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***Eredeti közlés /Original publication*:**
in: SEYANI, J. J. – CHIKUNI, A. C. ed.: *Proceedings of the XIIIth Plenary Meeting of AETFAT, Zomba, Malawi*, Zomba, National Herbarium and Botanic Gardens of Malawi, Vol. 2, 797–812. pp.
***Elektronikus újraközlés/Electronic republication*:**
AHU MAGYAR AFRIKA–TUDÁS TÁR – 000.003.237
Dátum/Date: 2018. november / November.
filename: pocs_1994_AltitudDistribKilimanjaro
Ezt az információt közlésre előkészítette
/This information prepared for publication by:
B. WALLNER, Erika és/and BIERNACZKY, Szilárd
Hivatkozás erre a dokumentumra/Cite this document:
PÓCS, Tamás: The Altitudinal Distribution of Kilimanjaro Bryophytes, *AHU MATT*, 2018**, pp. 1–18. old.,** No. 000.003.237, http://afrikatudastar.hu
Eredeti forrás megtalálható/The original source is available:
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Kulcsszavak/Key words
African studies in Hungary,
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ABSTRACT: The floristic data along four transects of the SSW slope of mount Kilimanjaro are summarized in diagrams showing the number of hepatic and moss species in each hundred meter altitudinal section and the numbers of lowermost and uppermost occurences are analyzed. On Mt. Kilimanjaro the number of species increases rapidly from 1800m altitude and species diversity shows two peaks, one at 2200m, where the montane rainforest are structurally most complex, then at 2700m altitude, in the cloud belt, where probably the precipitation maximum occurs. At the forest line (3000m) the number rapidly decreases then constant until 3800m, where the subalpine heath vegetation is becoming more open and dry with the decreasing amount of rainfall. Above this altitude the number of bryophytes decreases to a minimum, together with the rapidly disappearing moisture as the alpine belt of Kilimanjaro is very dry. Many bryophyte species appear (and disappear) at the lower limit of montane rainforests (1800m), at the lower edge of upper montane (mossy) forest (2600m), at the upper edge of closed, high forest (2900m) and at the border of subalpine heath and alpine tussock vegetation belts. The last boundary lies at 4500m, where most species disappear and only a few appear. The uppermost bryophyte record is from 5050m altitude. On this base six bryophyte zones are established. Each zone has its characteristic species combination and is parallel to the vegetation belts based on vascular plants.

J.H. Seyani & A.C. Chikuni, Proc. XIII[th] Plenary Meeting AETFAT, Malawi, 2: 797-812 (1994).

THE ALTITUDINAL DISTRIBUTION OF KILIMANJARO BRYOPHYTES

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ABSTRACT: The floristic data along four transects of the SSW slope of mount Kilimanjaro are summarized in diagrams showing the number of hepatic and moss species in each hundred meter altitudinal section and the numbers of lowermost and uppermost occurences are analyzed. On Mt. Kilimanjaro the number of species increases rapidly from 1800m altitude and species diversity shows two peaks, one at 2200m, where the montane rainforest are structurally most complex, then at 2700m altitude, in the cloud belt, where probably the precipitation maximum occurs. At the forest line (3000m) the number rapidly decreases then constant until 3800m, where the subalpine heath vegetation is becoming more open and dry with the decreasing amount of rainfall. Above this altitude the number of bryophytes decreases to a minimum, together with the rapidly disappearing moisture as the alpine belt of Kilimanjaro is very dry. Many bryophyte species appear (and disappear) at the lower limit of montane rainforests (1800m), at the lower edge of upper montane (mossy) forest (2600m), at the upper edge of closed, high forest (2900m) and at the border of subalpine heath and alpine tussock vegetation belts. The last boundary lies at 4500m, where most species disappear and only a few appear. The uppermost bryophyte record is from 5050m altitude. On this base six bryophyte zones are established. Each zone has its characteristic species combination and is parallel to the vegetation belts based on vascular plants.

