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Threatened bryophytes of the neotropical rain forest: a status report

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Abstract. Tropical deforestation, inevitably, leads to the local loss of bryophyte species. Recent studies show that the degree of species loss may vary considerably and depends on the scale or amount of habitat change that has occurred. Predictably, the shade epiphytes are most seriously affected by disturbance. An estimated 10% of the bryophyte species of neotropical rain forests are under threat. Based on data from recent monographs, a first list of 19 endangered and 27 rare species of these forests is presented. Critical areas for threatened species include Costa Rica and Panama, the Greater Antilles, the Chocó, southeastern Brazil, and parts of Amazonia. Protection of as much as possible of the remaining natural rain forest area seems the best approach to the conservation of the tropical bryophyte flora.

Bryophytes are an important component of the tropical rain forest (broadly defined here to include both the lowland and montane forest types of Richards 1952). In the neotropics probably an estimated 1500+ species occur in the rain forest, which amounts to more than half of the total neotropical bryophyte flora.

Tropical forests are now disappearing rapidly. Recent estimates by the Food and Agriculture Organization (FAO) of the United Nations indicate that almost half have already gone and that the remainder are disappearing at a rate of about 1% per year (Groombridge 1992). Deforestation is particularly alarming in areas with rapid population growth such as the Philippines, Indonesia, Sri Lanka, India, Madagascar, West Africa, the Atlantic coast of Brazil, and Central America (Table 1; Fig. 1). The rate of loss is so rapid that the view has been expressed that a significant proportion of all species of plants and animals of the tropical rain forest are likely to become extinct in the next few decades (see Whitmore and Sayer 1992).

Bryologists are becoming increasingly aware of the threatened status of the tropical bryophyte flora and resolutions expressing concern about this have been adopted at various recent conferences (e.g. Geissler and Greene 1982, Tan et al. 1991). It is therefore disturbing to note that, to date, almost nothing has been published about the actual impact of rain forest destruction on bryophytes. For my recent review of the subject (Gradstein 1992) I was able to find only three papers, two dealing with Papuan bryophytes (Hyvönen et al. 1987, Norris 1990) and one with bryophytes of Mt Kilimanjaro (Pócs 1992 and personal communication). In the neotropics the subject apparently remains completely uninvestigated.

