Phytotaxa 9: 266–274 (2010)
www.mapress.com/phytotaxa/

Article

ISSN 1179-3155 (print edition)
PHYTOTAXA
ISSN 1179-3163 (online edition)

Past and present activities and future strategy of bryophyte conservation

TOMAS HALLINGBÄCK[1] & BENITO C. TAN[2]

[1]*Swedish Species Information Centre, Swedish University of Agricultural Sciences, P.O.Box 7007, SE-75007 Uppsala, Sweden. Tomas.Hallingback@artdata.slu.se*

[2]*Singapore Botanic Gardens, 1 Cluny Road, Singapore 259569, Singapore*

Abstract

A review of past and present progresses in bryophyte conservation worldwide is attempted. The strategy and action program in bryophyte conservation in the future are also presented.

Key words: Red list, endemism, hot spots, *ex situ*, awareness, measures

Introduction

Why is bryophyte conservation needed?

The interest in conservation of bryophytes has increased significantly in the last two decades (Hylander & Jonsson 2007). Today we recognize that bryophytes provide important ecosystem services and we enjoy the existence of high bryodiversity for ethical and aesthetical reasons (Pócs 1980; Longton 1992). We follow the precautionary principle, which states, that lack of certainty regarding the threat of environmental harm should not be used as an excuse for not taking action to avert the threat (IUCN 2007). This reason alone justifies the motive and goal to protect and preserve the natural flora of bryophytes.

Some bryophytes species do have a direct economical value, e.g., peat mosses (*Sphagnum*) which cover large areas of northern hemisphere, including northern Europe, Canada and Russia (Joosten & Clarke 2002). Several species are valuable due to their medicinal properties. Some have chemical compounds that are active against certain cancer cell lines. Others have anti-bacterial, anti-microbial, and anti-fungal activities (e.g., Raymundo *et al.* 1989; Asakawa 1995; Asakawa *et al.* 2003; Nagashima *et al.* 2002).

Bryophytes play an important role in natural ecosystem and are also essential for the sustainability of human civilization and society. The most obvious are the contribution of bryophytes to water recycling, biomass production and carbon fixing (Hallingbäck & Hodgetts 2000) as well as Carbon and Nitrogen cycling (Turetsky 2003). They are also important food items for animals. In cold environments where seed plants do not grow in abundance, bryophytes are the main staple food for reindeers, geese, ducks, sheep, musk oxes, lemmings and other rodents (Longton 1992).

However, bryophyte flora is continually being impoverished in many countries today. A positive development, though, is that bryophyte species are redlisted also in many countries. The already published national red lists show that the rate of confirmed extinction of bryophytes, in most cases, ranges from 2–4%, and that a substantial proportion of the bryoflora worldwide is threatened in the short term (Vanderpoorten & Hallingbäck 2008). This prognosis is alarming—however, not hopeless.

 Accepted by M. Von Konrat: 12 Jul. 2010; published: 30 Sep. 2010

Understanding the threats

Bryophytes have biological properties that make them more vulnerable to environmental changes than many other plant groups. These properties include a dependence on high humidity microclimate, an intrinsic low competitive ability, and a reproduction process and population establishment heavily dependent on and contingent upon the combined environmental conditions of high moisture and cool temperature.

Today, many people are aware that the landscape on most continents has been modified in such a way that the land and water have become hostile for plants and animals to live in, and that this detrimental modification of landscape appears to continue, especially in densely populated regions (Vié *et al.* 2009). This is the main threat factor that is causing both a decline in the number of bryophyte species and the contraction of the geographic range of many species. The decline can be caused directly by deforestation, reclamation of land, urbanization, road building, dam-building, mining, peat industry, overgrazing and numerous other human activities. Habitat changes caused by man, in many cases, soon lead to changes in air and soil conditions, which create additional negative impacts against the survival of bryophytes.

Habitat loss is the fastest-growing threat to the survival of individual species and this will probably continue to be the dominant threat factor in the decades to come (Brooks *et al.* 2002; Fahrig 2002). This negative impact has gone already too far, especially in tropical lowlands with fertile soil, where forested land is cleared continuously for human population expansion and only small pieces of natural lowland vegetation that can harbour bryophytes are left (Hallingbäck & Hodgetts 2000).