INTRODUCTION

The most important environmental factors, which determine the vegetation zonation on Mt. Kilimanjaro, are the rainfall distribution and temperature gradient. The light factor acts indirectly, influenced highly by the cloudiness and by the density of vegetation cover. The rainfall is distributed on the mountain according to an altitudinal gradient, increasing rapidly from the foothills upwards. On the south-southwest slopes, Moshi town at 817m altitude receives 874 mm an average of precipitation. Kibosho on the same slope at 1479m receives 2158 mm rainfall and Kirua Wunjo well above 3000 mm. The precipitation is probably much higher in the cloud belt around 2700 m, where, according to vegetation analogies it may be as high as 3500 mm (Pócs 1976). Above 3000 m the precipitation decreases rapidly and at 4200 m altitude we reach the alpine semidesert with 200-300 mm precipitation (mostly snow). Above this altitude, in the alpine desert belt the almost complete lack of any precipitation limits the plant growth. The amount of rainfall is distributed unevenly on the different aspects at the same altitude. The above figures are valid only for the southern slopes. The northern slopes receive much less rains, and according to the distribution of vegetation types the driest site is probably the north-northeast around Rongai. We have no adequate records yet on the temperature gradient, only can conclude from analogies and extrapolate, that within the range of 700 m and 3000m the mean annual temperature varies beween 22 and 9 ^{0}C (Kenworthy, 1966; Pócs, 1976). Around 3000 m the night temperature is often below zero, which limits tree growth in the tropics and a natural forest line develops. Only trees specially adapted to these conditions, as the giant groundsels, can go beyond this limit.

This asymmetric rainfall distribution causes the asymmetric pattern of vegetation zonation (Pócs, 1991, see Fig. 1). The forest belts are much narrower on the north (as it was observed by Hedberg, 1951, and by Walter, 1964, and analysed further on other mountains by Hamilton & Perrott, 1981) and the forest types are very different from those on the southern slopes.

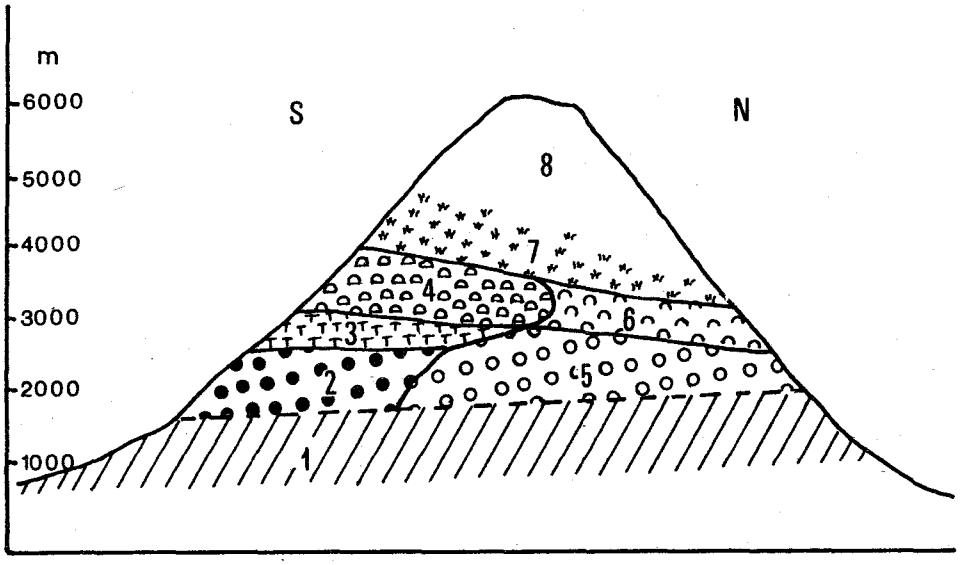

Figure 1
The vegetation belts of Mount Kilimanjaro (after Pócs 1991):1.Cultivated zone replacing savanna woodland, dry semi-deciduous forest and riverine forests, with transitions to montane evergreen forests. 2.Lower montane rainforests dominated by *Ocotea usambarensis*. 3.Upper montane rainforests (mossy forest, Erica forest). 4.Subalpine ericaceous (*Philippia*) heath. 5.Montane mesic and dry evergreen forest. 6.Dry subalpine *Stoebe-Anthospermum-Artemisia* bushes. 7.Alpine tussock (*Pentaschistis, Helichrysum*).8.Alpine desert (bare rock, sand, ice cover).

The vegetation and flora of Mount Kilimanjaro (including the bryophytes) are relatively well known, compared to the rest of East Africa (Hedberg, 1951, 1964; Pócs, 1976, 1991; Kis, 1985). Since the first publications of Mitten (1886) and Müller (1888, 1890) numerous bryological data have been published. Very important are Hedberg's bryological collections made during his Afroalpine vegetation studies (Arnell, 1956; Portier de la Varde, 1955; Vanden Berghen, 1953). A.J. Sharp's intensive collecting yielded many new records (Yamada, 1975; Bizot, Pócs & Sharp, 1979, 1985; Ochyra & Sharp, 1988). I have studied Kilimanjaro bryophytes in detail since 1970 and many of these records were published (e.g. Bizot & Pócs, 1974, 1979, 1982; Bizot, *et al.*, 1976; Ochyr & Pócs, 1982). In this paper both literature and own field records obtained from the southern slopes, which are far the best known and the richest bryologically, are summarized. The data were collected mainly along four transects, the four approaches from the SSW side: Machame, Umbwe, Mweka and Marangu Routes, and along many smaller paths and roads (see Fig. 2), from an area having uniform climatic zones and vegetational belts.

