, therefore, meets the IUCN criteria for Endangered based on the small fragmented area, the decline of habitat quality, and the declining number of locations. – EN (B1,2cd).

Orthotrichum scanicum Grönvall

Family: Orthotrichaceae.

Distribution: Austria, Czech Republic, Denmark, France, Germany, Greece, Hungary, Italy, Norway, Poland, Russian Federation, Spain, Sweden, Switzerland, and Yugoslavia. However, this distribution is based mostly on old reports, except Spain, and it is considered Endangered or Regionally Extinct in several countries. Its overall range is declining in Europe. Many local subpopulations are now extinct.

Habitat: On trunks and branches of conifers, as well as broadleaf deciduous trees.

Threat: Threatened by the felling of host trees and by air pollution.

Source: ECCB 1995, M.S. Ignatov pers. comm.

IUCN: The population is suspected to have declined by at least 20% over the last 15 years (three generations) because host trees have been cut and air pollution has lowered the vitality of this species. It, therefore, meets the IUCN criteria for Vulnerable. – VU (A1ce).

Orthotrichum truncato-dentatum C. Muell.

Family: Orthotrichaceae.

Distribution: Uruguay (Montevideo) and Argentina (Isla Recreo). It is not currently known from any locality. The old collections were made more than 100 years ago. The genus *Orthotrichum* may be under-recorded in southern South America and, therefore, more field work is needed to confirm its extent and population size.

Habitat: On trees near human settlements.

Threat: The known old localities are heavily urbanised today.

Source: Lewinsky 1992.

IUCN: The known area of occupancy is less than 500km² with fewer than five localities and the species' habitats seem to be declining. It, therefore, meets the IUCN criteria for Endangered based on the small fragmented area, less than five localities, and the decline of habitat quality. – EN (B1,2cd).

Ozobryum ogalalense G. L. S. Merrill.

Family: Pottiaceae.

Distribution: USA (Kansas). Known only from a single locality.

Habitat: Confined to an unusual habitat – strongly calcareous, porous rock outcrop ledges charged with moisture, and surrounded by prairie.

Threat: The location is threatened by cattle grazing and human disturbance.

Source: Merrill 1992, Merrill pers. comm.

IUCN: The known area of occupancy is today less than 10km² and the species' habitat seems to be declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small and unique locality and the declining habitat quality resulting from high pressure from cattle grazing and other human disturbances. – CR (B1,2c).

Pinnatella limbata Dixon

Family: Neckeraceae.

Distribution: India (Uttar Kanad, formerly North Kanara, District of Karnataka State). Known only from a single locality.

Habitat: A rheophyte attached to rocks in a fast flowing stream.

Threat: Threatened by the rapid destruction of forests in SW India due to population expansion.

Source: Enroth 1994, B. O'Shea pers. comm.

IUCN: The known area of occupancy is less than 10km² and the species' habitat seems to be declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small fragmented area and the decline of habitat quality. – CR (B1,2c).

Renauldia lycopodioides Bizot ex Pócs

Family: Pterobryaceae.

Distribution: Tanzania (Sagara Ridge of West Usambara Mts and Uzungwe Mts). Known only from two localities.

Habitat: Epiphyte on branches in mossy montane forest.

Threat: The forest habitat is threatened by illegal deforestation.

Source: T. Pócs pers. comm.

IUCN: The known area of occupancy is less than 500km² and the species' habitat appears to be declining. It, therefore, meets the IUCN criteria for Endangered based on the small fragmented area, the less than five localities, the decline of habitat quality, and the declining number of locations. – EN (B1,2cd).

Sciaromiopsis sinensis (Broth.) Broth.

Family: Amblystegiaceae.

Distribution: Known from three small localities, all in China (Sichuan, Daliang-shan at Yanyuan, Lungdschushan at Huili and Yunnan, Lidjiang). In spite of recent expeditions to the area, it has not been found again.

Habitat: Submerged in clean, flowing rivers.

Threat: The natural vegetation at the sites is seriously disturbed today by a growing human population, deforestation, and industrialisation, which cause rivers to be heavily blocked with silt.

Source: Ochyra 1986, C. Tong pers. comm.

IUCN: The known area of occupancy is less than 500km² and the species' habitat seems to be degrading. It, therefore, meets the IUCN criteria for Endangered based on the small remaining potential area, the less than five localities, the decline of habitat quality, and the declining number of locations. – EN (B1,2cd).

Skottsbergia paradoxa M.A. Cardenas

Family: Ditrichaceae.

Distribution: Argentina (South Georgia and part of Fuegian Island). Known only from a few localities.

Habitat: Associated with *Sphagnum* in boggy areas.

Threat: The localities are highly threatened by increasing human activities.

Source: C. Matteri pers. comm.

IUCN: The known area of occupancy is less than 500km² and the species' habitat seems to be declining. It, therefore, meets the IUCN criteria for Endangered based on the small fragmented area, the less than five localities, the decline of habitat quality, and the declining number of locations. – EN (B1,2cd).

Sphagnum leucobryoides T. Yamag., Seppelt and Z. Iwats.

Family: Sphagnaceae.

Distribution: Australia (SW Tasmania). Few localities.

Habitat: Buried in wet, sandy soil in alluvial wash sites.

Threat: Uncontrolled, intensive burning of the sedge vegetation.

Source: Yamaguchi *et al.* 1990.

IUCN: The species seems to have a very restricted distribution. It, therefore, meets the IUCN criteria for

Vulnerable based on an estimation that the number of localities is less than five. – VU (D2).

Sphagnum novo-caledoniae Paris and Warnst.

Family: Sphagnaceae.

Distribution: New Caledonia (Plateau de Dogny, Forêt de Tao, and Mt Panie). Confined to very few localities.

Habitat: Growing on rocks in small streams in shaded forest, between 730m and 1,200m a.s.l.

Threat: Pollution of stream water.

Source: T. Engelmark and T. Hallingbäck pers. comm.

IUCN: The species seems to have a very restricted distribution. It, therefore, meets the IUCN criteria for Vulnerable, based on an estimation that the number of localities is less than five. – VU (D2).

Takakia ceratophylla (Mitt.) Grolle

Family: Takakiaceae.

Distribution: India (Sikkim), Nepal, China (Xizang, Yunnan), and USA (Aleutian Islands). The largest subpopulation seems to occur on one of the Aleutian Islands (Smith and Davison 1993).

Habitat: On shaded, damp cliffs and very wet ground with late snow cover.

Threat: Its habitats are threatened by human activities.

Source: Hattori *et al.* 1968, Smith and Davidson 1993.

IUCN: The known area of occupancy is today less than 2,000km², with less than ten localities and the species' habitat seems to be declining. It, therefore, meets the IUCN criteria for Vulnerable based on the small fragmented area, the decline of habitat quality, and the declining number of locations. – VU (B1,2cd).

Taxitheliella richardsii Dixon

Family: Fabroniaceae.

Distribution: Malaysia (Sarawak). Known only from the type collection made in 1932.

Habitat: Epiphytic on rotten logs and lianas inside primary lowland rainforests.

Threat: The primary lowland forest in Sarawak is seriously threatened today by logging.

Source: Gradstein 1992a, B. C. Tan pers. comm.

IUCN: The known area of occupancy is less than 10km² and the deforestation at the localities continues. It, therefore, meets the IUCN criteria for Critically Endangered based on the small area, the single locality, and the decline of habitat quality. – CR (B1,2c).

Thamnobryum angustifolium (Holt) Crundw.

Family: Neckeraceae.

Distribution: Great Britain (only one locality in Derbyshire, England).

Habitat: Shaded cliff beside a calcareous spring or on limestone in a stream.

Threat: Although in a nature reserve, this species is sensitive

to disturbance from a possible new footpath, rock-climbers and cavers, and collection by bryologists. Any pollution of the spring in which it grows may also threaten it. Possibly the greatest threat is desiccation caused by extensive periods of drought when the spring does not flow.

Source: Hodgetts and Blockeel 1992, ECCB 1995, B. O'Shea pers. comm.

IUCN: The known area of occupancy is less than 10km² and the species is subject to a number of threats and potential threats. The number of old herbarium specimens clearly shows that it has declined. It, therefore, meets the IUCN criteria for Critically Endangered based on the small area, the only locality, and the decline. – CR (B1,2c).

Thamnobryum fernandesii (Sérgio) Ochyra [syn. *Crassiphyllum fernandesii* (Sérgio) Ochyra].

Family: Neckeraceae.

Distribution: Portugal (Madeira). Restricted to less than five locations.

Habitat: In permanently wet habitats, such as dripping rocks or waterfalls, in the central part of the island at high elevation above 1,000m.

Threat: Habitat is threatened by the expansion of agriculture and grazing.

Source: R. Ochyra 1991, L. Hedenäs pers. comm.

IUCN: The known area of occupancy is less than 500km² and the species' habitats appear to be declining. It, therefore, meets the IUCN criteria for Endangered based on the small fragmented area, the less than five localities, the decline of habitat quality, and the declining number of locations. – EN (B1,2cd).

LIVERWORTS (HEPATICAEE) and HORNWORTS (ANTHOCEROTAE)

Aitchinsoniella himalayensis Kashyap

Family: Aitchinsoniellaceae.

Distribution: India (Western Himalaya: Uttar Pradesh and Himachal Pradesh), in at least eight localities. However, six of them are old and probably destroyed (Kashyap 1929). During fieldtrips in 1988 and 1991, it was found at only two localities.

Habitat: On muddy, exposed slopes, moist rocks, and seeping cliffs, 2,000–2,950m a.s.l.

Threat: Habitat destruction (road construction) and sparse reproduction.

Source: Udar and Srivastava 1983a, Bischler *et al.* 1994, Pant *et al.* 1994.

IUCN: The area of occupancy is less than 500km² and known from less than five recent localities. The species was considered to be fairly common in western Himalaya before the 1920s (Kashyap 1929), and the population must have declined considerably since then. It, therefore, meets the IUCN criteria for Endangered based on fewer than

five recent localities and an observed decline in its small area of occupancy. – EN (B1,2b).

Andrewsianthus ferrugineus Grolle

Family: Jungermanniaceae.

Distribution: Nepal (east, three localities) and Bhutan (one locality) in eastern Himalaya

Habitat: On trunks of *Juniperus* in damp *Abies*/*Juniperus* forests.

Threat: Habitat destruction (deforestation).

Source: D. Long pers. comm., Grolle 1966, Hattori 1975, Long and Grolle 1990.

IUCN: The area of occupancy is less than 500km², in less than five localities, and deforestation of the habitat is under way. It, therefore, meets the IUCN criteria for Endangered based on the small area, number of locations, and the decline in habitat quality and extent. – EN (B1,2cd).

Anthoceros neesii Prosk.

Family: Anthocerotaceae.

Distribution: Czech Republic, Germany, Poland, and Austria. There are only two recent localities (from many past recorded localities), both situated in Austria (Köckinger pers. comm.).

Habitat: Clayey-loamy soils in open areas. Seems to be restricted to crop fields (primary habitat unknown).

Threat: Its habitat has undergone drastic changes due to changes in agricultural practices.

Source: J. Váňa pers. comm., ECCB 1995, Köckinger pers. comm.

IUCN: The area of occupancy is less than 500km², in only two localities, and there has been an observed decline in habitat quality. It, therefore, meets the IUCN criteria for Endangered based on the small area, less than five localities, and the decline in habitat quality. – EN (B1,2c).