The reason for this lack of data is obviously not

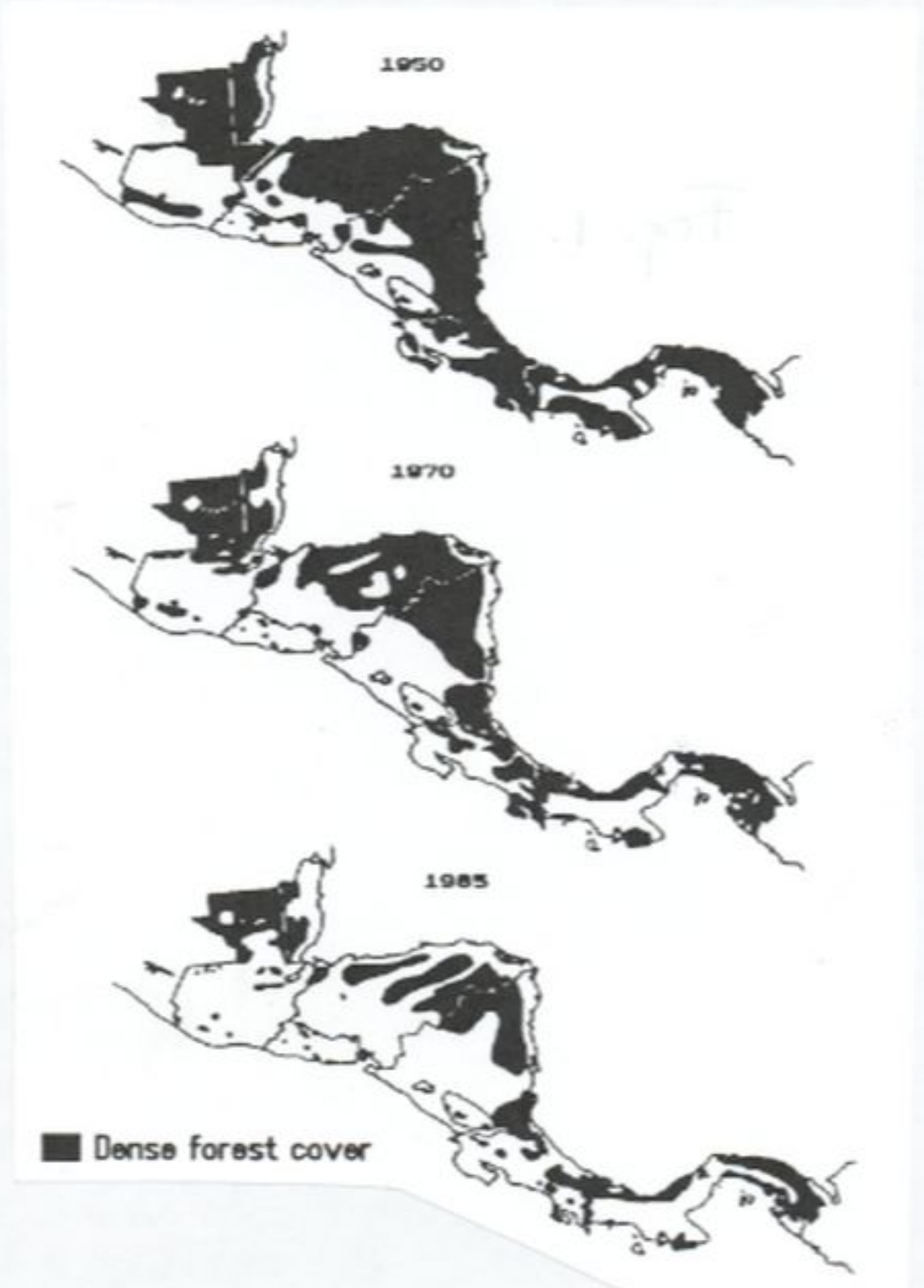

Figure 1. Deforestation in Central Central America 1950-1985. After Groombridge (1992).

COUNTRY	REMAINING (1983) PRIMARY FOREST (km^2)	CURRENT ANNUAL RATE OF FOREST LOSS (km^2)	% OF 1983 COVER LOST ANNUALLY
Nicaragua	27,000	1,000	3.7
Guatemala	25,700	600	2.3
Panama	21,500	500	2.3
Honduras	19,300	700	3.6
Costa Rica	15,400	600	3.9
Belize	9,750	32	0.3
El Salvador	0	0	-
Central America	118,650	3,432	2.9

Source: Nations, J.D. and Komer, D.I. 1983. Central America's Tropical Rainforests: positive steps for survival. *Ambio* 12(5):232-238.

Table 1. Status of lowland and tropical montane rain forests in Central America. After Groombridge (1992).

Table 2. Threatened bryophytes of the neotropical rain forest. For brevity coauthors of references are indicated by a stroke.

Species	Distribution	Reference
1. ENDANGERED SPECIES		
Brymela tutezona Crosby & Allen	Panama: Veraguas	Crosby/ 1985
Calypogeia rhynchophylla (Herz.) Bischl.	Costa Rica	Morales 1991
Campylopus atlanticus Allen	Panama	Allen 1990a
Dactylolejeunea acanthifolia Schust.	Dominica	Schuster 1970
Drepanolejeunea aculeata Bischl.	SE Brazil	Bischler 1964
D. senticosa Bischl.	Cuba: Oriente	ibid.
D. spinosa Herz.	Colombia: El Valle	ibid.
Fissidens hydropogon Spruce	Ecuador: Bombonasa	Pursell/ 1988
Fulfordianthus evansii (Fulf.) Gradst.	Central America	Gradstein 1992a
Leptolejeunea tridentata Bischl.	Colombia: Chocó	Bischler 1969
Myriocolea irrorata Spruce	Ecuador: Río Topo	Spruce 1884
Nowellia reedii Robins.	Costa Rica	Robinson 1970
N. wrightii Grolle	Cuba: Oriente	Grolle 1968
Phycolepidozia exigua Schust.	Dominica	Schuster 1966
Plagiochila wolframii Inoue	Northern Peru	Inoue 1987
Sphaerolejeunea umbilicata Herz.	Colombia: Cauca	Herzog 1938
Spruceanthus theobromae (Spruce) Gradst.	Ecuador: El Ríos	Gradstein in press
Syrrhopodon isthmi Reese	Panama: Cerro Jefe	Reese 1992
S. theriotii Bartr.	Costa Rica	Reese 1992