The first attempt to evaluate the altitudinal distribution of bryophytes in a tropical mountain was that of Siefriz (1924), who established altitudinal subzones among lichens and mosses on Mt. Gedeh, Java, taking into account both the occurence and the dominance of species. Van Reenen & Gradstein (1983) analyzed the bryovegetation along a transect on the Sierra Nevada de Santa Marta in Colombia, and (Van Reenen & Gradstein, 1984) investigated bryophyte distribution and ecology along an altitudinal gradient in the Colombian Andes. From this time two approaches were used to study the altitudinal distribution of bryophytes in tropical mountains.

According to one method the floristic composition of the different zones was studied and compared. Fulford, Crandall & Stotler (1971) attempted Sörensen coefficient and cluster analysis to establish the bryophyte zones of Mt. Luquillo in Puerto Rico. Van Reenen & Gradstein (1983, 1984) applied similar method in the Colombian Andes. Gradstein & Frahm (1987) studied bryophyte distribution along a transect in the Peruvian Andes introducing the counting of occurrences of lower and upper boundaries of distribution. Enroth (1990) evaluated the altitudinal data of the exhaustive bryological collections made in the mountainous area of Huon Peninsula, Papua New Guinea, using the same method. Finally the present author made a preliminary study on hepatic distribution along one transect on Mount Kilimanjaro within the frame of a conservational study (Pócs, 1991).

Authors using the other method compared the biomass or estimated the percentage of coverage and the thickness of epiphytes or of the whole bryovegetation at different altitudes, combinig these with other ecological parameters. Such evaluations were made in Eastern Tanzania (Pócs, 1980), in the Colombian Andes (Van Reenen & Gradstein, 1983, Veneklaas, 1990) and on Mt. Kinabalu in Borneo (Frahm, 1990a, b, c) or even compared the records from different continents (Frahm, 1990d).

MATERIALS AND METHODS

The present work is based on very rich material, using altitudinal records of both Hepaticae and Musci along four transects. As vegetation survey with quantitative data was not involved, only the records of occurence; the floristic approach seemed to be suitable for our purposes. The altitudinal distribution of the species was established from the available published and unpublished records, as it is demonstrated on Tables 1 and 2. These records on 540 species represent about 90% of the known Kilimanjaro bryoflora.