Bazzania bhutanica N. Kitag. and Grolle

Family: Lepidoziaceae.

Distribution: Bhutan (southern part), known from only one locality.

Habitat: On crumbling, shaded rock faces in subtropical forest of the Himalaya (Long and Grolle 1990).

Threat: Forests in the subtropical zone of the Himalaya are threatened by deforestation and other human activities.

Source: D. Long pers. comm., Long and Grolle 1990.

IUCN: The area of occupancy is less than 10km², in only one locality, and the quality of the habitat appears to be declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small area and the decline in habitat quality and extent. – CR (B1,2c).

Bryopteris gaudichaudii Gottsche

Family: Lejeuneaceae.

Distribution: Madagascar (northern part) and Réunion.

Only known from very few localities and found only once (Réunion) since 1900, in 1996.

Habitat: Epiphyte in rainforest.

Threat: Habitat destruction. Madagascar and Réunion are being rapidly deforested.

Source: S.R. Gradstein pers. comm., T. Pócs pers. comm., Gradstein 1992a.

IUCN: Facing an extremely high risk of extinction in the immediate future (IUCN category Critically Endangered) based on its small distribution (area of occupancy less than 10km² in only one locality) in combination with the declining extent of its habitat. – CR (B1,2c).

Calypogeia rhynchophylla (Herzog) Bischl.

Family: Calypogeiaceae.

Distribution: Costa Rica. Three localities on the mainland and one recently found in a nature reserve on Cocos Island off the coast of Costa Rica.

Habitat: Epiphytic on trunks in rainforest.

Threat: The small number of localities makes it vulnerable to stochastic events.

Source: S.R. Gradstein pers. comm., Bischler 1962, Morales 1991, Gradstein 1992b.

IUCN: The area of occupancy is less than 100km² in less than five localities. There is currently no evidence of decline. – VU (D2).

Caudalejeunea grolleana Gradst.

Family: Lejeuneaceae.

Distribution: Northern Madagascar (two localities).

Habitat: On bark of stems and dead wood in undisturbed lowland rainforest (Vanden Berghen 1984).

Threat: Habitat destruction. Rainforests, especially lowland rainforests, have decreased in area and are still decreasing. Less than 15% of the original area remains and the forest area, including the reserves, is threatened by destruction.

Source: Gradstein 1974, 1992a, Vanden Berghen 1984.

IUCN: The area of occupancy is less than 500km², the number of localities is less than five, and the habitat quality is declining. It, therefore, meets the IUCN criteria for Endangered based on the small area, few localities, and the decline in habitat quality and extent. – EN (B1,2cd).

Cladolejeunea aberrans (Steph.) Zwickel

Family: Lejeuneaceae.

Distribution: Tanzania (East Usambara Mountains). Known from two nearby localities.

Habitat: Epiphyllous on ferns in mountain forests (Pócs 1985).

Threat: Habitat destruction. Mountain forests are declining in area and habitat quality, and the species is declining in number.

Source: T. Pócs pers. comm.

IUCN: The area of occupancy is less than 500km² in less than five localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Endangered based on the small area and the decline in habitat quality and extent – EN (B1,2cd).

Cololejeunea magnilobula (Horik.) S. Hatt.

Family: Lejeuneaceae.

Distribution: Known from the type locality in Taiwan (not seen since 1934) and two recently discovered localities in mainland China (Zhejiang Province).

Habitat: Epiphyllous and epiphytic on trunks.

Threat: Suitable forests for this species in East Asia are declining in habitat quality and extent. Although the two recent localities in mainland China are in protected reserves, this does not necessarily mean that they are safe.

Source: Zhu *et al.* 1994, Zhu 1995.

IUCN: The area of occupancy is less than 500km² in less than five localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Endangered based on the small area and the decline in habitat quality and extent – EN (B1,2c).

Dactylolejeunea acanthifolia R.M. Schust.

Family: Lejeuneaceae.

Distribution: Dominica in the Caribbean. Used to be known from only two localities, but has recently been found at a number of new localities (I. Schaefer-Verwimp pers. comm. to P. Geissler). However, the total number of localities is still less than 10.

Habitat: Epiphyllous in old-growth rainforest.

Threat: Deforestation and habitat degradation.

Source: P. Geissler pers. comm., Gradstein 1992a, Schuster 1970.

IUCN: The area of occupancy is less than 2,000km² in less than 10 localities, and the habitat quality appears to be declining. It, therefore, meets the IUCN criteria for Vulnerable based on the small area and the decline in habitat quality and extent. – VU (B1,2c).

Dendroceros japonicus Steph.

Family: Anthocerotaceae.

Distribution: Taiwan, Japan (central part, Ryukyu Is. and Bonin Is.), and Federated States of Micronesia (Kusaie).

Habitat: On tree trunks or rocks in evergreen forest.

Threats: Disappearing from the northern parts of its range due to destruction of habitat and forest quality.

Source: T. Furuki pers. comm., J. Hasegawa pers. comm., Shin 1970, Hasegawa 1980, Miller *et al.* 1983.

IUCN: It is suspected to have declined by at least 20% in the last 30 years (three generations) due to declining habitat quality. It, therefore, meets the IUCN criteria for Vulnerable based on recent decline. – VU (A1c).

***Diplocolea sikkimensis* Amakawa**

Family: Jungermanniaceae.

Distribution: Known from two localities in India (Sikkim) and one in Nepal.

Habitat: Epiphytic on bark in humid forest, 3,650–4,000m a.s.l.

Threat: Although the threats to this species are not well understood, it is clearly extremely rare, and grows in a generally threatened area and habitat. Therefore, following the precautionary principle, we consider it important to highlight the species on the Red List.

Source: J. Váňa pers. comm., Amakawa 1963, Hattori 1968, Váňa 1973.

IUCN: The area of occupancy is less than 500km² in less than five localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Endangered based on the small area and the decline in habitat quality and extent. – EN (B1,2c).

***Drepanolejeunea aculeata* Bischl.**

Family: Lejeuneaceae.

Distribution: Known from two localities in southeastern Brazil (Rio de Janeiro and São Paulo States). Not found since 1922.

Habitat: Epiphyllous in old-growth rainforest.

Threat: Although the threats to this species are not well understood, it is clearly extremely rare, and grows in a generally threatened area and habitat. Therefore, following the precautionary principle, we consider it important to highlight the species on the Red List.

Source: A. Schäfer-Verwimp pers. comm., Bischler 1964, Gradstein 1992b.

IUCN: It is assumed that this species has declined due to habitat destruction and may, in fact, have already become extinct. However, until suitable localities are searched it cannot be considered extinct without reasonable doubt. The area of occupancy is less than 500km² in less than five localities and the habitat is declining. It, therefore, meets the IUCN criteria for Endangered based on the small area and the decline in habitat quality and extent – EN (B1,2c)

***Drepanolejeunea bakeri* Herzog**

Family: Lejeuneaceae.

Distribution: Philippines (Luzon Island). Known from three localities.

Habitat: Epiphyllous in moist forest.

Threat: Threatened by extensive logging and agricultural expansion.

Source: Tixier pers. comm.

IUCN: The area of occupancy is less than 500km² with fewer than five localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Endangered based on the small area and the decline in habitat quality and extent. – EN (B1,2cd).

***Drepanolejeunea senticosa* Bischl.**

Family: Lejeuneaceae.

Distribution: Cuba. Only known from the type specimen. Perianth and capsules unknown, but males frequent.

Habitat: Epiphyllous.

Threat: Although the threats to this species are not well understood, it is clearly extremely rare, and grows in a generally threatened area and habitat. Therefore, following the precautionary principle, we consider it important to highlight the species on the Red List.

Source: Bischler 1964.

IUCN: Only one locality known. It, therefore, meets the criteria for the IUCN category Critically Endangered based on the small area and decline in habitat quality, and the probable extremely small number of individuals. It may even be extinct. However, until several searches in its old locality and in similar habitat around have proved unsuccessful, it must be considered Critically Endangered. – CR (B1, 2bcde; D).

***Eopleurozia simplicissima* (Herzog) R.M. Schust.**

Family: Pleuroziaceae.

Distribution: Malaysia (Sarawak, two localities), Indonesia (Kalimantan)

Habitat: Submontane rainforest.

Threat: Habitat destruction (deforestation).

Source: Gradstein 1992a.

IUCN: The area of occupancy is less than 500km² in less than five localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Endangered based on the small area and the decline in habitat quality and extent. – EN (B1,2c).

***Fulfordianthus evansii* (Fulf.) Gradst.**

Family: Lejeuneaceae.

Distribution: It is currently known from three localities in Belize and Costa Rica. Four old records are known from Guatemala, Belize, and Panama.

Habitat: Shade epiphyte in undisturbed, wet lowland rainforest.

Threat: Although the threats to this species are not well understood, it is clearly extremely rare, and grows in a generally threatened area and habitat. Therefore, following the precautionary principle, we consider it important to highlight the species on the Red List.

Source: S.R. Gradstein pers. comm., Gradstein 1992b.

IUCN: The area of occupancy is less than 2000km² in less than 10 localities, and the habitat quality is declining. It, therefore, meets the IUCN criteria for Vulnerable based on the small area and the decline in habitat quality and extent. – VU (B1,2cd).

***Geothallus tuberosus* Campb.**

Family: Sphaerocarpaceae.

Distribution: USA (southern California). Previously known

only from the immediate vicinity of San Diego, but recently found in a reserve 110km to the north (Doyle 1998).

Habitat: On soil in extremely xeric conditions.

Threat: Threatened by urbanisation. Wolery and Doyle (1969) searched for it in the wild and found eight subpopulations in less than five localities in a small area around San Diego. Since then, the human population of the urban area has doubled, and rapid and intense urban development has occurred. The most recently found subpopulation is, however, not immediately threatened.

Source: Whittemore (in letter), Wolery and Doyle 1969, Doyle 1998.

IUCN: The area of occupancy is less than 500km² in less than five localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Endangered based on the small area and the decline in habitat quality and extent. – EN (B1,2c).

Haesselia roraimensis Grolle and Gradst.

Family: Cephaloziaceae.

Distribution: Guyana, found in less than five localities at the foot of Mt Roraima.

Habitat: On rotten logs in periodically flooded, riverine forest, and in dense, submontane "mossy" forest between 550 and 1,550m a.s.l.

Threat: Small distribution.

Source: Grolle and Gradstein 1988, Gradstein 1992a.

IUCN: The small area of occupancy and the less than five localities means that this species meets the IUCN criteria for Vulnerable. – VU (D2).

Hattoria yakushimensis (Horik.) R.M. Schust.

Family: Jungermanniaceae.

Distribution: Southern Japan. Formerly known from three localities. It is currently known only from one of these sites.

Habitat: Epiphyte.

Threat: The main threats are deforestation of evergreen forest in the vicinity, and the subsequent changes in humidity and light conditions.

Source: T. Furuki pers. comm., Kitagawa 1966, Vána 1973.

IUCN: The small area of occupancy and the less than five localities mean that this species meets the IUCN criteria for Vulnerable. – VU (D2).

Jamesoniella undulifolia (Nees) K. Muell.

Family: Jungermanniaceae.