One newly documented threat for some bryophyte species is the harvesting of living plants for commercial purposes (Muir *et al.,* 2006). In forest, large mats of mosses are peeled off from tree trunks and boulders and sold in the market in United States, India, Japan and China (Peck 2006). Harvested bryophytes are used, for example, in decorating plant pots, packing bulbs for transport, making moss-sticks and moss-bags, etc. Large quantities of mosses are harvested, irrespective of the status of the species in the country. This trade is often not controlled by the governments and can result in considerable ecological damage to the plant group (Muir 2004).

Past and present activities

Conservation of species

Interest in biodiversity and conservation biology of bryophytes is increasing. Bryophytes have been successfully introduced into the IUCN system, and the protection of threatened species and their habitat, although still limited, is gaining attention worldwide. Threats and mechanisms that make bryophytes vulnerable are being increasingly understood, even if additional research is still needed to better understand the causes of species rarity and decline in bryophytes (Cleavitt 2005).

Increased field activities in several countries in Asia have resulted in the identification of bryological hot spots (Tan & Iwatsuki 1996). Bryophyte species and their habitats have been part of legislation in Europe (Porley *et al*. 2008). Practical conservation has received new tools to design and manage the network of conserved areas for bryophytes. Likewise, promising new methods of *ex situ* conservation are being developed (Rowntree *et al.* 2010).

Some concrete examples of successful activities in bryophyte conservation are presented below:

There is a global red list, since the year 2000, with 80 species (36 mosses, 43 liverworts and one hornwort) included (see http://www.iucnredlist.org/ or http://www.artdata.slu.se/ guest/SSCBryo/ WorldBryo.htm). The species are selected on the basis of their threat at global level, frequency of occurrence in threatened habitats, and possessing a narrow distribution range. Even if this list only covers a small part of all the globally threatened species, this is a good start towards a more comprehensive global red list.

Already, bryophytes are included in several national conservation agendas and activities. In countries like

United Kingdom, mosses and liverworts have been included in the network of designation of areas of wildlife importance—Site of Special Scientific Interest (SSSI) (Hodgetts 2000). In the European Union, the habitats of 32 more or less threatened bryophyte species are protected under the Habitats Directive (http://ec.europa.eu/environment/nature/ nature_conservation/eu_nature_legislation/habitats_directive/index_en.htm). This has led to the protection of more than 1000 localities included in the Natura 2000 network (Hallingbäck 2003).

Encouragingly, international cooperation among bryologists regarding endangered habitats and species under threat has been developed since 1990 when the first symposium on Bryophyte Conservation was held (Hedenäs & Söderström 1992). At that meeting two international committees were established, one for Europe (European Committee for Conservation of Bryophytes) and one global (International Committee for Endangered Bryophytes). A year later IUCN asked us to establish a SSC bryophyte specialist group, and constitute the members of the ICEB conservation committee (affiliated with International Association of Bryologists). These committees have been very active producing first a European and than a global redlist under the umbrella of IUCN.

The ASEAN BIOTROP example

In tropical SE Asia, ASEAN, the regional governmental organization, has supported its regional research institution on tropical biology named BIOTROP located in Bogor, Java of Indonesia to conduct a 10–12 days workshop on the identification, economic importance and conservation of local bryophytes and lichens. The regional workshop has been organized by Prof. S. Tjitrosoedirdjo at BIOTROP and offered to participants from the ten member countries of ASEAN who are the on-duty staff of national parks and forest reserves, government offices in charge of conservation, and also botany teachers in university and colleges. The various topics involving the regional lichen and bryophyte diversity are taught by experienced lichenologists and bryologists invited from Europe and SE Asia. The workshops have been offered five times since 1990 and have trained or educated more than a hundred participants; many of them have become today professional and active lichenologists and bryologists in their respective resident country in SE Asia.