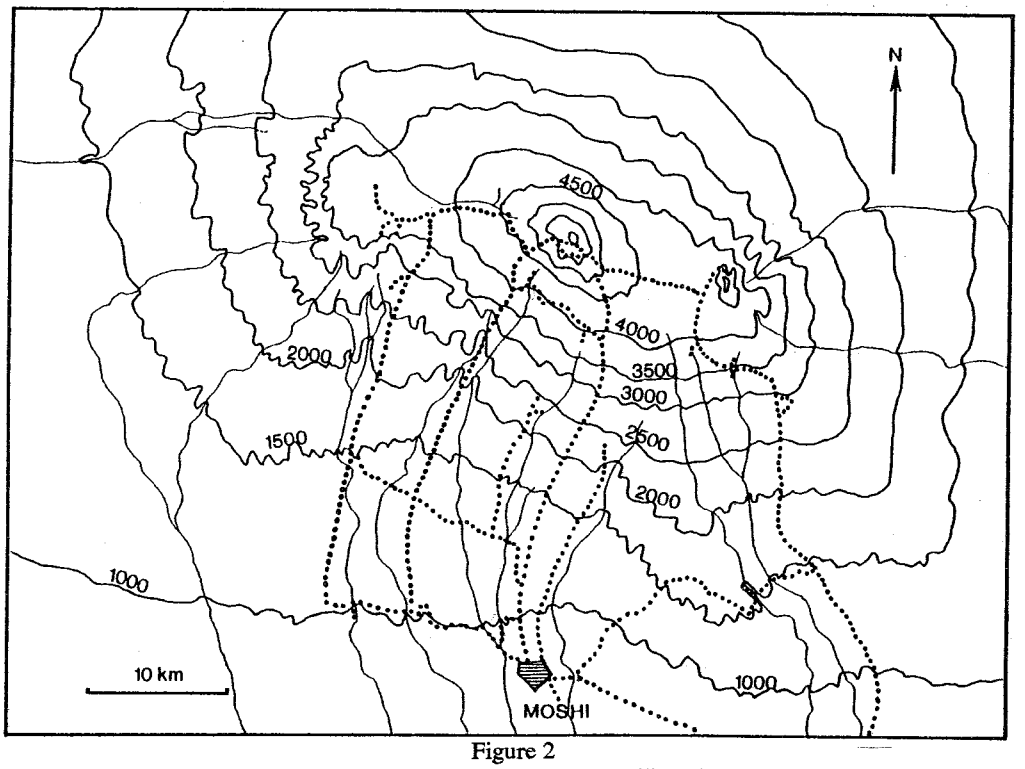

Figure 2
Transects (dotted lines) were on the southern slopes of Mount Kilimanjaro, where altitudinal records were collected for the present study.

To find the boundaries between the supposed bryophyte zones the method of Gradstein & Frahm (1987) and Enroth (1990) was used. According to this method the lower and upper altitudinal boundaries of the different species were established (see Table 1 & 2) and the occurrence of lower and upper boundaries within each 100m section were counted. In cases when only one altitudinal record was available for a species, they were defined as lowermost or uppermost occurrence based on experiences from other mountains of East Africa. In these cases in Table 1 and 2 the altitudinal records concerned are marked by a hyphen after or before the elevation record concerned. Where the record was not obviously a lowest or highest occurrence it was not taken into account. The number of lowermost and uppermost occurences is pictured on Fig. 4. The peaks of the curves at certain altitudes where a larger number of species have their upper or lower altitudinal limit represent the boundaries of the supposed bryological zones. Frahm (1990b) tried to compare the vegetational belts of equatorial mountains and proposed a general classification and nomenclature for their altitudinal zonation. His proposed general terminology is as follows:

1. Tropical Lowland Forest
2. Tropical Submontane Forest
3. Tropical Montane Forest with subdivision into Lower and Upper Tropical Montane Forest
4. Tropical Subalpine Forest

In the following I am using this terminology.

The number of hepatic and moss species in every 100m section was counted and expressed in graphs on Fig. 3.

RESULTS AND DISCUSSION

It can be seen from Figs. 3 & 4 that the variation in species number coincides well with the peaks of the altitudinal limits of bryophytes. For example the graphs on Fig. 3 shows rapid increase in the number of taxa above 1800m. Then, around 2200 m there is the first maximum in the number of species. The second maximum at 2700m altitude shows the

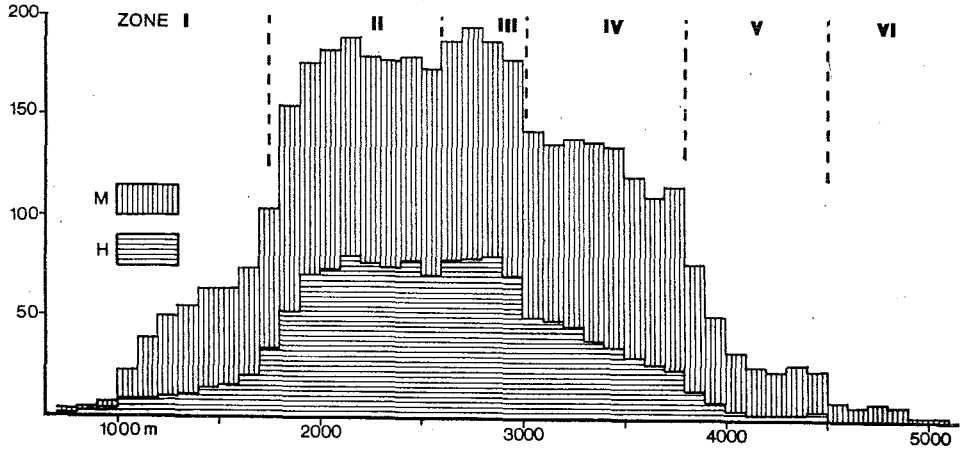

Figure 3
The altitudinal distribution of mosses (M) and hepatics (H) on the southern slopes of Mount Kilimanjaro, Tanzania. On the horizontal axis the altitude in metres above sea level, on the vertical one the number of species in each 100m section is marked

TABLE 1: The altitudinal distribution of Hepaticae on the SSW slopes of Mt. Kilimanjaro.