a lack of interest in the subject. Rather, it would seem that attempts to evaluate the problem are hampered by a serious lack of information on the taxonomy, distribution and ecology of tropical bryophyte species. Large rain forest areas of tropical America remain poorly explored bryologically, including portions of the Amazon basin, the Pacific coastal forests of northwestern South America and the remnants of the Central American rain forest, while many bryophyte genera have not been monographed. However, as shown by Buck and Thiers (1989) and Gradstein (1991), the number of monographs and regional floras published or in preparation is now increasing and more and more information is becoming available on the ranges of rain forest species. For an evaluation of the rarity of species and the degree to which they are threatened, these publications are an indispensable source of information. There is also a growing literature on the ecology of rain forest bryophytes (Frahm and Gradstein 1990).

In this paper I have tried to evaluate the impact of tropical deforestation on bryophytes and to identify rare and endangered species based on recently published taxonomic, phytogeographic and ecological data. For the reasons given above, my treatment must be considered preliminary. Nevertheless, I have found it a challenge to deal with a subject on which so little has been publis hed. I hope that this paper will stimulate bryologists, especially those living or stationed in the tropics, to tackle this much neglected field of research.

Impact of deforestation

In a dense, undisturbed rain forest bryophytes usually do not grow in a random fashion. Different species are found on tree bases, trunks, branches, twigs or leaves, or on logs in various stages of decay (Pócs 1982, Richards 1984), due to subtle differences in the ecological conditions of the substrate: water supply, light, nutrients, etc. Moreover, some species occur exclusively in the moist, shaded understorey of the forest and inner canopy whereas others are only found in the drier, outer portions of the canopy high above the ground. Following Richards (1954, 1984), these two ecological species groups may be called "shade epiphytes" and "sun epiphytes", respectively. They are ecological "specialists". In addition, "generalists" with wide vertical distributions have been recorded. In the rain forests of the Guianas, the following species belonging to these categories have been recorded (after Richards 1954, Cornelissen and Ter Steege 1989, Montfoort and Ek 1990, Cornelissen and Gradstein 1991):

SHADE EPIPHYTES

Archilejeunea parviflora
Callicosta bipinnata
Callicostella rufescens
Calymperes platyloma
Calypogeia spp.
Cololejeunea appressa
Crossotolejeunea boryana
Fissidens spp.
Glossadelphus truncatulus
Haplolejeunea cucullata
Hookeriopsis parkeriana
Lejeunea caespitosa
Lepidopilum surinamense
Leptolejeunea exocellata
Leucobryum martianum
Leucoloma cruegerianum
Leucophanes mittenii
Lophocolea spp.
Lopholejeunea muelleriana
Micropterygium trachyphyllum
Mniomalia viridis
Octoblepharum pulvinatum
Pictolejeunea picta
Phyllodrepanium falcifolium
Pilosium chlorophyllum
Plagiochila laetevirens
Porotrichum plicatulum
Prionolejeunea spp.
Racopilopsis trinitensis
Riccardia amazonica
Sematophyllum subsimplex
Stictolejeunea balfourii
Syrrhopodon circinnatum
S. cryptocarpos
S. incompletus
S. ligulatus