Educational work in Venezuela

Another good example is the success of a bryophyte educational project in Venezuela by a group of bryologists headed by Dr Yelitza León Vargas at Mérida Botanical Garden. They have become successful in their educational campaign to raise the public awareness about what are bryophytes in science, the need to preserve the bryophyte diversity, and to stop harvesting bryophytes from nature. The group collaborated with the environmental office of the State and many other organizations, such as, State government, City mayor office, National Park office, etc. They produced educational materials for free distribution and organized a team of environmental educators to spread the message in paramo towns and villages. The project was awarded with a regional prize for public outreach in science (Premio regional de Difusion de la ciencia para publicos amplios) in recognition of the educational works done to protect bryophytes (León & Ussher 2005).

New harvesting guideline for bryophytes

New guidelines for bryophyte harvesting have recently been proposed in a number of countries, which include standardizing the reporting of requirements before a harvesting permit be given and creating incentives for the buyers and the participating harvesters to protect and conserve the natural resources of bryophytes (Peck & Studlar 2007); see also http://www. artdata.slu.se/guest/SSCBryo/files/IAB_Moss_Harvest_Guidelines.pdf .

Ex situ conservation

In 2000 The UK Country Agencies in partnership with Royal Botanic Gardens, Kew, launched the *ex situ* project for the conservation of threatened bryophytes, the first such project of its "kind" in the world (Ramsay & Burch 2001; Rowntree & Ramsay 2005). The Target 8 of GSPC (Global Strategy for Plant Conservation) states that 60% of threatened plant species should be preserved in accessible, *ex situ* collections. Recognizing the fact that *ex situ* collection of live plants can not be a time-limited project, but requires time for its development, the partnership between Natural England and Royal Botanic Gardens, Kew, has been re-established recently, with funding for 3 additional years.

Centres of endemism

There are several "centres of endemism" of bryophytes identified today, and almost all such centres lie in geographically isolated, geologically or climatically unique regions (Schofield 1985, 1992; Tan & Pócs 2000). The characteristic patterns of endemism in bryophytes do not appear to be the same as what has been shown in higher plants or animals. Various lines of evidence suggest that the different dispersal capacity and the geographic isolation of this group of non-vascular plants over the geological time period may provide the clue to our understanding of their present day distribution patterns (Heinrichs *et al.* 2009).

While it is known that local endemism can be very high for some bryophytes in certain areas (von Konrat *et al.* 2005), this varies widely from group to group. Highest rate of narrow endemism seems to be found mainly on islands with mountains. For instance, more than 20% of the liverworts of Madagascar and 30% of those on Saint Helena are endemic to each of these islands (Martin Wigginton, pers. comm. 2006), and the endemism rate of the liverwort flora of Hawaii is reported to be 49% (Staples & Imada 2006). Islands with high mountains like New Zealand and Japan have an endemism rate of 52% and 20% respectively for the liverwort floras (von Konrat *et al.* 2005). Some large mountain areas surrounded by lowlands seem also to harbour a high rate of endemism, e.g., in tropical Andes the number of endemic mosses is 31% of the total recorded species (Churchill 2009).

Hot spots of bryophytes

Centre of endemism can be considered a hot spot, but hot spot is more than just being a centre of endemism. Hot spots are places with high bryodiversity (including the endemic taxa) and at the same time highly threatened by negative environmental factors.

Since the diversity patterns in bryophytes do not always coincide with the diversity patterns of angiosperms, mammals and birds (Pharo *et al.* 2005; Sérgio *et al.* 2007), field studies show that the sites of high bryophyte diversity do have different substrate and habitat conditions (Sérgio *et al.* 2007). Therefore an effort to identify bryophyte hot spots has become increasingly necessary to carry through the protection of bryophyte diversity.