	Alt. in m		Alt. in m
Acanthocoleus chrysophyllus	2200-2950	C. mocambiquensis	2000-2800
A. madagascariensis	1850-2200	C. pusilla var. obtusifolia	1700-1900
Adelanthus decipiens	1700-2670	C. usambarica	1700-1900
A. lindenbergianus	2530-2900	Colura berghenii	2800-3250
Anastrophyllum auritum	2820-4500	C. calyptrifolia	2600-2850
Andrewsianthus bilobus	2700-	C. hedbergiana	2900-3400
A. kilimanjaricus	2850-3400	C. digitalis	-1930
Anthoceros myriandraceus	-1400	C. kilimanjarica	2850-2900
Aphanolejeunea exigua	1800-3000	C. saroltae	2600-3300
A. fadenii	1900	C. tenuicornis	1900-2450
A. mamillata	1900-3000	C. usambarica	2600-2850
A. microscopica	-1900	Cyathodium africanum	-750
A, moramangae	-1900	Diplasiolejeunea cornuta	1980-2450
Arachniopsis diacantha	2000-2800	D. kraussiana	-1900
Asterella dissoluta	2985	D. symoensii	-2450
A. volkensii	2900-4000	Diplophyllum africanum	2900-4020
Bazzania decrescens	1830-3000	Drepanolejeunea cultrella	2150-2450
B. nitida	1700-2700	D. physaefolia	2130-3600
B. roccatii	2000-3400	D. pocsii	-2150
Blepharostoma trichophyllum	2600-3900	Dumortiera hirsuta	1000-2950
Brachiolejeunea tristis	1400-2450	Exormotheca pustulosa	800-900
Calycularia crispula	2200-2800	Fossombronia grandis	4000
Calypogeia afrocaerulea	1750-2150	Frullania angulata	1900-2700
C. arguta	2100-2300	F. apicalis	-3225
C. fissa	2100-2950	F. arecae	1830-3800
C. fusca	1800-2900	F. caffraria	1650-3000
Cephalozia bicuspidata	2800-2900	F. capensis	3800
C. vallis-gratiae	2100-3800	F. depressa	-2700
Cephaloziella kiaerii	1850-4000	F. ecklonii	2200
C. transvaaliensis	1800-2100	F. ericoides	1350-1650
C. vaginans	1900-2100	F. lindenbergii	-2650
Chandonanthus cavallii	2900-3800	F. obscurifolia	-2700
Ch. hirtellus	1830-3000	F. schimperi	1750-3400
Ch. h. ssp. giganteus	2590-3660	F. serrata	2200-2440
Cheilolejeunea brevifissa	2450-2830	Gongylanthus ericetorum	3050-3750
Ch. cordistipula	1700-2650	G. renifolius	2950-3800
Ch. pluriplicata	2400-3800	G. richardsii	2850-3660
Chiloscyphus breutelii	2500-3300	Gottschelia schizopleura	1800-2200
Ch. concretus	1700-2900	Gymnoleopsis multiflora	4400
Ch. cuspidatus	2700-3000	Gymnomitrion laceratum	2900-4000
Ch. difformis	1260-1640	Herbertus dicranus	2200-2750
Ch. fragrans	1800	H. subdentatus	1700-3275
Ch. lucidus	1850-2150	Isotachys aubertii	2900-3600
Ch. martianus	1700-2200	Jungermannia abyssinica	1500-3800
Clasatocolea vermicularis	2130-2850	J. borgenii	1250-2950
Cololejeunea adhaesiva	-2150	J. mildbraedii	1900-2900
C. cardiocarpa	-1900	J. pocsii	2650-3800
C. distalopapillata	1700-2200	J. spaerocarpa	2300-2900
C. duvignaudii	1900-2150	Kurzia irregularis	2800-3100
C. grossidens	1900-2200	Lejeunea caespitosa	1600-2150
C. malanjae	1700-2830	L. cyathearum	1920-3000
C. minutissima ssp. utriculifera	-2450	L. eckloniana	2150-2450