Taxithelium planum
Trachylejeunea pandurantha
Vesicularia vesicularis

SUN EPIPHYTES

Acanthocoleus aberrans
Acrolejeunea torulosa
Acroporium pungens
Ceratolejeunea desciscens
Cyrtolejeunea holostipa
Frullania spp.
Frullanoides liebmanniana
Groutiella spp.
Holomitrium arboreum
Lejeunea laetevirens
Leucodontopis geniculata
Lopholejeunea subfusca
Macromitrium spp.
Mastigolejeunea spp.
Neurolejeunea seminervis
Orthostichopsis tetragona
Papillaria nigrescens
Pycnolejeunea spp.
Lopholejeunea muelleriana
Schiffneriolejeunea amazonica
Schlotheimia spp.
Syrrhopodon parasiticus
Thysananthus amazonicus
Verdoornianthus griffinii

GENERALISTS

Acroporium pungens
Archilejeunea fuscescens
Calymperes erosum
C. lonchophyllum
Ceratolejeunea maritima
Cheilolejeunea spp.
Neckeropsis undulata
Octoblepharum pellucidum
Odontolejeunea lunulata
Radula caldana
R. flaccida
Sematophyllum subsimplex
Symbiezidium barbiflorum
Zelometeorium patulum

What are the consequences for bryophytes when the rain forest is damaged or destroyed? Hyvönen et al. (1987) compared the bryophyte flora of virgin rain forest in Papua New Guinea with that of moderately disturbed vegetation in the same general area: depleted forest, secondary growth, and slash-and-burn agricultural fields. They found that the bryophyte flora of the disturbed habitats was quite luxuriant and scarcely poorer in species than the virgin forest. The flora of the disturbed habitats included "newcomers", which were absent from the dense forest, as well as "stayers", which occurred in both areas. Newcomers were mainly weedy, ruderal species characteristic of man-made environments. The stayers included species that had become rarer in the disturbed areas, and those that had become more common. About 30% of the species of the undisturbed forest were lacking in the disturbed areas.

Very different results were obtained by Pócs (personal communication) in the course of a study on Mt Kilimanjaro, Tanzania. He compared the bryophyte flora of virgin rain forest on the lower slopes of the mountain with that of a plantation of exotic tree species in the same area. Only 10% of the forest species reappeared in the plantation and thus 90% of the rain forest flora had become lost! Depletion of the rich habitat diversity of the primary forest, as well as the predominance of fast-growing tree species in the plantation, seemed to be important reasons why bryophyte species of the rain forest had been unable to re-establish themselves in the plantation.

The above studies indicate that the floristic changes due to deforestation are dependent on the amount of damage inflicted upon the forest. In monocultures and other areas with large-scale farming methods and total clearance of the forest, the forest flora is much more impoverished than in areas of shifting cultivation and small-scale damage to the forest.

The studies also show that the shade epiphytes of the forest undergrowth are more seriously affected by the disturbance than the sun epiphytes. The former are, predictably, less well adapted to desiccation and are the first to disappear when the forest canopy is opened up. The sun epiphytes, on the other hand, are adapted to

relatively dry habitats and are, predictably, more capable of surviving in disturbed areas. They may "come down" from the canopy in the opened-up areas and establish themselves nearer to the ground in secondary habitats. Generalists may also be expected to survive disturbance.

Examples of sun epiphytes which, in the neotropics, are very common near ground level in secondary growth, scrub, orchards or on fallen trees include *Acroporium pungens*, *Frullania* spp., *Leucodontopsis geniculata* (= *Henicodium geniculatum*), various Lejeuneaceae (*Acrolejeunea, Ceratolejeunea* spp., *Cheilolejeunea, Frullanoides*, *Lopholejeunea subfusca* and *Mastigolejeunea auriculata*), *Orthostichopsis tetragona*, *Papillaria nigrescens*, and the Orthotrichaceae: *Groutiella, Schlotheimia* and *Macromitrium* spp.