The overlap between the bryophyte hot spots identified to date and those identified for angiosperms and animals by Myers *et al.* (2000) is only partial (see also Tan & Pócs 2000). New Zealand, New Caledonia, the Pacific Islands, and the Indonesian part of eastern Malesia are bryophyte hot spots. These areas, although listed by Myers *et al.* (2000), are not ranked among the important hot spots for vertebrates and angiosperms. Shared hot spots between liverworts and vertebrate and angiosperms, but not mosses, include the northern Andes and Madagascar. The Mediterranean and many tropical areas, e.g., the Galapagos Islands, the Caribbean Islands, Amazonia, and Equatorial Africa, are listed among the most important hot spots for angiosperms and vertebrates, but do not exhibit a spectacular rate of endemism for mosses nor liverworts. By contrast, several temperate areas, including Japan, Patagonia, the northern part of the Pacific Northwest region, and Tasmania, are bryophyte hot spots, but are not listed as priority areas for the conservation with respect to their vertebrate fauna and angiosperm flora (von Konrat *et al.* 2005).

Defining a hot spot can be done in many ways – whether it is based on species richness, percentage of endemism, habitat threats, or a combination of these factors (Reid 1998). For bryophytes we seldom have the detailed information needed in determining a hot spot, and so we prefer to stay with the set of basic criteria proposed by Tan & Iwatsuki (1996).

Future strategy

Extending *ex situ* programmes

Ideally all species should be given a chance to exist and grow in the wild. However, for those species at the brink of extinction, *ex situ* preservation may be the most effective rescue solution (Ramsay & Burch 2001, Rowntree & Ramsay 2009). The above mentioned Kew Garden program should be extended and expanded to cover globally endangered species (not only those found in Great Britain).

Ex situ storage of bryophyte spores and propagules is also fundamental for future translocation and reintroduction of species. It provides living materials for use in new experimental studies (Sarasan *et al.* 2006).

The possibility to keep the species alive in labs and man-made storing facilities offers, in addition, the good opportunity to study the population biology and genetic conservation issues using newly developed laboratory techniques and instruments (Rowntree *et al.* 2010) and this can play a decisive role in the discovery of the still unknown underlying biological developmental processes in bryophytes (Rowntree *et al.* 2007).

Species or habitat approach?

Bryophyte plants are too small to be suitable as a flagship species for conservation and they sometimes are difficult to see in the field, which make it hard for the public to appreciate their beauty and unique morphological features. Therefore the protection of bryophytes is best achieved by protecting the habitats (Sastre-D & Tan 1995).

However, even if most bryophytes are too small and inconspicuous to serve as the functional flagship plant, still, the protection of a certain species of moss or liverwort maybe necessary since some rare and unique species need species-specific protection measures. The work to identify these species includes setting a priority system to make sure that cost-effective measures are applied. The focus on rapidly declining and extremely rare species must be a top priority. Once we lose the species, we lose them forever.

How, then, do we select species of the highest priority for protection? The IUCN has long elaborated an assessment system for estimating the extinction risk of a species (IUCN 2001). This system has been applied recently to bryophytes with slight modifications (Hallingbäck *et al.* 1998; Hodgetts 2002; Kučera & Váňa 2005; Molloy *et al.* 2002; Sérgio *et al.* 2007).

The proposed solutions

To be effective, bryophyte conservation programmes and action plans need to work on three fronts: increasing of knowledge, raising of public awareness, and implementing the knowledge in practical conservation measures.

(1) Increasing of knowledge: Without scientifically sound basic knowledge we may choose the wrong target species to manage, identify the wrong site as a hot spot, undertake incorrect protective measures, and adopt inappropriate strategies and priorities of conservation (Bisang & Hedenäs 2000).

Compared to vascular plants, our knowledge about bryophyte biology, ecology and distribution is relatively little. The shortage of knowledge is a serious problem when evaluating what appropriate actions to take, including prioritizing the actions to be taken. Information on actual hot spots and the species distribution, the population size of species, as well as its susceptibility to anthropogenic environmental changes are all crucial to the development of efficient and effective conservation measures.

The building of awareness must start with the identification of threatened habitats/species/ genotypes, continue with the analyses of threats, and finally result in an effective action plan to ensure the long-term survival of the species (Söderström 2006). Bisang & Hedenäs (2000) described a phylogenetic approach to identify the most distinctive species in terms of the genetic information content, thus, providing a different rational basis for selecting the priority species among the rare and declining taxa for conservation.