L. isophylla	1700-3225
L. flava	1950-2830
L. hepaticola	2000
L. longirostris	-2850
L. rhodesiae	1260-1830
Lepidozia abyssinica	1800-2700
L. cupressina	1830-3000
L. pearsonii var. lacerata	2530-3140
L. pearsonii var. pearsonii	2600-3600
L. stuhlmannii	1920-3000
Leptoscyphus hedbergii	2000-3300
L. infuscatus	1800-2400
Lethocolea congesta	2850-3800
Leucolejeunea xanthocarpa	1700-3200
Lopholejeunea abortiva var. fragilis	-1880
L. laciniata	1750-1830
Lophozia decolorans	2200-3660
Lunularia cruciata	900-1600
Marchantia parviloba	-1600
M. polymorpha	2950-3930
M. wilmsii	1000-1300
Marsupella africana	3800-4500
M. emarginata	2950-3750
Marsupidium limbatum	1800
Mastigolejeunea auriculata	800-1600
Metzgeria agnewii	2150-2850
M. consanguinea	2200-2450
M. convexa	3800
M. elliottii	3225-3800
M. leptoneura	1900-2950
M. limbato-setosa	1750-1900
Microlejeunea africana	1830-2830
M. kamerunensis	1920-2450
Notothylas flabellata	1000-1200
Pallavicinia serrata	2700-3040
Plagiochasma eximium	-1600
P. rupestre var. rupestre	900-1400
Plagiochila barteri	2200-2890
P. barteri var valida	2950
P. boryana	1900-3040
P. colorans	2730-3200
P. corniculata	2200-3300
P. divergens	1900-3000
Plagiochila effusa	2000-3500
P. eriocicola	2150-3000
P. fusifera	2780-2850
P. lastii	2800-3500
P. squamulosa var. sinuosa	1620-2600
P. subalpina	2200-3750
P. terebrans	2000-3500
Porella abyssinica	2700-2900
P. capensis	2000-3000
P. hoehnelii	1850-2900
P. subdentata	1600-2830
P. triquetra	2000-3000
Ptychanthus striatus	1600-1960
Radula allamanoi	1900-2890
R. boryana	1600-2150
R. evelyne	1900-2000
R. holstiana	1800-3500
R. madagascariensis	-2000
R. meyeri	1350-2200
R. recurvifolia	1700-2700
R. stipatiflora	1400-2890
Riccardia compacta	2930-3900
R. fastigiata	1450-2860
R. limbata	-1800
R. longispica	1800-2300
R. saccatiflora	1900-2100
Riccia fluitans	1000-1200
R. lamellosa	-1400
Scapania esterhuyseniae	3800-
Schiffneriolejeunea pappeana	-2100
Sch. polycarpa	1350-1750
Symphyogyna brasiliensis	2700-3000
S. podophylla	2200-4000
S. volkensii	3100-
Syzygiella geminifolia	1840-2200
Targionia hypophylla	1000-1400
T. lorbeeriana	1460-3800
Taxilejeunea conformis	1900-3000
T. pulchriflora	-1500
Telaranea nematodes	1830-2700
Tritomaria exsecta	2850-3800
Tylimanthus ruwenzorensis	1900-2750

highest number of bryophytes. At 3000m there is a rapid decrease in the bryophyte species number, followed by a slow, gradual decrease until 3800m, where there is a rapid decrease again. Finally a last step at 4500m reduces species number almost to zero. Concerning the lower and upper boundaries, they show several peaks on the graphs of Fig. 4: at 1200, 1800-1900, 2200, 2900 and at 3900m. On this base the bryophyte zones of the moist side of Mt. Kilimanjaro could be established. These zones are discussed, characterized by their species composition and an attempt is made to find analogy between the bryological zones and the major vegetational belts of the mountain (see also Fig. 1).