Summing up, the available data lead to the following conclusions:

1. Tropical deforestation, inevitably, leads to the local loss of bryophyte species. The degree of the loss may vary considerably and depends on the scale or amount of habitat change that has occurred.

2. *Predictably, the shade epiphytes are most seriously affected by disturbance.*

Threatened species

No bryophyte species has as yet been reported as extinct in the neotropics. However, one would expect that quite a number of species, in particular rare and endemic ones, are threatened with extinction as the forest vanishes. Table 2 lists 46 species (18 mosses, 28 hepatics) which I have identified as threatened. The selection of the taxa was made according to the following criteria:

1) The species should be narrowly endemic or more widely distributed but nowhere common. They should be restricted to the neotropics and rare on a world-wide scale.

2) The species should occur exclusively in undisturbed rain forest (broadly defined here and including montane cloud forests), and be unable to re-establish themselves in secondary vegetation. Most of the species that fit this criterion are shade epiphytes.

3) The taxonomic status and distribution of the species must have been verified by a specialist, preferably in a monograph.

Based on an estimated 1500 neotropical rain forest bryophyte species, the present list represents about 3.5% of the forest flora. Since only about 20-30% of rain forest species have been monographed, the list represents only a small portion of the threatened flora. Many rare taxa, known from only 1-2 collections, are still of doubtful taxonomic status, e.g. members of the Hookeriaceae, Lejeuneoideae, Plagiochilaceae, Pterobryaceae, Radulaceae and Sematophyllaceae. Revision of these groups will undoubtedly reveal further threatened taxa. (*)

Within the families of neotropical rain forest bryophytes that have been monographed, the number of threatened species varies considerably and is about 1% in the Fissidentaceae, 8% in the Neckeraceae, 10-15% in the Lejeuneaceae and 20% in the Calymperaceae. The figures indicate that it is difficult to determine the total number of threatened species. Based on the above data, I estimate that about 10% of the bryophyte species of neotropical rain forests are threatened. This would amount to about 150 species or three times the number listed in Table 2.

In order to establish the status of those species and to qualify the degree of threat, I have applied the IUCN Red Data Book categories as defined by Mori and Prance (1990) in their monograph of neotropical Lecythidaceae. I have been able to recognize the following categories:

(*) Dr. Angela Newton (pers. comm.) has recently found several species of the genus *Pireella* (Pterobryaceae) with very limited distributions. Two species are known only from a single locality and may be considered endangered: *P. falcifolia* Bartr. (Guatemala) and *P. gemmescens* Robins. (Ecuador).

2. RARE SPECIES

Adelanthus squarrosus Grolle	Guyana: Roraima	Grolle 1989
Arachniopsis pecten Spruce	N Amazonia, Guianas	Gradstein/ 1989
Blepharolejeunea saccata (Steph.) Slag. & Kruijt	Neotropical	Slageren/ 1985
Calymperes mitrafugax Florsch.	N Amazonia, Guianas	Reese 1992
C. platyloma Mitt.	Amazonia, Guianas	ibid.
D. smithii Bartr.	Amazonia, Guianas	ibid.
Campylopus gemmatus (C.Müll.) Par.	SE Brazil	Frahm 1991
Crossomitrium acuminatum Bartr.	C America, Chocó	Allen 1990
Drepanolejeunea bischleriana Porto & Grolle	Eastern Brazil	Schäfer 1989
D. evansii Bischl.	Antilles	Bischler 1964
Haesselia roraimensis Grolle & Gradst.	Guyana: Roraima	Grolle/ 1988
Haplomitrium andinum (Spruce) Schust.	Neotropical	Barthol. 1991
Jubula bogotensis Steph.	Neotropical	Guercke 1974
Leucomium steerei Allen & Veling	Guayana, SE Brazil	Schäfer 1992
Lopholejeunea quelchii Steph.	Antilles, Guianas	Gradstein in press
Mastigolejeunea innovans (Spruce) Schiffn.	C Amazonia, Guianas	Gradstein in press
Neurolejeunea catenulata (Nees) Schiffn.	Antilles	Gradstein in press
Pictolejeunea sprucei Grolle	Brazil: Amazonia	Grolle 1977
Plagiochila cucullifolia Jack & Steph.	C America, Colombia	Gradstein MS
Renauldia paradoxica Allen	Mt Roraima, Panama	Gradstein/ 1989
Sematophyllum pacimoniense (Mitt.) Florsch.	N Amazonia, Surinam	Florschütz 1992
Symbiezidium dentatum Herz.	Chocó	Gradstein/ 1985
Syrrhopodon elatus Mont.	Amazonia, Guianas	Reese 1992
S. erubescens Bartr.	C America, Puerto Rico	ibid.
S. fimbriatus Mitt.	Amazonia	ibid.
S. flexifolius Mitt.	N Amazonia, Costa Rica	ibid.
S. helicophyllus Mitt.	Northern Amazonia	ibid.