There are still large gaps in our knowledge about bryophytes, which must be filled before the conservation measures can be totally effective. These include preparation of species checklists for less known parts of the world, research on bryogeography, and the study of habitat requirement, natural dynamics and capability of dispersal, population structure and the genetics of endangered species. Also needed are handbooks on how species can be recognized (floras), what are their present ranges, and the information of narrowly endemics in a region (Scott *et al.* 1997).

(2) Raising the public awareness: Today, a serious problem in plant conservation is still the general lack of public awareness**.** Bryophytes are not well known to the general public, even among some conservationists. It is necessary to continue our effort to highlight the importance of their presence in nature and their beneficial role in ecosystem.

Below are some facts about bryophytes that can be highlighted: a). The importance of bryophytes in water and nutrient cycling, photosynthetic biomass production, and prevention of soil erosion; b). The important role of bryophytes in land plant evolution; c). The use of bryophytes in landscape and aquascape; d). The use of bryophytes as medicinal plants, growing medium for orchid plants, etc.; e). The use of bryophytes as teaching materials in school and university (Sastre-D & Tan 1995); and f). The intrinsic value of bryophytes being part of the nature.

Listed below are ways to raise the public awareness towards the conservation of bryophytes—

(i) Establish permanent education centres and nature trails in park areas with information plates explaining how interesting and important bryophytes are. This information of nature trail and guided nature walk can be made into a self-guiding booklet for public dissemination.

(ii) Install in public places visual and multimedia displays of bryophytes showing their ecological importance. In all available occasions, employ artistically and beautifully designed, photographic materials, or a television film, to exhibit the astounding morphological forms of bryophytes and to report on any new find on the unique biology of bryophyte.

(iii) Participate in environmental awareness programs set up by various governmental and non-governmental organizations to communicate the importance of bryophytes in ecology and conservation at the grass-roots level (Sastre-D. & Tan 1995). The use of modern media like You Tube to present short film with a message to reach a large audience should be attempted. The importance of bryophytes as indicator plants in assessing the environmental health status can also be publicized. In doing so, however, we should present the facts and information carefully and accurately (Mosler 1995).

(iv) Select a likable and credible person in the community to implement the public education programmes. The not concern attitude of the public towards bryophytes must be changed into a positive understanding that "bryophytes have a justifiable place in nature". The most important step here is to make sure that the leadership of the campaign for bryophyte conservation locally and internationally be represented by a respectable and knowledgeable person who, in the eyes of the public, embodies the correct belief and attitude. The designated spokesman of bryophyte conservation in public must not be seen to exploit the issue of endangered bryophytes for personal gain.

(3) Implementing the knowledge in practical conservation measures: In a world with limited resources for conservation, the use of resources has to be wisely prioritised.

Practical implementation of conservation actions becomes often a matter of convenience for politicians and conservation managers to undertake (Söderström 2006). Often, conservation actions taking place locally are affected also by international commitments and responsibilities. Since the approval of Convention on Biological Diversity (CBD) programme in 1992, the commitments outlined for the conservation of biodiversity have become an agreement among politicians from around the world. In recent years, these commitments are linked to climate changes, which pose a new threat to the ecosystem worldwide (Millennium Ecosystem Assessments 2005). Because of this urgent situation, one effective way to carry out the conservation of bryophyte species and flora would be to protect land areas with a species rich bryophyte flora.

The following are some practical action plans of bryophyte conservation that can be implemented as group effort:

(i) Identify what species are declining, or are close to the brink of extinction, both at the regional and global levels.

(ii) Conduct rapid surveys to identify more hot spots of bryophyte diversity. Based on the rapid but dependable inventories, national or regional lists of hot spots can be dependably determined and the included target species *in situ* can be legally protected.

(iii) Protect all identified sites with high bryophyte diversity and also conserve the sites with threatened and narrowly endemic species (cf. centre of endemism). In the short term, creating such a nature reserve or protected area with large and diverse species of bryophytes helps to buy time to save the species diversity until a solution to the problem is found.

Conclusions

We believe that the knowledge on bryophytes must be spread to non-bryologists and the general public so that conservation programmes can be successfully implemented.