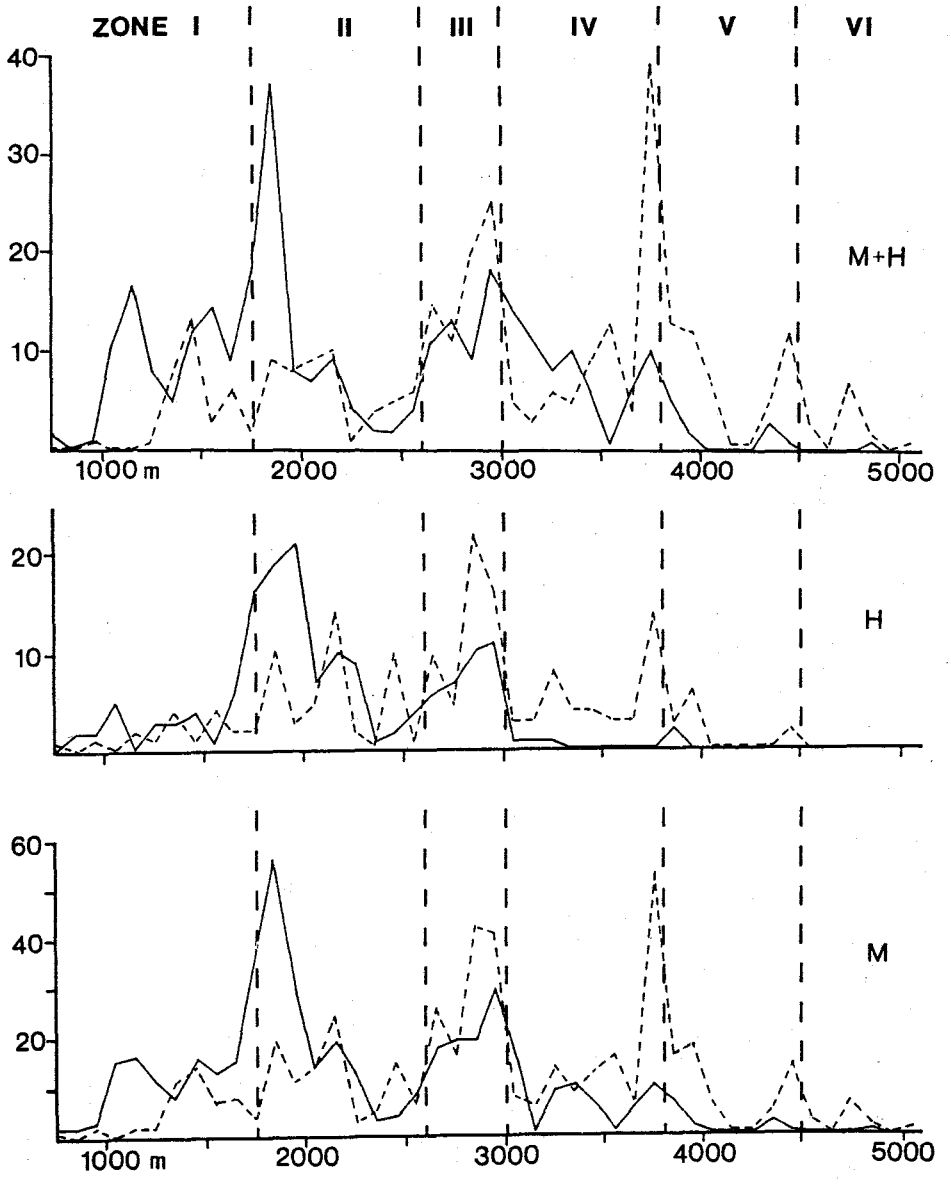

Figure 4
The altitudinal distribution of the lower (solid line) and upper (broken line) limits of moss (M), hepatic (H) and all bryophte species (M+H). On the horizontal axis the altitude in metres, while on the vertical one the number of occurences in each 100 m section is marked.

TABLE 2: The altitudinal distribution of Musci on the SSW slopes of Mt. Kilimanjaro.

	Alt. in m		Alt. in m
Aerobryidium subpiligerum	1750-2830	B. recurvirostre	3650-4500
Amphidum tortuosum	2900-4900	B. rubrum	3900-4000
Anacolia laevisphaera	3050-4100	Bryohumbertia filifolia	1600-2100
Andreaea cucullata	3800-4000	B. flavicoma	1600-2600
A. firma	3250-3550	Bryum afro-calophyllum	3360-3850
A. mildbraedii	3250-4200	B. alpinum	2950-3800
A. obovata	3060-3890	B. apiculatum	2700-3600
Anisothecioum ugandae	-3850	B. arachnoideum	3050-3650
Anoectangium eukilimandscharicum	1500-2810	B. argentisetum	1350-3700
A. hanningtonii	1000-1500	B. andicolum	1280-1500
Anomobryum filiforme	2300-3800	B. capillare	3440-3800
A. minutirete	2950	B. ellipsifolium	3700-4500
Antitrichia curtipendula	2000-3800	B. erythocaulon	2200
Aongstroemia julacea	2950-3800	B. haematoneuron	3700
Anomobryum filiforme	3000-3440	B. hedbergii	3260-3420
Atractylocarpus alticaulis	1800-2900	B. huillense	1220-1500
Bartramia afro-ithyphylla	2950-3800	B. inclusum	3800
B. gigantea	3000-3250	B. keniae	1900-2100
B. hampeana	3240-3800	B. laevigatum	2960-
B. ithyphylla	3800	B. leptoneuron	2750-2960
B. jungneri	3330-3650	B. pallens	-3850
B. ruwenzorensis	2900-4270	B. pseudotriquetrum	3700-4400
B. strictula	3700-	B. subargenteum	-3350
Bartramidula globosa	3330-	B. umbraculum	1350-
Brachymenium acuminatum	1830-3800	B. voelzkowii	1830-2130
Brachymenium leptophyllum	1280-1900	Calyptothecium hoehnelii	1700-2500
B. procerrimum	1830-	Campylopodium euphorocladum	1800-2100
B. rigidum	1280-	Campylopus chrismarii	3800
B. acuminatum	1700	C. dicranoides	2650-2850
Brachymitrion pocsii	2890-	C. flexuosus	2950
Brachythecium afro-glareosum	2000-4020	C. fragilis	2950-3330
B. borgenii	2600-3000	C. hensii	1600
B. dummeri	1500-	C. jamesonii	1600-3500
B. glorisum	2900-3000	C. johannis-meyeri	3000-4000
B. hedbergii	2400-3800	C. nivalis	1800-4500
B. implicatum	1750-	C. pilifer	1500-3050
B. mildeanum	-4800	Ceratoon purpureus	2470-3800
B. nigro-viride	-3800	C. viridatus	3600-3800
B. plumosum	3000-3050	Cinclidotus fontinaloides	-3050
B. populeum	-4800	Cratoneurum filicinum	3700-4400
B. ramicola	-3200	C. subcurvicaule	4700
B. spectabile	2600-4400	Cryphaea protensa	1830-3200
B. ugandae	3800-	C. robusta	2600-2870
B. vellereum	2000-3800	Cyclodictyon borboncium	1470-3600
Braunia arbuscula	-2700	C. brevifolium	2150-2800
B. camptoclada	1350-3260	C. perlimbatum	-2000
B. secunda	2900-3440	C. vallis-gratiae	1800-2700
Breutelia borbonica	3000-3600	Cynodotium tanganyikae	4000
B. diffracta	1900-3800	Daltonia angustifolia	1800-2900
B. humbertii	3500-3760	D. mildbraedii	1800-2960
B. perrieri	2850-3600	D. mittenii	2200-2960
B. muhavurensis	3000-3700	Dicranella kenyae	2130-2660
B. stuhlmannii	2700-3420	D. subsubulata	1850-3800
Bryoerythrophyllum alpigenum	3700-	D. usambarica	1500-2200