Distribution: Austria, Czech Republic, Denmark, Finland, France, Germany, Poland, Sweden, Switzerland, Great Britain, Greenland (two sites), Russian Federation (Siberia, Chukotka, Kamchatka), China (Manchuria), and Democratic Peoples Republic of Korea. Several old localities are known, but it has disappeared from most of these in Europe; very few sites are unspoiled today except for several recently found sites in northern Asia, where it may be more common than is currently known.

Habitat: In fens and mires.

Threat: Habitat destruction by drainage, flooding for reservoirs, forest planting, and cattle grazing.

Source: N. Konstantinova pers. comm., Grolle 1971, Piippo 1990, ECCB 1995, Konstantinova and Czernjadieva 1995, Konstantinova and Potemkin 1996, Schuster and Konstantinova 1996, Yamada and Choe 1997.

IUCN: A decline of populations has occurred in at least part of its distribution area, and more than 20% of its populations have probably disappeared within the last 30 years (three generations). This species, therefore, meets the IUCN criteria for Vulnerable. – VU (A1ac).

Kurzia sinensis Chang

Family: Lepidoziaceae.

Distribution: China (Zhejiang Province). Only known from the type specimen.

Habitat: Humid forest, 300m a.s.l.

Threat: Habitat destruction caused by rapid development resulting from growth in the tourism industry.

Source: Mizutani and Chang 1986, Zhu *et al.* 1994.

IUCN: The area of occupancy is less than 10km² in only one locality, and the habitat is declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small area, single locality, and the decline in habitat quality and extent. – CR (B1,2c).

Leptolejeunea tridentata Bischl.

Family: Lejeuneaceae.

Distribution: Colombia (Chocó Department). Known only from the type specimen found in 1957. It has been looked for since then, but without success.

Habitat: Epiphyllous in old-growth lowland rainforest.

Threat: Habitat destruction.

Source: Bischler 1969, Gradstein 1992b.

IUCN: The area of occupancy is less than 10km² in only one locality and the habitat is declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small area, the single locality, and the decline in habitat quality and extent. – CR (B1,2c).

Luteolejeunea herzogii (Buchloh) Piippo

Family: Lejeuneaceae.

Distribution: Panama, Colombia, and Peru, at less than five localities.

Habitat: Dead wood in lowland to submontane forests.

Threat: The major threat is the deforestation of the lowland rain forest.

Source: Piippo 1986, Gradstein 1992a.

IUCN: The area of occupancy is less than 500km² in less than five currently known localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Endangered based on the small area and the decline in habitat quality and extent. – EN (B1,2c).

***Myriocolea irrorata* Spruce**

Family: Lejeuneaceae.

Distribution: Ecuador (along the Rio Topo in the Amazonian sector). Known only from the type collection made in 1857. Recent efforts to relocate the species have been unsuccessful.

Habitat: On twigs of shrubs located near streams in undisturbed rainforest areas, about 1,000m a.s.l.

Threat: Deforestation and deterioration of water courses.

Source: S.R. Gradstein pers. comm., Spruce 1884, Gradstein 1992b.

IUCN: The unsuccessful efforts to locate it at the original locality suggest that it is extinct, but the area has not received enough study to be certain of this. However, if not extinct, it is facing an extremely high risk of extinction in the immediate future. The area of occupancy might be less than 10km² in only one locality, and the habitat is declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small area and the decline in habitat quality and extent. – CR (B1,2c).

***Myriocoleopsis fluviatilis* (Steph.) Reiner and Gradst.**

Family: Lejeuneaceae.

Distribution: Endemic to the state of Sao Paulo (SE Brazil) and known from only three localities, two from the 19th century and one from 1975.

Habitat: A rheophyte, occurring in and along rivers.

Threat: Deforestation and deterioration of water courses due to hydroelectric schemes and water pollution.

Source: S.R. Gradstein pers. comm., Gradstein and Vital 1975.

IUCN: The area of occupancy is less than 2,000km² in less than 10 localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Vulnerable based on the small area and the decline in habitat quality and extent. – VU (B1,2c).

***Nardia huerlimannii* Grolle and Váňa**

Family: Jungermanniaceae.

Distribution: South part of New Caledonia. Known only from three localities within a small area, 580–880m a.s.l.

Habitat: On rotten logs and bark in moist forest.

Threat: Although the threats to this species are not well understood, it is clearly extremely rare, and grows in a generally threatened area and habitat. Since neither sexual nor asexual reproduction has been found, the future of this species is by no means assured. Therefore, following the precautionary principle, we consider it important to highlight the species on the Red List.

Source: H. Hürlimann and J. Váňa pers. pers. comm., Váňa 1970.

IUCN: The area of occupancy is less than 500km² and known only from one locality, however we have no information about any decline. Therefore, this species meets the IUCN criteria for Vulnerable. – VU (D2).

***Nowellia wrightii* Grolle**

Family: Cephaloziaceae.

Distribution: Cuba. Four localities in the Orient Province in east Cuba. Váňa (in letter) assumes there are less than five localities, according to Pócs.

Habitat: On bark and rotten logs in undisturbed lower montane rainforest.

Threat: Although the threats to this species are not well understood, it is clearly extremely rare, and grows in a generally threatened area and habitat. Therefore, following the precautionary principle, we consider it important to highlight the species on the Red List.

Source: T. Pócs pers. comm., J. Váňa pers. comm., Grolle 1968, Gradstein 1992b.

IUCN: The area of occupancy is less than 2,000km² in less than 10 localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Vulnerable based on the small area and the decline in habitat quality and extent. – VU (B1,2c).

***Phycolepidozia exigua* R.M. Schust.**

Family: Phycolepidoziaaceae.

Distribution: Dominica. Known only from the type collection.

Habitat: On tree bark in humid rainforest, 450m a.s.l.

Threat: Habitat destruction. Original locality destroyed by a hurricane. Efforts to relocate the species have been unsuccessful.

Source: Schuster 1967, Gradstein 1992b.

IUCN: The only known locality has been destroyed and the species has not been located since. It could thus be regarded as extinct. However, other species with similar habitat requirements have been rediscovered on Dominica, and it cannot be assumed that this species will not be found following further searches. It is thus best treated as facing extremely high risk of extinction in the immediate future, meeting the IUCN criteria for Critically Endangered based on the small area, the single site, and the decline in habitat quality and extent. – CR (B1,2bc).

***Perssoniella vitreocincta* Herzog**

Family: Personiellaceae.

Distribution: Endemic to New Caledonia. Known from five localities.

Habitat: On tree trunks in montane *Araucaria* forests.

Threat: Although the threats to this species are not well understood, it is clearly extremely rare, and grows in a generally threatened area and habitat. Therefore, following the precautionary principle, we consider it important to highlight the species on the Red List.

Sources: Herzog 1952, Hürlimann 1978, Gradstein 1992a.

IUCN: The area of occupancy is less than 2000km² with less than 10 localities and the habitat is declining. It, therefore, meets the IUCN criteria for Vulnerable based on the small area and the decline in habitat quality and extent. – VU (B1,2c).

Plagiochila wolframii Inoue

Family: Plagiochilaceae.

Distribution: Peru. Only known from one locality.

Habitat: Subalpine forests.

Threat: The major threats are deforestation and forest fire.

Source: Inoue 1987, Gradstein 1992a,b.

IUCN: The area of occupancy is less than 10km² with only one locality, and the habitat is declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small area and the decline in habitat quality and extent. – CR (B1,2cd).

Radula jonesii Bouman, Dirkse, and Yamada

Family: Radulaceae.

Distribution: Spain (Canary Islands) and Portugal (Madeira).

Habitat: On wet, shaded rocks in evergreen forests.

Threat: Habitat destruction (deforestation).

Source: Bouman and Dirkse 1992, ECCB 1995.

IUCN: The area of occupancy is less than 500km² with less than five localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Endangered based on the small area and the decline in habitat quality and extent. – EN (B1,2cd).

Radula visianica C. Massal.

Family: Radulaceae.

Distribution: Italy. Known from two localities and not seen since 1938.

Habitat: Poorly known. On soil or the base of trees.

Threat: Extinct.

Source: ECCB 1995.

IUCN: Searched for several times without success and therefore regarded as Extinct. – EX.

Riccia atlantica Sérgio and Perold

Family: Ricciaceae.

Distribution: Portugal (east Madeira in a restricted area).

Habitat: On volcanic deposits near cliffs exposed to the sea.

Threat: Although the threats to this species are not well understood, it is clearly extremely rare, and grows in a generally threatened area and habitat. Therefore, following the precautionary principle, we consider it important to highlight the species on the Red List.

Source: ECCB 1995.

IUCN: The area of occupancy is less than 20km² with less than five localities. It, therefore, meets the IUCN criteria for Vulnerable based on the small area of occupancy and the less than five localities. – VU (D2).

Scapania sphaerifera Buch and Tuom.

Family: Scapaniaceae.

Distribution: Russian Federation (Kola Peninsula, one old locality which probably was destroyed, and southern Siberia, four more recent localities).

Habitat: On acidic boulders in dry habitats.

Threat: Small distribution.

Source: N. Konstantinova (in letter), Váňa 1993, Konstantinova and Potemkin 1994, ECCB 1995.

IUCN: The area of occupancy is very small but there is no evidence of continuing decline. It, therefore, meets the IUCN criteria for Vulnerable based on its small area of occupancy and less than five recent localities. – VU (D2).

Scaphophyllum speciosum (Horik.) Inoue

Family: Jungermanniaceae.

Distribution: Taiwan (five localities, Váňa (in letter)), China (Yunnan), Bhutan (one locality), and recently found in East Nepal. A subsp. *villosum* Schust. has recently been separated and the Himalayan (and probably also the Yunnan) specimens belong to this subsp., while the subpopulations on Taiwan belong to subsp. *speciosum* (Schuster 1998).

Habitat: In Taiwan, occurring on forest floor at 2,000–2,400m a.s.l. In Bhutan, on a damp, mossy log in a shady ravine in wet, mixed broadleaved forest (Long and Grolle 1990).

Threat: Habitat destruction.

Source: Váňa and Inoue 1983, Zhu *et al.* 1994, Long and Grolle 1990, Schuster 1998, Lai 1999.

IUCN: The area of occupancy is less than 2,000km² in less than 10 localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Vulnerable based on the small area and the decline in habitat quality and extent. – VU (B1,2cd).

Schistochila macrodonta W.E. Nicholson

Family: Schistochilaceae.

Distribution: China (Yunnan) and Bhutan, in one locality each.

Habitat: On plant stems in rainforest (Nicholson 1930). In Bhutan, on a damp, mossy log in a shaded ravine in wet, mixed broadleaved forest (Long and Grolle 1990).

Threat: Although the threats to this species are not well understood, it is clearly extremely rare, and grows in a generally threatened area and habitat. Therefore, using the precautionary principle, we consider it important to highlight the species on the Red List.

Source: D. Long pers. comm., Nicholson *et al.* 1930, Long and Grolle 1990.

IUCN: The area of occupancy is less than 500km² with only two localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Endangered based on the small area and the decline in habitat quality and extent. – EN (B1,2cd).

Schistochila undulatifolia Piippo

Family: Schistochilaceae.

Distribution: Papua New Guinea (West Sepik Province). Only known from the type locality.

Habitat: On fallen trunks in undisturbed tropical rainforest, 800–1,050m a.s.l.

Threats: Mining of copper and logging activities near the locality.