We need to raise the public awareness through the uses of education programmes, establishment of visitor centres, offer of guided nature walk in national parks, production of bryophyte videos, conduction of large press conference and organization of bryological symposia, etc.

We need to take various approaches to reach out also to the special targeted group of land-users, landowners and business sectors in agro-forestry. People who know and care about bryophytes must be active in collecting data and informing the conservation organizations and governmental authorities about the need for bryophyte conservation (Hallingbäck 2007; Scott *et al*. 1997).

Formal education to train a new generation of bryologists is indispensable. As modern education in biology becomes increasingly molecular and mechanistic in emphasis, teaching about bryophytes as a group of evolving and diversifying plants becomes necessary and relevant for the survival of bryophytes. Only through formal training will there be a new generation of well-informed professionals to continue the study and protection of bryophytes, especially in the tropics (Sastre-D. & Tan 1995).

We urge people in each country who wish to have a rich bryodiversity to take up the mandated challenge to suggest and implement good environmental protective measures (including beneficial silvicultural and agricultural practices) to help maintain a rich bryophyte flora growing *in situ* in the country.

Acknowledgement

Warm thanks to Margaret Ramsay (*ex situ*) and Åsa Berggren for valuable comments on the manuscript.

References

Asakawa, Y. (1995) Chemical constituents of the bryophytes. *In*: Herz W., Kirby G.W., Moore RE., Steglich W. & Tamm C. (Eds), *Progress in the chemistry of organic natural products*. Vol. 65. Wien: Springer.

Asakawa, Y., Toyota, M., von Konrat, M. & Braggins, J.E. (2003) Volatile components of selected species of the liverwort genera *Frullania* and *Schusterella* (Frullaniaceae) from New Zealand. Australia, and South America: A Chemosystematic approach. *Phytochemistry* 62: 439–452.

Bisang, I. & Hedenäs, L. (2000) How do we select bryophytes species for conservation, and how do we conserve them? *Lindbergia* 25: 62–77.

Brooks, T.M., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Rylands, A.B., Konstant, W.R., Flick, P., Pilgrim, J., Oldfield, S., Magin, G. & Hilton-Taylor, C. (2002) Habitat loss and extinction in the hotspots of biodiversity. *Conservation Biology* 16: 909–923.

Churchill, S.P. (2009) Moss diversity and endemism of the Tropical Andes. *Annals Missouri Botanical Garden*. 96: 434–449.

Cleavitt, N. (2005) Patterns, hypotheses and processes in the biology of rare bryophytes. *The Bryologist* 108: 554-566.

Fahrig, L. (2002) Effect of habitat fragmentation on the extinction threshold: a synthesis. *Ecological applications* 12: 346–353.

Hallingbäck, T. & Hodgetts, N.G. (2000) *Mosses, liverworts & hornworts. Status survey and conservation action plan for bryophytes*. IUCN/SSC Bryophyte Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.

Hallingbäck, T. (2003) Including Bryophytes in International Conventions – a success story from Europe. *The Journal of Hattori Botanical Laboratory Journal* 93: 201–214.

Hallingbäck, T. (2007) Working with Swedish cryptogarn conservation. *Biological Conservation* 135: 334–340.

Hallingbäck, T., Hodgetts, N., Raeymaekers, G., Schumacker, R., Sérgio, C., Söderström, L., Stewart, N. & Váňa, J. (1998) Guidelines for application of the revised IUCN threat categories to bryophytes. *Lindbergia* 23: 6–12.

Hedenäs, L. & Söderström, L. (1992) Introduction to special issue of Biological Conservation 1992, 59. *Biological Conservation* 59: 85–86.

Heinrichs, J., Hentschel, J., Feldberg, K., Bombosch, A. & Schneider, H. (2009) Phylogenetic biogeography and taxonomy of disjunctly distributed bryophytes. *Journal of Systematics and Evolution* 47: 497–508.

Hodgetts, N.G. (2000) Bryophyte Conservation and the British National Biodiversity Network: Using Data for Conservation. *Lindbergia* 25: 140–143.

Hodgetts, N.G. (2002) A new model for species status assessment. *Portugaliae Acta Biologica* 20: 3–9.