1. **Endangered species**. This category includes narrowly endemic species known from a few (1-3) localities, in areas undergoing rapid deforestation. Neotropical areas where deforestation is most alarming at present include Mexico and Central America (Fig. 1; Table 1), the Caribbean, the Pacific coast of northern South America, especially Ecuador, western, eastern and southern portions of the Amazon basin, the Andes, and the Atlantic coast of Brazil (see Myers 1983, Groombridge 1992).

2. **Rare species**. This category includes narrowly endemic species known from areas which are not threatened with immediate deforestation, such as inner Amazonia and the Guianas, and neotropical species occurring over a wider range but nowhere common. The number of localities of species included in this category should be less than 10.

Mori and Prance (1990) also recognized "*Vulnerable Species*", which are less threatened than the Endangered ones (at least at present) because of their occurrence in protected areas. Since the occurrence of bryophyte species in neotropical forest reserves is poorly documented, I have not been able to apply this criterion in my evaluation.

Based on the above categories, I have been able to recognize 19 **endangered** and 27 **rare** species of neotropical rain forest bryophytes. The group of rare species is, admittedly, somewhat heterogeneous as it includes species known from only one locality, e.g. the Roraima endemics *Adelanthus squarrosus* and *Haesselia roraimensis*, as well as rather widespread neotropical taxa such as *Blepharolejeunea saccata*, *Haplomitrium andinum* and *Jubula bogotensis*. The number of recent records of these widespread taxa is so small (most of the collections are from the 19th century!), however, that I have not hesitated to include them in the list of threatened species.

Several remarkable, phylogenetically isolated taxa are among the threatened species. *Dactylolejeunea acanthifolia*, *Myriocolea irrorata*, *Phycolepidozia exigua*, *Sphaerolejeunea umbilicata* belong to monotypic genera while *Calypogeia rhynchophylla*, *Blepharolejeunea sacccata* and *Plagiochila cucullifolia* represent monotypic subgenera. *Brymela tutezona*, *Fissidens hydropogon*, *Arachniopsis pecten*, *Haesselia roraimensis*, *Nowellia reedii* and *Drepanolejeunea bischleriana* are also morphologically unusual within the genera to which they belong. Other important species are *Haplomitrium andinum*, *Jubula bogotensis*, *Renauldia paradoxica* and *Spruceanthus theobromae*, which are the only neotropical representatives of the genera and are thus of considerable phytogeographical interest. Details concerning the morphology and localities of the threatened taxa will be found in the papers listed in Table 2.

Further exploration of underexplored areas may reveal that some species listed here as threatened are in fact more common than currently known. The Chocó endemics *Fulfordianthus pterobryoides* and *Luteolejeunea herzogii*, for example, were listed as rare species in a draft version of this paper based on information on their distribution provided in recent monographs (Gradstein 1992a, Piippo 1986). However, during my travels in the Chocó Department (Colombia) in the summer of 1992, I found that they were very common in the area and occurred in both primary and secondary forest. Therefore, I have excluded them from the list. Other discoveries and new monographs may necessitate further changes.