Source: Piippo 1986, Gradstein 1992a.

IUCN: The area of occupancy is less than 10km² with only one locality, and the habitat is declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small area, the single locality, and the decline in habitat quality and extent. – CR (B1,2c).

Sewardiella tuberifera Kashyap

Family: Fossombroniaceae.

Distribution: India (western Himalaya: Himchal Pradesh and Uttar Pradesh). Recorded from several localities at 1,000–2500m a.s.l., but has disappeared from some of them.

Habitat: Moist rocks at high altitudes.

Threats: Habitat destruction at lower altitudes, where it has not been seen recently at some localities around Naini Tal.

Source: S.R. Kashyap 1929, Pant *et al.* 1994.

IUCN: The area of occupancy is less than 2,000km² with less than 10 localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Vulnerable based on the small area and the decline in habitat quality and extent. – VU (B1,2bc).

Sphaerocarpos drewei Wigglesw.

Family: Sphaerocarpaceae.

Distribution: USA (California). Known from seven localities within one small region around San Diego (some of them, however, having been recently destroyed), plus a recent one on Santa Rosa Plateau, approximately 110km north of the localities around San Diego (Doyle 1998).

Habitat: Under shade of coastal sage brush (Doyle 1998). Appears to be associated with *Geothallus tuberosus*.

Threat: Most localities are within urbanised areas and are, therefore, threatened by urban development. However, the recently discovered new locality is in an ecological reserve without any immediate human threat.

Source: A. Whittemore (in letter), Wolery and Doyle 1969, Doyle 1998.

IUCN: The area of occupancy is less than 500km² and the habitat is declining. It, therefore, meets the IUCN criteria for Endangered based on the small area, the less than five localities, and the decline in habitat quality and extent. – EN (B1,2cd).

Sphaerolejeunea umbilicata Herzog

Family: Lejeuneaceae.

Distribution: Colombia (Cauca Department). Known only from the type collection.

Habitat: Epiphyllous in montane forest.

Threat: Although the threats to this species are not well understood, it is clearly extremely rare, and grows in a generally threatened area and habitat. Therefore, following

the precautionary principle, we consider it important to highlight the species on the Red List.

Source: Gradstein 1992a,b.

IUCN: The area of occupancy is less than 10km² with only one locality, and the habitat is declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small area, the single locality, and the decline in habitat quality and extent. – CR (B1,2c).

Spruceanthus theobromae (Spruce) Gradst.

Family: Lejeuneaceae.

Distribution: Ecuador (El Ríos Department, western Ecuador). Only one extant locality known.

Habitat: On the bark of five old cacao trees, in a site at the bottom of a narrow valley and close to remnant natural forest influenced by periodical flooding.

Threat: The forest in the area has now mostly been destroyed.

Source: Gradstein 1992a,b, and 1999b.

IUCN: The area of occupancy is less than 10km² with only one locality, and the habitat is declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small area and the decline in habitat quality and extent. – CR (B1,2c).

Stephensoniella brevipedunculata Kashyap

Family: Exormothecaceae.

Distribution: India (western Himalaya: Himachal Pradesh and Uttar Pradesh), 1,000–2,700m a.s.l.

Habitat: Exposed soil.

Threat: Habitat destruction due to urbanisation at lower altitudes.

Source: G. Pant (in letter), Pant *et al.* 1994.

IUCN: The area of occupancy is less than 500km² with less than five localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Endangered based on the small area and the decline in habitat quality and extent. – EN (B1,2cd).

Symbiezidium madagascariensis Steph.

Family: Lejeuneaceae.

Distribution: Northeast Madagascar and the Seychelles. Found in less than five localities.

Habitat: On bark in lowland rainforest.

Threat: Deforestation.

Source: Gradstein and van Beek 1985, Gradstein 1992a.

IUCN: The area of occupancy is less than 500km² with less than five localities, and the habitat is declining. It, therefore, meets the IUCN criteria for Endangered based on the small area and the decline in habitat quality and extent. – EN (B1,2cd).

Vandiemenia ratkowskiana Hewson

Family: Vandiemeniaceae.

Distribution: Australia (Tasmania). Only known from the

type locality, where it has been looked for recently without success.

Habitat: On rotten logs.

Threat: Although the threats to this species are not well understood, it is clearly extremely rare, and grows in a generally threatened area and habitat. Therefore, following the precautionary principle, we consider it important to highlight the species on the Red List.

Source: H. Streimann pers. comm.

IUCN: The area of occupancy is less than 10km² with only one locality, and the habitat is declining. It, therefore, meets the IUCN criteria for Critically Endangered based on the small area, the single locality, and the decline in habitat quality and extent. – CR (B1,2c).

Assessors

<i>Acritodon nephophilus</i>	Tan, B.C.
<i>Aitchinsoniella himalayensis</i>	Geissler, P.
<i>Andrewsianthus ferrugineus</i>	Söderström, L.
<i>Anthoceros neesii</i>	Geissler, P.
<i>Archidium elatum</i>	Tan, B.C.
<i>Aschisma kansanum</i>	Tan, B.C.
<i>Bazzania bhutanica</i>	Söderström, L.
<i>Brymela tutezona</i>	Tan, B.C.
<i>Bryopteris gaudichaudii</i>	Geissler, P.
<i>Bryoxiphium madeirense</i>	Tan, B.C.
<i>Calypogeia rhynchophylla</i>	Geissler, P.
<i>Caudalejeunea grolleana</i>	Geissler, P.
<i>Cladolejeunea aberrans</i>	Geissler, P.
<i>Cololejeunea magnilobula</i>	Geissler, P.
<i>Dactylolejeunea acanthifolia</i>	Geissler, P.
<i>Dendroceros japonicus</i>	Geissler, P.
<i>Diplocolea sikkimensis</i>	Söderström, L.
<i>Distichophyllum carinatum</i>	Hallingbäck, T.
<i>Ditrichum cornubicum</i>	Unspecified
<i>Donrichardsia macroneuron</i>	Tan, B.C.
<i>Drepanolejeunea aculeata</i>	Geissler, P.
<i>Drepanolejeunea bakeri</i>	Geissler, P.
<i>Drepanolejeunea senticosa</i>	Geissler, P.
<i>Echinodium renauldii</i>	Tan, B.C.
<i>Echinodium setigerum</i>	Tan, B.C.
<i>Eopleurozia simplicissima</i>	Söderström, L.
<i>Fissidens hydropogon</i>	Tan, B.C.
<i>Flabellidium spinosum</i>	Tan, B.C.
<i>Fulfordianthus evansii</i>	Geissler, P.
<i>Geothallus tuberosus</i>	Geissler, P.
<i>Gradsteinia torrenticola</i>	Hallingbäck, T.
<i>Haesselia roraimensis</i>	Geissler, P.
<i>Hattoria yakushimensis</i>	Söderström, L.
<i>Hypnodontopsis apiculata</i>	Tan, B.C.

<i>Jaffueliobryum arsenei</i>	Tan, B.C.
<i>Jamesoniella undulifolia</i>	Söderström, L.
<i>Kurzia sinensis</i>	Söderström, L.
<i>Lepidopilum grevilleanum</i>	Tan, B.C.
<i>Leptolejeunea tridentata</i>	Geissler, P.
<i>Leucoperichaetium eremophilum</i>	Tan, B.C.
<i>Limbella fryei</i>	Tan, B.C.
<i>Luteolejeunea herzogii</i>	Geissler, P.
<i>Mamillariella geniculata</i>	Tan, B.C.
<i>Merrillliobryum fabronioides</i>	Tan, B.C.
<i>Mitrobryum koelzii</i>	Tan, B.C.
<i>Myriocolea irrorata</i>	Geissler, P.
<i>Myriocoleopsis fluviatilis</i>	Gradstein, S.R.
<i>Nardia huerlimannii</i>	Söderström, L.
<i>Neckeropsis pocsii</i>	Tan, B.C.
<i>Neomacounia nitida</i>	Tan, B.C.
<i>Nowellia wrightii</i>	Geissler, P.
<i>Ochyraea tatrensis</i>	Tan, B.C.
<i>Orthodontopsis bardunovii</i>	Tan, B.C.
<i>Orthotrichum scanicum</i>	Tan, B.C.
<i>Orthotrichum truncato-dentatum</i>	Tan, B.C.
<i>Ozobryum ogalalense</i>	Tan, B.C.
<i>Perssoniella vitreocincta</i>	Söderström, L.
<i>Phycolepidozia exigua</i>	Söderström, L.
<i>Pinnatella limbata</i>	Tan, B.C.
<i>Plagiochila wolframii</i>	Söderström, L.
<i>Radula jonesii</i>	Söderström, L.
<i>Radula visianica</i>	Söderström, L.
<i>Renauidia lycopodioides</i>	Tan, B.C.
<i>Riccia atlantica</i>	Geissler, P.
<i>Scapania sphaerifera</i>	Söderström, L.
<i>Scaphophyllum speciosum</i>	Söderström, L.
<i>Schistochila macrodonta</i>	Söderström, L.
<i>Schistochila undulatifolia</i>	Söderström, L.
<i>Sciariomopsis sinensis</i>	Tan, B.C.
<i>Sewardiella tuberifera</i>	Söderström, L.
<i>Skottsbergia paradoxa</i>	Tan, B.C.
<i>Sphaerocarpos drewei</i>	Geissler, P.
<i>Sphaerolejeunea umbilicata</i>	Geissler, P.
<i>Sphagnum leucobryoides</i>	Hallingbäck, T.
<i>Sphagnum novo-caledoniae</i>	Hallingbäck, T.
<i>Spruceanthus theobromae</i>	Geissler, P.
<i>Stephensoniella brevipedunculata</i>	Geissler, P.
<i>Symbiezidium madagascariensis</i>	Geissler, P.
<i>Takakia ceratophylla</i>	Tan, B.C.
<i>Taxitheliella richardsii</i>	Tan, B.C.
<i>Thamnobryum angustifolium</i>	Tan, B.C.
<i>Thamnobryum fernandesii</i>	Tan, B.C.
<i>Vandiemenia ratkowskiana</i>	Geissler, P.

Evaluators for the entire Red List: Tomas Hallingbäck, Nick Hodgetts, Patricia Geissler (†), and Ben Tan.

Examples of Projects for Bryophyte Conservation

These are examples only, but they can be used as a measure of success to monitor whether or not this Action Plan is being implemented while these are still in the very conceptual stages. If readers are interested in undertaking these projects please contact the Bryophyte Specialist Group.

1. Gypsum sites and salinas in southwest Europe

Contact: Dr Rosa Maria Espinosa, Dept. Biología Vegetal Fac. de Biología, Universidad de Murcia 30100 Murcia, SPAIN

Email: rmros@fcu.um.es; Fax: (34) 6 836 3963, Tel: (34) 6 830 7100 X 2385

Aim: To mitigate the threats to the bryophyte floras of gypsum outcrops and inland saline soil in the southeastern part of the Iberian Peninsula.

Background: Earlier studies undertaken in southeast Spain have shown that numerous species of bryophytes exclusive to gypsum-rich and saline soils are threatened. Commercial exploitation for the building industry and quarries resulting from this activity are filling these sites with rubbish and waste from factories, farms, etc. Saline soils are increasingly being reclaimed for farming by drainage, etc.