Hylander, K. & Jonsson, B.G. (2007) The conservation ecology of cryptogams. *Biological Conservation* 135: 311–314.

Inés Sastre-D, J. & Tan, B.C. (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.

IUCN (2001) *IUCN Red List Categories and Criteria: Version 3.1.* IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK. ii + 30 pp.

IUCN (2007) *Guidelines for applying the precautionary principle to biodiversity conservation and natural resource management*. http://cmsdata.iucn.org/downloads/ln250507_ppguidelines.pdf

Joosten, H. & Clarke, D. (2002) *Wise use of mires and peatlands background and principles including a framework for decision-making*. International Mire Conservation Group. http://www.imcg.net/docum/wise.htm

Kučera, J. & Váňa, J. (2005) Seznam a cervený seznam mechorostn Ceské republiky (2005). - *Príroda, Praha* 23: 1–104.

León, V.Y. & Ussher, M.S. (2005) Educational Campaign directed towards the preservation of Venezuelan Andean Bryophytes. *The Journal of Hattori Botanical Laboratory Journal* 97: 52–54.

Longton, R.E. (1992) The role of bryophytes and lichens in terrestrial Ecosystems. *In*: Bates, J.W. & Farmer, A.M. (Eds.), *Bryophytes and lichens in a changing environment.* Oxford University Press, New York, pp. 32–76.

Millennium Ecosystem Assessment (2005) *Our human planet. Island press*. Washington. ISBN 1-55963-386-7

Molloy, J., Bell, B., Clout, M., de Lange, P., Gibbs, G., Given, D., Norton, D., Smith, N. & Stephens, T. (2002) Classifying species according to threat of extinction. A system for New Zealand. *Threatened species occasional publication* 22, 26 p.

Mosler, H.-J. (1995) Psychological foundation of interventions to protect bryophytes. *Cryptogamica Helvetica* 18: 159–167.

Muir, P.S. (2004) An assessment of commercial “Moss” harvesting from forested lands in the pacific Northwestern and Appalachian regions of the United States: How much moss is harvested and sold domestically and internationally and which species are involved? *Final report to U.S. Fish and Wildlife Service and U.S. Geological Survey, Forest and Rangeland Ecostystem Science Center.* 78 p.

Muir, P.S., Norman, K.N. & Sikes, K.G. (2006) Quantity and value of commercial moss harvest from forests of the Pacific Northwest and Appalachian regions of the U.S. *The Bryologist* 109: 197–214.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B. & Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature* 403: 853–858.

Nagashima, F., Kondoh, M., Kawase, M., Simizu, S., Osada, H., Jujii, M., Watanabe, Y., Sato, M. & Asakawa, Y. (2003) Apoptosis-inducing properties of entkaurene-type diterpenoids from the liverwort Jungermannia truncata. *Planta Medica* 69: 377–379.

Peck, J.E. & Studlar, S.M. (2007) Establishing International Guidelines for the Sustainable Harvest of Forest Moss. *Evansia* 25 (2): 65–71.

Peck, J.E. (2006) Towards sustainable commercial moss harvest in the Pacific Northwest of North America. *Biological Conservation* 128: 289–297.

Pharo, E.J., Kirkpatrick, J.B., Gilfedder, L., Mendel, L. & Turner, P.A.M. (2005) Predicting bryophyte diversity in grassland and eucalypt-dominated remnants in subhumid Tasmania. *Journal of Biogeography* 32: 2015–2024.

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* 26: 143–167.

Porley, R., Papp, B., Söderström, L. & Hallingbäck, T. (2008) European Bryophyte Conservation In the New Millennium. *In*: Mohamed H, Baki BB, Nasrulhaq-Boyce A, Lee PKY (Eds). *Bryology in the New Millennium*. Kuala Lumpur: University of Malaya, pp. 459–485.

Ramsay, M.M. & Burch, J. (2001) *Ex situ* techniques in support of UK bryophyte conservation. *Novitates Botanicae ex Universitatis Carolinae Pragensis* 15: 27–33.