Based on the distribution of the threatened species, the following areas can be identified as the most critical for threatened neotropical rain forest bryophytes:

1) **Costa Rica and Panama**.

This area has six endangered species or the largest concentration of endangered taxa in a single area: *Brymela tutezona*, *Calypogeia rhynchophylla*, *Campylopus atlanticus*, *Fulfordianthus evansii*, *Nowellia reedii*, *Syrrhopodon isthmi*, and *S. theriotii*.

2) **The Pacific coast of Ecuador and Colombia and the adjacent western slopes of the Andes.**

This area, known as the "Chocó Phytogeographic province" (Gentry 1982), has nine threatened species, including three endangered ones:

Drepanolejeunea spinosa, Leptolejeunea tridentata, and *Sphaerolejeunea umbilicata.* As shown below, large parts of the Chocó are still bryological "terra incognita" and future exploration of this area may well lead to changes in the list.

3) **Inner and northern Amazonia, including Guayana.**
This is the neotropical centre of endemism for rain forest species and 17 of its endemic species have been identified as threatened (Table 2). Since deforestation in most portions of this area is not (yet) alarming, the threatened Amazonian taxa are usually classified as rare. An exception are two endemic species of Amazonian Ecuador, *Fissidens hydropogon* and *Myriocolea irrorata*, which are classified as endangered because the forest in the area is under considerable pressure. Both species were discovered by Richard Spruce around the middle of the 19th century and have not been collected since. Hopefully they are not extinct!

4) **The Greater Antilles**.

Five threatened species occur on the islands of the Greater Antilles. A particularly critical area is eastern Cuba, which has two endangered taxa: *Drepanolejeunea senticosa* and *Nowellia wrightii.* It is also the only area from which the rare *Neurolejeunea catenulata* has been collected in recent years.

5) **Southeastern Brazil**.

The rain forest remnants along the Atlantic coast of southeastern Brazil harbour four threatened species, including the endangered *Drepanolejeunea aculeata*. Another very rare endemic of this area is *Campylopus gemmatus*, which is known from only three or four localities. The continued existence of this species seems safeguarded, however, by its occurrence in Mt Itatiaia National Park. The species should therefore not be considered endangered (A. Schäfer-Verwimp, personal communication).

Conservation

Because of their small size, bryophytes can only be protected effectively by the protection of their habitats (Pócs 1992). In many tropical countries virgin forest areas have been set aside as parks or forest reserves and when well managed these protected areas may serve as refugia for rain forest species. Preliminary data on the species density of bryophyte species in a tropical rain forest (Gradstein 1992) suggest that small reserves could preserve many species, provided the "host" trees are capable of rejuvenation. The Rio Palenque Science Center in coastal Ecuador, consisting of 87 ha of mature virgin rain forest surrounded by cultivated land, may serve as an example of a small reserve with a well-developed bryophyte flora (Gradstein, personal observation).

Whether the bryophyte species will survive in these small reserves remains uncertain, however. According to Pócs (personal communication) some species are disappearing from preserved forest fragments in East Africa due to local climatic change and desiccation caused by large-scale forest destruction in the region. Also, I am not aware of the presence of any of the threatened species in these forest fragments. The relationship between habitat area and species survival thus remains unclear in bryophytes. Protection of as much as possible of the remaining natural rain forest area, as advocated by Conservation organizations such as the IUCN and the WWF, may therefore be the best approach to the conservation of the bryophyte flora.

Recommendations for future work

I would like to re-emphasize that the data and conclusions on tropical deforestation and bryophyte endangerment presented in this paper are preliminary. We need many more inventories to find out which species are locally common and which are rare. We also need more comparisons between the floras of undisturbed forest and those of secondary growth or plantations, to determine the impact of disturbance. Finally, there should be much more work on the taxonomy and habitat preferences of the rain forest taxa, to find out which species are truly endemic and

to identify those which are unable to survive in disturbed habitats. Because of the speed at which the forests are vanishing, these studies are urgent and should be undertaken today rather than tomorrow.

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