Action needed: Studies directed at the species exclusive to these habitats will stimulate measures to protect some of these habitats, following representations to the appropriate authorities.

Estimated start-up cost: US\$40,000

2. Red List of Russian Arctic Hepaticae

Contact: Dr. Nadezhda A. Konstantinova, Polar-Alpine Botanical Garden, Kirovsk-6 Murmansk Prov. 184230, RUSSIA

Email: nadyak@ksc-bg.murmansk.su; Fax: (7) 81 555 30925; Tel: (7) 81 531 93189

Aim: To assess the status of rare and endangered species in the Russian Arctic and establish protected areas for their conservation.

Background: Russia includes the largest sector of the

Arctic. A great part of this has been destroyed by the building of pipelines (as on the Yamal and Talimyr Peninsulas), by heavy mining and smelting (Kola and Talimyr Peninsulas), and by tanks and other vehicles. The number of nature reserves in the Russian Arctic are very few and comparatively small.

Action needed: An analysis of both the distribution patterns of rare and endangered species, and the causes of threats to these species is needed. The delimitation of regions with high concentrations of the rare and endangered species, and the preparation of proposals for the establishment of protected areas.

Estimated start-up cost: US\$10,000.

3. Mosses as bioindicators and influences of pollutants on moss communities

Contact: Dr. H.R. Felix, Bündtenstrasse 20, CH-4419 Lupsingen, SWITZERLAND

Aim: It is important to determine which species of bryophytes are declining due to air pollution, and how to mitigate the depletion of sensitive bryophyte communities in regions heavily impacted by air pollution.

Background: Today, there is a wealth of information about concentrations of air pollutants in many countries and regions, but hardly any analysis of how air pollution affects bryophyte communities and rare species. Many recent studies have concentrated on a limited number of widespread bryophyte species and not on rare species or whole communities.

Action needed: To develop a study on the changes of the bryophyte flora as a result of different kinds of air pollution.

Estimated start-up cost: US\$10,000

4. Conservation of rare and endangered bryophytes of India

Contact: Dr. Virendra Nath, Head of Bryological Section of National Botanical research Institute, Lucknow 226001, INDIA

Email: manager@nbri.sirnet.ed.ernet.in.

Aim: In order to increase bryophyte conservation actions in India, it is first important to survey all known bryologically rich localities, and make an assessment of the level of threat to various species, habitats, and sites, including an analysis of the causes of threat. The second step is to compile a Red Data Book of Indian bryophytes and specify all major conservation measures that need to be taken.

Background: It has recently been observed in India that a tremendous loss of bryoflora is occurring due to deforestation, agricultural and industrial development, extensive buildings of roads, hotels, etc., as well as selective harvesting of bryophytes to prepare moss sticks and moss bags used for various horticultural purposes.

Action needed: It is important to begin these surveys and the Red Data Book project as soon as possible. Support must also be sought from the Ministry of Environment and Forests of the Government of India in order to make this project official and to ensure that it is high-profile.

Estimated start-up cost: US\$40,000

5. Towards the conservation of montane cloud forests and páramo vegetation in the Los Nevados area, central Cordillera, Colombia

Contact: Dr. Jan H. D. Wolf, ECOSUR
Apdo. Postal No. 63 29290 San Cristobal de Las Casas
Chiapas, MEXICO
Email: jwolf@slc.ecosur.mx, Fax: (52) 967 82322, Tel: (52) 967 81883 X 5106

Aim: First, to protect part of a well-studied montane cloud forest in the central Cordillera of Colombia, which is extremely rich in bryophyte species and under immediate threat. Second, to educate and inform the local public about conservation and sustainable land use. The final objective is to conserve the ecosystems in their natural state and on a long-term basis.

Background: The primary montane cloud forest in the Andes is disappearing at an average rate of approximately 500 km²/yr., and in some parts of central Cordillera the rate of destruction is even greater. The montane cloud-forests and páramo vegetation in the Los Nevados area, central Cordillera, Colombia, contain an exclusive and extremely diverse flora and fauna, including many rare bryophytes. The forest is a unique example of a so-called 'mossy forest'. There is not a single forest known worldwide where the organic bryophytic mass that covers the trees is

more exuberant in terms of thickness and weight. Moreover, the ecosystems in this particular area have additional value in that they are well known to the international scientific community, having been the subject of over 75 publications.

Action needed: To first bring 1,500ha of privately owned terrain into a nature reserve. Construction of an elementary biological field station and education centre is also needed. This station will also house a permanent guard and manager.

Estimated start-up cost: US\$50,000.

6. Endangered Marchantiales in the Himalaya

Contact: Dr. David Long, Royal Botanic Garden
Edinburgh, Scotland EH3 5LR, UNITED KINGDOM
Email: d.long@rbge.org.uk, Fax: (44) 131 552 0382

Aim: To assess the actual status of a number of critically endangered species belonging to the order Marchantiales, which are endemic to the Himalaya, in order to establish reliable baseline data.

Background: Several species belonging to the hepatic group Marchantiales occurring in the Indian part of the Himalayan southern slopes have repeatedly been reported as near extinction.

Action needed: In order to evaluate this information thoroughly, a bryological expedition is needed to visit all known sites again and search for these species.

Estimated start-up cost: US\$5,000

7. An Updated Red List of Chinese mosses

Contact: Dr. Benito C Tan, Department of Botany, School of Biological Sciences, National Univ. of Singapore
Singapore, 119260, SINGAPORE
Email: dbsbct@nus.edu.sg

Aim: To identify the currently most endangered moss species in China, following the new IUCN criteria and guidelines for bryophytes (Hallingbäck *et al.* 1998) in selecting the regionally most threatened bryophytes.

Background: For a vast country like China with a rich, diverse, but much threatened flora, there is an urgent need to summarise the present knowledge of the status of

endangered moss species. This information can be brought to the Chinese governmental institutions and agencies, urging the need for their protection. A recent Red Data Book of Chinese plant species was published but did not include the bryophytes and other cryptogams. With the publication of the updated checklist of Chinese mosses by Redfearn, Tan, and He (1996), which includes local distribution or range for each of the species known from China, the baseline information is available to attempt to compile a scientifically based Red List of Chinese mosses.

Action needed: The project has already started and we are now preparing the next steps. A series of workshops will be organised for the participants of this project. The workshops will continue to nominate, review, and discuss the most endangered mosses of the country, following the IUCN criteria in its selection of the most endangered bryophytes. A consensus list of the most endangered moss species in China will be the main outcome of this workshop. The list will include habitat and distribution information for each of the selected mosses. A joint appeal, to all concerned government bureaucracies identified at the meeting, for immediate protection of these endangered mosses will be drafted and issued, hopefully creating mass media attention. The project requests the travel, lodging, and food expenses for the participants in China for the three days duration, and also for the project proponent from abroad to be present at the mini-workshop. The project proponent, B. C. Tan, is an active member of the IUCN/SSC Bryophyte Specialist Group and International Association of Bryologists Committee on Endangered Bryophytes and is deemed the appropriate person to participate in the workshop in order to assure that the outcome of the project will meet the IUCN criteria and international scientists' expectations.

Estimated start-up cost: US\$10,000.

8. Assessment of the conservation status of three highly endangered bryophyte species of Ecuador

Contact: Prof. S. Rob Gradstein, Systematisch-Geobotanisches Institut, University of Göttingen, Untere Karspüle 2, D-73073 Göttingen, GERMANY
Email: sgradst@gwdg.de

Aim: To assess the conservation status of three endemic bryophyte species of Ecuador, *Fissidens hydropogon* Spruce ex Mitt., *Myriocolea irrorata* Spruce, and *Spruceanthus theobromae* (Spruce) Gradst., that are listed as Endangered in the 2000 IUCN World Red List of Bryophytes.

Background: These three species are very rare and are known from only one or two localities. Two of them, *Fissidens hydropogon* and *Myriocolea irrorata*, were collected once, about 150 years ago, and have not been seen since; *Spruceanthus theobromae* has been collected around 1850, in 1947, and in 1997. All species seem to be characteristic of lowland or submontane rainforest areas. Since much of the forest in the areas where the species were collected has been destroyed, the species are obviously highly endangered and may be near extinction. An assessment of their conservation status is, therefore, urgently needed. Such action is also important in view of the special evolutionary and biogeographical status of the three taxa: *Myriocolea* is a monotypic genus, *Spruceanthus theobromae* is the only neotropical representative of an Asiatic genus, and *Fissidens hydropogon* is the only neotropical species of the subgenus *Pachyfissidens*.

Action needed: In order to evaluate their current status, a team of trained bryologists should revisit the known sites of the species and undertake a thorough search of these areas.

Cost: US\$8000

Resolutions from the Second Symposium on Conservation of Bryophytes in Europe held in Zürich, 5–8 September 1994

Concerning political activities of the European Committee for Conservation of Bryophytes (ECCB) proposed by the second working group of the conference in Zürich 1994:

1. ECCB should request national authorities to include the sites listed in the European Bryophyte Site Register in the list of sites representing natural habitat types cited in Annex I of the Habitat and Species Directive, insofar as the 'important bryophyte sites' are covered by Annex I habitat types and are within the EU territory. National authorities should be requested to designate these sites as Special Areas of Conservation.

2. ECCB should ask the scientific community to propose a strategy to promote the interests of plant conservation to be undertaken through the Cohesion Fund and the Structural Fund of EU.

3. ECCB urges that all EU and national environmental legislation concerned, for example, with maintaining the quality of air, soil and water, and with disposal of waste, should make appropriate provision for the conservation of bryophytes and other plants, and that such legislation should be implemented through sectorial policies concerned with matters such as energy, agriculture, industry, transport, and tourism.

4. ECCB should seek to ensure that bryophyte and other non-vascular plants are given equal weight with vascular plants and animals in conservation legislation throughout Europe and elsewhere.

5. ECCB should collaborate with the IUCN legal programme to develop strategies aimed at ensuring that

the judiciary and other authorities involved in enforcing environmental legislation are adequately trained in conservation biology, with particular attention to plant conservation.

6. ECCB and the IUCN specialist group for Eastern Europe should offer to collaborate with administrative authorities, the Academies of Science in Eastern European countries, and other relevant bodies, with the objective of developing the structure necessary to strengthen and enforce legislation aimed at conserving bryophytes and other plants.

7. ECCB recommends that funding agencies, such as the World Bank and the EU Commission through its PHARE programme, should allocate a significant percentage of their development aid to nature conservation within their environmental programmes. It is recommended that the governments of all European countries should recognise the need to make adequate financial provision for measuring designed to conserve bryophytes and other plants.

8. ECCB should collaborate with scientists from throughout Europe within its action plans for bryophyte conservation by offering to share expertise, and in other appropriate ways.

Concerning Kutsa area (proposed by N. A. Konstantinova)
The Symposium of the 'European Committee for Conservation of Bryophytes' (ECCB), held in 1994 in Zürich on the conservation of threatened bryophytes in Europe, requests the competent authorities to give legal protection to the territory of Kutsa area (Murmansk Province, Russia).