Raymundo, A.K., Tan, B.C. & Asuncion, A.C. (1989) Antimicrobial activities of some Philippine cryptogams. *Philippine Journal of Science* 118: 59–75.

Reid, W.V. (1998) Biodiversity hotspots. *TREE* 13, no. 7 July 1998.

Rowntree, J.K., Cowan, R.S., Leggett, M., Ramsay, M.M. & Fay, M.F. (2010) Which moss is which? Identification of the threatened moss Orthodontium gracile using molecular and morphological techniques. *Conservation Genetics* 11: 1033–1042.

Rowntree, J.K. & Ramsay, M.M. (2005) Ex situ conservation of bryophytes: progress and potential of a pilot project. *Boletín de la Sociedad Española de Briología* 26–27: 17–22.

Rowntree, J.K. & Ramsay, M.M. (2009) How bryophytes came out of the cold: successful cryopreservation of threatened species. *Biodiversity Conservation* 18: 1413–1420.

Rowntree, J.K., Duckett, J.G., Mortimer, C.L., Ramsay, M.M. & Pressel, S. (2007) Formation of Specialized Propagules Resistant to Desiccation and Cryopreservation in the Threatened Moss Ditrichum plumbicola (Ditrichales, Bryopsida). *Annals of Botany* 100: 483–496.

Sarasan,V., Cripps, R., Ramsay, M.M., Atherton, C., McMichen, M., Prendergast, F.G. & Rowntree, J.K. (2006) Conservation *in vitro* of threatened plants – progress in the last decade. *In Vitro Cellular Developmental Biology Plant* 42: 206–214.

Sastre-D., J.I. & Tan, B.C. (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.

Schofield, W.B. (1985) *Introduction to bryology.* Macmillan Publishing Co., New York, 431 pp.

Schofield, W.B. (1992) Bryophyte distribution patterns. Pp. 103–130. *In*: Bates, J.W. & Farmer A.M. *Bryophytes and Lichens in a Changing Environment*. Claredon Press. Oxford.

Scott, G.A.M., Entwisle, T.J., May, T.W. & Stevens, G.N. (1997) A conservation overview of Australian non-marine lichens, bryophytes, algae and fungi. Environment Australia, May 1997. ISBN 0 6422 1399 2.

Sérgio, C., Brugués, M., Cros, R.M., Casas, C. & Garcia, C. (2007) The 2007 Red List of Bryophytes of Iberian Peninsula (Portugal, Spain and Andorra). *Lindbergia* 31: 109–125.

Söderström, L. (2006) Conservation biology of bryophytes. *Lindbergia* 31: 24–32.

Staples, G.W. & Imada, C.T. (2006) Checklist of Hawaiian Anthocerotes and Hepatics. *Tropical Bryology* 28: 15–47.

Tan, B.C. & Iwatsuki, Z. (1996) Hot spots of mosses in East Asia. *Anales del Instituto de Biologia de la Universidad Nacional Autonoma de México. Serie Botanica* 67: 159–167.

Tan, B.C. & Pócs, T. (2000) Biogeography and conservation of bryophytes, pp. 403–448. In: A.J. Shaw & B. Goffinet (eds.). *Bryophyte Biology.* Cambridge University Press, UK.

Turetsky, M.R. (2003) The Role of Bryophytes in Carbon and Nitrogen Cycling. *The Bryologist* 106(3): 395–409.

Vanderpoorten, A. & Hallingbäck, T. (2008) Conservation biology of bryophytes. Ch 12 in: *Bryophyte Biology.* Second Edition, eds. Goffinet, B. & Shaw, A.J. Cambridge University Press 2008. p: 487–532.

Vié, J.-C., Hilton-Taylor, C. & Stuart, S.N. (2009) *Wildlife in a Changing World – An Analysis of the 2008 IUCN Red List of Threatened Species*. Gland, Switzerland: IUCN. 180 pp.

von Konrat, M.J., Glenny, D.S., de Lange, P.J., Engel, J.J., Braggins, J.E. & Renner, M.A.M. (2005) Rare and endangered liverworts: A new area of conservation in New Zealand. *Australasian Plant Conservation* 14: 17–19.