Resolutions Adopted by the Second Planta Europa Conference

Uppsala, Sweden, 13 June 1998

4. THE CONSERVATION OF CRYPTOGRAMS

CONSIDERING the ecological importance of cryptogams, as shown:

a) in the fungi by mycorrhizal symbionts, decomposers of litter and wood, in the lichens by primary colonisation of bare substrates, and in the mosses and liverworts by their water-retention capacity, and

b) by the great species diversity in cryptogams, comprising mosses (c. 1200 species in Europe), liverworts (c. 500 species in Europe), lichens (c. 2500 species in Europe), fungi (c. 30,000 species in Europe), and algae;

NOTING the decline and threatened status of many species in Europe, as shown by:

a) the European Bryophyte Red Data Book, which lists c. 25% of the flora as threatened;

b) the list of threatened lichens in the European Union;

c) the national Red Lists of macrofungi, which include a total of c. 3000 species threatened in at least one country;

The participants of Planta Europa, the second conference on the conservation of wild plants, meeting in Uppsala, Sweden, 9–14 June 1998:

1. ENCOURAGE the botanical community to make increased efforts to raise awareness among scientists, land managers, politicians, and conservationists of the importance of cryptogams, by means of education and publicity;

2. ENCOURAGE nature conservation organisations to employ cryptogamic botanists to facilitate the conservation of cryptogams;

3. URGE the compilation of national checklists of cryptogamic taxa and their amalgamation into a European

checklist, with an indication of the distribution of each species; and the publication of Red Lists and the production of popular publications to promote conservation and raise the status of cryptogams;

4. RECOMMEND that the Standing Committee of the Berne Convention and the European Commission consider the inclusion on Appendix 1 of the Berne Convention and Annexes II and IV of the Habitats Directive, of selected threatened fungi (including lichenised fungi), in particular species

a) that are distinctive,

b) that represent specific habitats,

c) that occur in communities with many other threatened cryptogams, and

d) that are representative of sites rich in cryptogams;

5. FURTHER RECOMMEND that the European Union consider the need for including on Annex V of the Habitats Directive (92/43/EEC) the larger fungi and lichens that are commercially harvested on a large scale, and of strengthening the wording of the accompanying Article 14, and to assist this process RECOMMEND that a project be undertaken to determine the influence of mushroom harvesting in Europe, both on the long-term sustainability of these fungi and the secondary effects on their habitats;

6. SUGGEST that conservation agencies make special efforts to promote the effective conservation of habitats in which cryptogams form a significant component, such as semi-natural grasslands, bogs, sand dunes, saxicolous and epiphytic communities, and forests on oligotrophic soils;

7. COMMEND the use of cryptogams as indicator species for the identification of ancient habitats that are of special importance for rare and threatened species, such as ancient grasslands, old-growth forests, and pasture woodland;

8. RECOMMEND the development of an *ex-situ* strategy for the conservation of cryptogams in Europe and its integration into conservation programmes.

IUCN/SSC Bryophyte Specialist Group Members and Contributing Authors

René J. Belland – Member
Devonian Botanic Garden
University of Alberta, Edmonton
Alberta T6G 2E1
CANADA
E-mail:
rbelland@pop.srv.ualberta.ca

Patricia Geissler (†) – Member

Robbert S. Gradstein – Member
Systematisch-Geobotanisches Institut
University of Göttingen
Untere Karspüle 2
D-73073 Göttingen
GERMANY
E-mail: sgradst@gwdg.de

Tomas Hallingbäck – Member (chair)
Swedish Threatened Species Unit
Swedish University of Agricultural
Sciences
P O Box 7007
S-75007 Uppsala
SWEDEN
E-mail:
tomas.hallingback@dha.slu.se

Nick G. Hodgetts – Member
Joint Nature Conservation
Committee
Monkstone House, City Road,
Peterborough PE1 1JY
UNITED KINGDOM
E-mail: hodget_n@jncc.gov.uk

Celina M. Matteri – Member
Museo Argentino de Ciencias
Naturales
Av. Angel Gallaedo 470
1405 Buenos Aires
ARGENTINA
E-mail: cmatteri@muanbe.gov.ar

Brian O'Shea
141 Fawnbrake Avenue,
London SE24 0BG
UNITED KINGDOM
E-mail: Brian@oshea.demon.co.uk

Tamás Pócs – Member
Felsotarkany,
Ady E.u. 67,
H-3324,
HUNGARY
E-mail: colura@gemini.ektf.hu

Geert Raeymaekers – Member
Ecosystem LTD
Beckersstraat 11
B-1050 Brussel
BELGIUM
E-mail: ecosystems.ltd@glo.be

Wilfred Schofield
Department of Botany
University of British Columbia
Vancouver
BC V6T 1W5
CANADA
wilfs@interchg.ubc.ca

Cecilia Sérgio – Member
Museu Laboratório Botânico
Faculdade de Ciências
P-1294 Lisboa Codex
PORTUGAL
E-mail: csergio@fc.ul.pt

Lars Söderström – Member
Department of Botany
Norwegian University of Science
and Technology
Trondheim,
N-7055 Dragvoll
NORWAY
E-mail: Larss@alfa.itea.ntnu.no

Heinar Streimann – Member
Australian National Botanical
Gardens
GPO Box 1777
Canberra, A.C.T.2601,
AUSTRALIA
E-mail: heinar@anbg.gov.au

Benito C. Tan – Member
Department of Botany
School of Biological Sciences
National Univ. of Singapore,
Singapore
119260 SINGAPORE
E-mail: dbsbct@nus.edu.sg

Edwin Urmi – Member
Institut für Syst. Botanik
Zürcher Universität
Zollikerstrasse 107
CH-8008 Zürich
SWITZERLAND
E-mail: urmi@systbot.unizh.ch

Jiří Váňa – Member
Department of Botany
Faculty of Natural Sciences
Charles University, Benátská 2,
CS-128 01, Praha 2
CZECH REPUBLIC
E-mail: vana@prfdec.natur.cuni.cz

IUCN Red List Categories

Prepared by the IUCN Species Survival Commission
As approved by the 40th Meeting of the IUCN Council, Gland, Switzerland
30 November 1994

I) Introduction

1. The threatened species categories now used in Red Data Books and Red Lists have been in place, with some modification, for almost 30 years. Since their introduction these categories have become widely recognised internationally, and they are now used in a whole range of publications and listings, produced by IUCN as well as by numerous governmental and non-governmental organisations. The Red Data Book categories provide an easily and widely understood method for highlighting those species under higher extinction risk, so as to focus attention on conservation measures designed to protect them.

2. The need to revise the categories has been recognised for some time. In 1984, the SSC held a symposium, 'The Road to Extinction' (Fitter and Fitter 1987), which examined the issues in some detail, and at which a number of options were considered for the revised system. However, no single proposal resulted. The current phase of development began in 1989 with a request from the SSC Steering Committee to develop a new approach that would provide the conservation community with useful information for action planning.

In this document, proposals for new definitions for Red List categories are presented. The general aim of the new system is to provide an explicit, objective framework for the classification of species according to their extinction risk.

The revision has several specific aims:

- to provide a system that can be applied consistently by different people;
- to improve the objectivity by providing those using the criteria with clear guidance on how to evaluate different factors which affect risk of extinction;
- to provide a system which will facilitate comparisons across widely different taxa;
- to give people using threatened species lists a better understanding of how individual species were classified.

3. The proposals presented in this document result from a continuing process of drafting, consultation and validation. It was clear that the production of a large number of draft proposals led to some confusion, especially as each draft has been used for classifying some set of species for conservation purposes. To clarify matters, and to open the way for modifications as and when they became necessary, a system for version numbering was applied as follows:

Version 1.0: Mace & Lande (1991)

The first paper discussing a new basis for the categories, and presenting numerical criteria especially relevant for large vertebrates.

Version 2.0: Mace *et al.* (1992)

A major revision of Version 1.0, including numerical criteria appropriate to all organisms and introducing the non-threatened categories.

Version 2.1: IUCN (1993)

Following an extensive consultation process within SSC, a number of changes were made to the details of the criteria, and fuller explanation of basic principles was included. A more explicit structure clarified the significance of the non-threatened categories.

Version 2.2: Mace & Stuart (1994)

Following further comments received and additional validation exercises, some minor changes to the criteria were made. In addition, the Susceptible category present in Versions 2.0 and 2.1 was subsumed into the Vulnerable category. A precautionary application of the system was emphasised.

Final Version

This final document, which incorporates changes as a result of comments from IUCN members, was adopted by the IUCN Council in December 1994.

All future taxon lists including categorisations should be based on this version, and not the previous ones.

4. In the rest of this document the proposed system is outlined in several sections. The Preamble presents some basic information about the context and structure of the proposal, and the procedures that are to be followed in applying the definitions to species. This is followed by a section giving definitions of terms used. Finally the definitions are presented, followed by the quantitative criteria used for classification within the threatened categories. It is important for the effective functioning of the new system that all sections are read and understood, and the guidelines followed.

References:

- Fitter, R., and M. Fitter, ed. (1987) *The Road to Extinction*. Gland, Switzerland: IUCN.
- IUCN. (1993) *Draft IUCN Red List Categories*. Gland, Switzerland: IUCN.
- Mace, G. M. *et al.* (1992) "The development of new criteria for listing species on the IUCN Red List." *Species* 19: 16–22.
- Mace, G. M., and R. Lande. (1991) "Assessing extinction threats: toward a reevaluation of IUCN threatened species categories." *Conserv. Biol.* 5.2: 148–157.
- Mace, G. M. & S. N. Stuart. (1994) "Draft IUCN Red List Categories, Version 2.2". *Species* 21–22: 13–24.

II) Preamble

The following points present important information on the use and interpretation of the categories (= Critically Endangered, Endangered, etc.), criteria (= A to E), and sub-criteria (= a,b etc., i,ii etc.):

1. Taxonomic level and scope of the categorisation process

The criteria can be applied to any taxonomic unit at or below the species level. The term 'taxon' in the following notes, definitions and criteria is used for convenience, and may represent species or lower taxonomic levels, including forms that are not yet formally described. There is a sufficient range among the different criteria to enable the appropriate listing of taxa from the complete taxonomic spectrum, with the exception of micro-organisms. The criteria may also be applied within any specified geographical or political area although in such cases special notice should be taken of point 11 below. In presenting the results of applying the criteria, the taxonomic unit and area under consideration should be made explicit. The categorisation process should only be applied to wild populations inside their natural range, and to populations resulting from benign introductions (defined in the draft IUCN Guidelines for Re-introductions as "... an attempt to establish a species, for the purpose of conservation, outside its recorded distribution, but within an appropriate habitat and eco-geographical area").

2. Nature of the categories

All taxa listed as Critically Endangered qualify for Vulnerable and Endangered, and all listed as Endangered qualify for Vulnerable. Together these categories are described as 'threatened'. The threatened species categories form a part of the overall scheme. It will be possible to place all taxa into one of the categories (see Figure 1).

3. Role of the different criteria

For listing as Critically Endangered, Endangered or Vulnerable there is a range of quantitative criteria; meeting any one of these criteria qualifies a taxon for listing at that level of threat. Each species should be evaluated against all the criteria. The different criteria (A–E) are derived from a wide review aimed at detecting risk factors across the broad range of organisms and the diverse life histories they exhibit. Even though some criteria will be inappropriate for certain taxa (some taxa will

never qualify under these however close to extinction they come), there should be criteria appropriate for assessing threat levels for any taxon (other than micro-organisms). The relevant factor is whether any one criterion is met, not whether all are appropriate or all are met. Because it will never be clear which criteria are appropriate for a particular species in advance, each species should be evaluated against all the criteria, and any criterion met should be listed.

4. Derivation of quantitative criteria

The quantitative values presented in the various criteria associated with threatened categories were developed through wide consultation and they are set at what are generally judged to be appropriate levels, even if no formal justification for these values exists. The levels for different criteria within categories were set independently but against a common standard. Some broad consistency between them was sought. However, a given taxon should not be expected to meet all criteria (A–E) in a category; meeting any one criterion is sufficient for listing.

5. Implications of listing

Listing in the categories of Not Evaluated and Data Deficient indicates that no assessment of extinction risk has been made, though for different reasons. Until such time as an assessment is made, species listed in these categories should not be treated as if they were non-threatened, and it may be appropriate (especially for Data Deficient forms) to give them the same degree of protection as threatened taxa, at least until their status can be evaluated.

Extinction is assumed here to be a chance process. Thus, a listing in a higher extinction risk category implies a higher expectation of extinction, and over the time-frames specified more taxa listed in a higher category are expected to go extinct than in a lower one (without effective conservation action). However, the persistence of some taxa in high risk categories does not necessarily mean their initial assessment was inaccurate.

6. Data quality and the importance of inference and projection

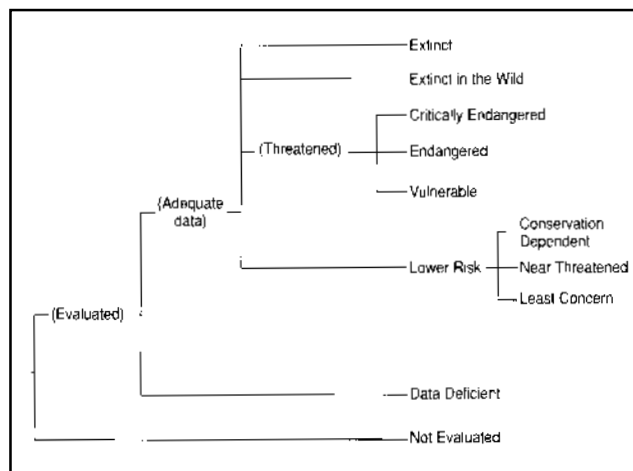
The criteria are clearly quantitative in nature. However, the absence of high quality data should not deter attempts at applying the criteria, as methods involving estimation, inference and projection are emphasised to be acceptable throughout. Inference and projection may be based on extrapolation of current or potential threats into the future (including their rate of change), or of factors related to population abundance or distribution (including dependence on other taxa), so long as these can reasonably be supported. Suspected or inferred patterns in either the recent past, present or near future can be based on any of a series of related factors, and these factors should be specified.

Taxa at risk from threats posed by future events of low probability but with severe consequences (catastrophes) should be identified by the criteria (e.g. small distributions, few locations). Some threats need to be identified particularly early, and appropriate actions taken, because their effects are irreversible, or nearly so (pathogens, invasive organisms, hybridization).

7. Uncertainty

The criteria should be applied on the basis of the available evidence on taxon numbers, trend and distribution, making due allowance for statistical and other uncertainties. Given that data are rarely available for the whole range or population of a taxon, it may often be appropriate to use the information

Figure 1: Structure of the Categories



that is available to make intelligent inferences about the overall status of the taxon in question. In cases where a wide variation in estimates is found, it is legitimate to apply the precautionary principle and use the estimate (providing it is credible) that leads to listing in the category of highest risk.

Where data are insufficient to assign a category (including Lower Risk), the category of 'Data Deficient' may be assigned. However, it is important to recognise that this category indicates that data are inadequate to determine the degree of threat faced by a taxon, not necessarily that the taxon is poorly known. In cases where there are evident threats to a taxon through, for example, deterioration of its only known habitat, it is important to attempt threatened listing, even though there may be little direct information on the biological status of the taxon itself. The category 'Data Deficient' is not a threatened category, although it indicates a need to obtain more information on a taxon to determine the appropriate listing.

8. Conservation actions in the listing process

The criteria for the threatened categories are to be applied to a taxon whatever the level of conservation action affecting it. In cases where it is only conservation action that prevents the taxon from meeting the threatened criteria, the designation of 'Conservation Dependent' is appropriate. It is important to emphasise here that a taxon require conservation action even if it is not listed as threatened.

9. Documentation

All taxon lists including categorisation resulting from these criteria should state the criteria and sub-criteria that were met. No listing can be accepted as valid unless at least one criterion is given. If more than one criterion or sub-criterion was met, then each should be listed. However, failure to mention a criterion should not necessarily imply that it was not met. Therefore, if a re-evaluation indicates that the documented criterion is no longer met, this should not result in automatic down-listing. Instead, the taxon should be re-evaluated with respect to all criteria to indicate its status. The factors responsible for triggering the criteria, especially where inference and projection are used, should at least be logged by the evaluator, even if they cannot be included in published lists.

10. Threats and priorities

The category of threat is not necessarily sufficient to determine priorities for conservation action. The category of threat simply provides an assessment of the likelihood of extinction under current circumstances, whereas a system for assessing priorities for action will include numerous other factors concerning conservation action such as costs, logistics, chances of success, and even perhaps the taxonomic distinctiveness of the subject.

11. Use at regional level

The criteria are most appropriately applied to whole taxa at a global scale, rather than to those units defined by regional or national boundaries. Regionally or nationally based threat categories, which are aimed at including taxa that are threatened at regional or national levels (but not necessarily throughout their global ranges), are best used with two key pieces of information: the global status category for the taxon, and the proportion of the global population or range that occurs within the region or nation. However, if applied at regional or national level it must be recognised that a global category of threat may not be the same as a regional or national category for a particular taxon. For example, taxa classified as Vulnerable on the basis of their global declines in numbers or range might

be Lower Risk within a particular region where their populations are stable. Conversely, taxa classified as Lower Risk globally might be Critically Endangered within a particular region where numbers are very small or declining, perhaps only because they are at the margins of their global range. IUCN is still in the process of developing guidelines for the use of national red list categories.

12. Re-evaluation

Evaluation of taxa against the criteria should be carried out at appropriate intervals. This is especially important for taxa listed under Near Threatened, or Conservation Dependent, and for threatened species whose status is known or suspected to be deteriorating.

13. Transfer between categories

There are rules to govern the movement of taxa between categories. These are as follows: (A) A taxon may be moved from a category of higher threat to a category of lower threat if none of the criteria of the higher category has been met for five years or more. (B) If the original classification is found to have been erroneous, the taxon may be transferred to the appropriate category or removed from the threatened categories altogether, without delay (but see Section 9). (C) Transfer from categories of lower to higher risk should be made without delay.

14. Problems of scale

Classification based on the sizes of geographic ranges or the patterns of habitat occupancy is complicated by problems of spatial scale. The finer the scale at which the distributions or habitats of taxa are mapped, the smaller the area will be that they are found to occupy. Mapping at finer scales reveals more areas in which the taxon is unrecorded. It is impossible to provide any strict but general rules for mapping taxa or habitats; the most appropriate scale will depend on the taxa in question, and the origin and comprehensiveness of the distributional data. However, the thresholds for some criteria (e.g. Critically Endangered) necessitate mapping at a fine scale.

III) Definitions

1. Population

Population is defined as the total number of individuals of the taxon. For functional reasons, primarily owing to differences between life-forms, population numbers are expressed as numbers of mature individuals only. In the case of taxa obligately dependent on other taxa for all or part of their life cycles, biologically appropriate values for the host taxon should be used.

2. Subpopulations

Subpopulations are defined as geographically or otherwise distinct groups in the population between which there is little exchange (typically one successful migrant individual or gamete per year or less).

3. Mature individuals

The number of mature individuals is defined as the number of individuals known, estimated or inferred to be capable of reproduction. When estimating this quantity the following points should be borne in mind:

- Where the population is characterised by natural fluctuations the minimum number should be used.

- This measure is intended to count individuals capable of reproduction and should therefore exclude individuals that are environmentally, behaviourally or otherwise reproductively suppressed in the wild.
- In the case of populations with biased adult or breeding sex ratios it is appropriate to use lower estimates for the number of mature individuals which take this into account (e.g. the estimated effective population size).
- Reproducing units within a clone should be counted as individuals, except where such units are unable to survive alone (e.g. corals).
- In the case of taxa that naturally lose all or a subset of mature individuals at some point in their life cycle, the estimate should be made at the appropriate time, when mature individuals are available for breeding.

4. Generation

Generation may be measured as the average age of parents in the population. This is greater than the age at first breeding, except in taxa where individuals breed only once.

5. Continuing decline

A continuing decline is a recent, current or projected future decline whose causes are not known or not adequately controlled and so is liable to continue unless remedial measures are taken. Natural fluctuations will not normally count as a continuing decline, but an observed decline should not be considered to be part of a natural fluctuation unless there is evidence for this.

6. Reduction

A reduction (criterion A) is a decline in the number of mature individuals of at least the amount (%) stated over the time period (years) specified, although the decline need not still be continuing. A reduction should not be interpreted as part of a natural fluctuation unless there is good evidence for this. Downward trends that are part of natural fluctuations will not normally count as a reduction.

7. Extreme fluctuations

Extreme fluctuations occur in a number of taxa where population size or distribution area varies widely, rapidly and frequently, typically with a variation greater than one order of magnitude (i.e. a tenfold increase or decrease).

8. Severely fragmented

Severely fragmented refers to the situation where increased extinction risks to the taxon result from the fact that most individuals within a taxon are found in small and relatively isolated subpopulations. These small subpopulations may go extinct, with a reduced probability of recolonisation.

9. Extent of occurrence

Extent of occurrence is defined as the area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon, excluding cases of vagrancy. This measure may exclude discontinuities or disjunctions within the overall distributions of taxa (e.g. large areas of obviously unsuitable habitat) (but see 'area of occupancy'). Extent of occurrence can often be measured by a minimum convex polygon (the smallest polygon in which no internal angle exceeds 180 degrees and which contains all the sites of occurrence).

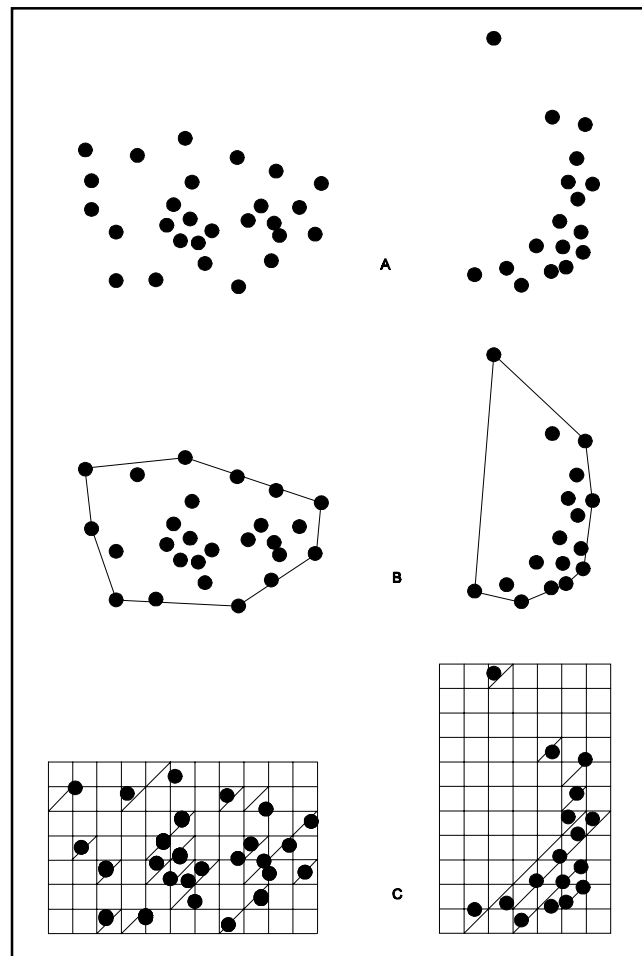


Figure 2: Two examples of the distinction between extent of occurrence and area of occupancy. (a) is the spatial distribution of known, inferred or projected sites of occurrence. (b) shows one possible boundary to the extent of occurrence, which is the measured area within this boundary. (c) shows one measure of area of occupancy which can be measured by the sum of the occupied grid squares.

10. Area of occupancy

Area of occupancy is defined as the area within its 'extent of occurrence' (see definition) which is occupied by a taxon, excluding cases of vagrancy. The measure reflects the fact that a taxon will not usually occur throughout the area of its extent of occurrence, which may, for example, contain unsuitable habitats. The area of occupancy is the smallest area essential at any stage to the survival of existing populations of a taxon (e.g. colonial nesting sites, feeding sites for migratory taxa). The size of the area of occupancy will be a function of the scale at which it is measured, and should be at a scale appropriate to relevant biological aspects of the taxon. The criteria include values in km², and thus to avoid errors in classification, the area of occupancy should be measured on grid squares (or equivalents) which are sufficiently small (see Figure 2).

11. Location

Location defines a geographically or ecologically distinct area in which a single event (e.g. pollution) will soon affect all individuals of the taxon present. A location usually, but not always, contains all or part of a subpopulation of the taxon, and is typically a small proportion of the taxon's total distribution.

12. Quantitative analysis

A quantitative analysis is defined here as the technique of population viability analysis (PVA), or any other quantitative form of analysis, which estimates the extinction probability of a taxon or population based on the known life history and specified management or non-management options. In presenting the results of quantitative analyses the structural equations and the data should be explicit.

IV) The Categories ¹

EXTINCT (EX)

A taxon is Extinct when there is no reasonable doubt that the last individual has died.

EXTINCT IN THE WILD (EW)

A taxon is Extinct in the wild when it is known only to survive in cultivation, in captivity or as a naturalised population (or populations) well outside the past range. A taxon is presumed extinct in the wild when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycle and life form.

CRITICALLY ENDANGERED (CR)

A taxon is Critically Endangered when it is facing an extremely high risk of extinction in the wild in the immediate future, as defined by any of the criteria (A to E) on pages 101–102.

ENDANGERED (EN)

A taxon is Endangered when it is not Critically Endangered but is facing a very high risk of extinction in the wild in the near future, as defined by any of the criteria (A to E) on page 102.

VULNERABLE (VU)

A taxon is Vulnerable when it is not Critically Endangered or Endangered but is facing a high risk of extinction in the wild in the medium-term future, as defined by any of the criteria (A to D) on pages 102 and 103.

LOWER RISK (LR)

A taxon is Lower Risk when it has been evaluated, does not satisfy the criteria for any of the categories Critically Endangered, Endangered or Vulnerable. Taxa included in the Lower Risk category can be separated into three subcategories:

1. **Conservation Dependent (cd).** Taxa which are the focus of a continuing taxon-specific or habitat-specific conservation programme targeted towards the taxon in question, the cessation of which would result in the taxon qualifying for one of the threatened categories above within a period of five years.
2. **Near Threatened (nt).** Taxa which do not qualify for Conservation Dependent, but which are close to qualifying for Vulnerable.
3. **Least Concern (lc).** Taxa which do not qualify for Conservation Dependent or Near Threatened.

DATA DEFICIENT (DD)

A taxon is Data Deficient when there is inadequate information to make a direct, or indirect, assessment of its

risk of extinction based on its distribution and/or population status. A taxon in this category may be well studied, and its biology well known, but appropriate data on abundance and/or distribution is lacking. Data Deficient is therefore not a category of threat or Lower Risk. Listing of taxa in this category indicates that more information is required and acknowledges the possibility that future research will show that threatened classification is appropriate. It is important to make positive use of whatever data are available. In many cases great care should be exercised in choosing between DD and threatened status. If the range of a taxon is suspected to be relatively circumscribed, if a considerable period of time has elapsed since the last record of the taxon, threatened status may well be justified.

NOT EVALUATED (NE)

A taxon is Not Evaluated when it has not yet been assessed against the criteria.

V) The Criteria for Critically Endangered, Endangered and Vulnerable

CRITICALLY ENDANGERED (CR)

A taxon is Critically Endangered when it is facing an extremely high risk of extinction in the wild in the immediate future, as defined by any of the following criteria (A to E):

A) Population reduction in the form of either of the following:

- 1) An observed, estimated, inferred or suspected reduction of at least 80% over the last 10 years or three generations, whichever is the longer, based on (and specifying) any of the following:
 - a) direct observation
 - b) an index of abundance appropriate for the taxon
 - c) a decline in area of occupancy, extent of occurrence and/or quality of habitat
 - d) actual or potential levels of exploitation
 - e) the effects of introduced taxa, hybridisation, pathogens, pollutants, competitors or parasites.

- 2) A reduction of at least 80%, projected or suspected to be met within the next 10 years or three generations, whichever is the longer, based on (and specifying) any of (b), (c), (d) or (e) above.

B) Extent of occurrence estimated to be less than 100km² or area of occupancy estimated to be less than 10km², and estimates indicating any two of the following:

- 1) Severely fragmented or known to exist at only a single location.
- 2) Continuing decline, observed, inferred or projected, in any of the following:
 - a) extent of occurrence
 - b) area of occupancy
 - c) area, extent and/or quality of habitat
 - d) number of locations or subpopulations
 - e) number of mature individuals.

- 3) Extreme fluctuations in any of the following:

- a) extent of occurrence
- b) area of occupancy
- c) number of locations or subpopulations
- d) number of mature individuals.

C) Population estimated to number less than 250 mature individuals and either:

- 1) An estimated continuing decline of at least 25% within three years or one generation, whichever is longer or
- 2) A continuing decline, observed, projected, or inferred, in numbers of mature individuals and population structure in the form of either:
 - a) severely fragmented (i.e. no subpopulation estimated to contain more than 50 mature individuals)
 - b) all individuals are in a single subpopulation.

D) Population estimated to number less than 50 mature individuals.

E) Quantitative analysis showing the probability of extinction in the wild is at least 50% within 10 years or three generations, whichever is the longer.

ENDANGERED (EN)

A taxon is Endangered when it is not Critically Endangered but is facing a very high risk of extinction in the wild in the near future, as defined by any of the following criteria (A to E):

A) Population reduction in the form of either of the following:

- 1) An observed, estimated, inferred or suspected reduction of at least 50% over the last 10 years or three generations, whichever is the longer, based on (and specifying) any of the following:
 - a) direct observation
 - b) an index of abundance appropriate for the taxon
 - c) a decline in area of occupancy, extent of occurrence and/or quality of habitat
 - d) actual or potential levels of exploitation
 - e) the effects of introduced taxa, hybridisation, pathogens, pollutants, competitors or parasites.
- 2) A reduction of at least 50%, projected or suspected to be met within the next 10 years or three generations, whichever is the longer, based on (and specifying) any of (b), (c), (d), or (e) above.

B) Extent of occurrence estimated to be less than 5000km² or area of occupancy estimated to be less than 500km², and estimates indicating any two of the following:

- 1) Severely fragmented or known to exist at no more than five locations.
- 2) Continuing decline, inferred, observed or projected, in any of the following:
 - a) extent of occurrence
 - b) area of occupancy
 - c) area, extent and/or quality of habitat
 - d) number of locations or subpopulations
 - e) number of mature individuals.
- 3) Extreme fluctuations in any of the following:
 - a) extent of occurrence
 - b) area of occupancy
 - c) number of locations or subpopulations
 - d) number of mature individuals.

C) Population estimated to number less than 2500 mature individuals and either:

- 1) An estimated continuing decline of at least 20% within five years or two generations, whichever is longer, or
- 2) A continuing decline, observed, projected, or inferred, in numbers of mature individuals and population structure in the form of either:
 - a) severely fragmented (i.e. no subpopulation estimated to contain more than 250 mature individuals)
 - b) all individuals are in a single subpopulation.

D) Population estimated to number less than 250 mature individuals.

E) Quantitative analysis showing the probability of extinction in the wild is at least 20% within 20 years or five generations, whichever is the longer.

VULNERABLE (VU)

A taxon is Vulnerable when it is not Critically Endangered or Endangered but is facing a high risk of extinction in the wild in the medium-term future, as defined by any of the following criteria (A to E):

A) Population reduction in the form of either of the following:

- 1) An observed, estimated, inferred or suspected reduction of at least 20% over the last 10 years or three generations, whichever is the longer, based on (and specifying) any of the following:
 - a) direct observation
 - b) an index of abundance appropriate for the taxon
 - c) a decline in area of occupancy, extent of occurrence and/or quality of habitat
 - d) actual or potential levels of exploitation
 - e) the effects of introduced taxa, hybridisation, pathogens, pollutants, competitors or parasites.
- 2) A reduction of at least 20%, projected or suspected to be met within the next ten years or three generations, whichever is the longer, based on (and specifying) any of (b), (c), (d) or (e) above.

B) Extent of occurrence estimated to be less than 20,000km² or area of occupancy estimated to be less than 2000km², and estimates indicating any two of the following:

- 1) Severely fragmented or known to exist at no more than ten locations.
- 2) Continuing decline, inferred, observed or projected, in any of the following:
 - a) extent of occurrence
 - b) area of occupancy
 - c) area, extent and/or quality of habitat
 - d) number of locations or subpopulations
 - e) number of mature individuals
- 3) Extreme fluctuations in any of the following:
 - a) extent of occurrence
 - b) area of occupancy
 - c) number of locations or subpopulations
 - d) number of mature individuals

- C) Population estimated to number less than 10,000 mature individuals and either:
- 1) An estimated continuing decline of at least 10% within 10 years or three generations, whichever is longer, or
 - 2) A continuing decline, observed, projected, or inferred, in numbers of mature individuals and population structure in the form of either:
 - a) severely fragmented (i.e. no subpopulation estimated to contain more than 1000 mature individuals)
 - b) all individuals are in a single subpopulation
- D) Population very small or restricted in the form of either of the following:
- 1) Population estimated to number less than 1000 mature individuals.
 - 2) Population is characterised by an acute restriction in its area of occupancy (typically less than 100km²) or in the number of locations (typically less than five). Such a taxon would thus be prone to the effects of human activities (or stochastic events whose impact is increased by human activities) within a very short period of time in an unforeseeable future, and is thus capable of becoming Critically Endangered or even Extinct in a very short period.
- E) Quantitative analysis showing the probability of extinction in the wild is at least 10% within 100 years.
- Note: copies of the IUCN Red List Categories booklet, are available on request from IUCN (address on back cover of this Action Plan)*
- ¹ Note: As in previous IUCN categories, the abbreviation of each category (in parenthesis) follows the English denominations when translated into other languages.