Dicranoloma billarderi	1830-2900	F. kilimandscharica	2700-3200
Dicranoweisia africana	3760-4000	F. perlaxa	3000-3050
Dicranum acanthoneurum	1800-3000	Glossadelphus vivicolor	1980
D. johnstonii	1900-3800	Grimmia affinis	3050-4570
Didymodon alpigena	3700-	G. afroincurva	4320-4820
D. paucidentatus	3350-4000	G. apiculata	3750
Distichium capillaceum	3300-4020	G. doniana	3650-4570
Ditrichum difficile	1470-3000	G. laevigata	2850-4570
D. pallidum	-3400	G. ovalis	3260-3950
Ectropothecium sericeum	1520-4050	G. trichophyllum	4320-4500
Encalypta ciliata	3480-3850	G. t. var. brachycarpa	3660-4500
E. hebdergii	4400-4800	Haplocladium angustifolium	-1400
Enthostodon usambaricus	2750-3800	Hedwigia ciliata	3000-3800
E. volkensii	2950-3570	Hedwigidium integrifolium	3000-3850
Erpodium beccarii	780-1450	Heterophyllium flexile	1700-2830
Eucladium verticillatum	4700	H. kilimandscharicum	-1960
Erythrodontium subjulaceum	1130-1520	Homalothecium afro-striatum	1830-3600
Eurhynchiella decurrens	2600-4000	Hookeriopsis mittenii	-2000
Eurhynchium hians	3300-3600	H. pappeana	-2150
Fabronia abyssinica	1130-1350	Hygroamblystegium irriguum	3750-3800
Fabronia leikipiae	1130	Hyrohypnum hedbergii	2950-3850
F. longipila	1130-1350	Hylocomiopsis cylindricarpa	1700-2350
F. pilifera	1000-1500	Hylocomium splendens	2600-3300
Fissidens angolensis	1000-1350	Hymenostylium recurvirostre	2985-4020
F. asplenioides	1000-1350	Hyophila acuminata	-1400
F. caloglittis	3000-4000	H. involuta	1860-2000
F. comorensis	-1350	H. potieri	-1000
F. crateris	1400-	Hypnum ~~aduncoides~~ Macrogyrium	2150-3000
F. curvifolius	1280	H. africanum (Breidleria a.)	1900-2100
F. flavolimbatus	1400-1700	H. cupressiforme	2000-4500
F. gibbonii	1500-2700	Hypopterygium laricinum	1140-1500
F. glaucescens	1400-2750	H. mildbraedii	1700-2100
F. helictocaulos	1000-1450	H viridissimum	1260-1900
F. hoegii	-1500	Isopterygium m'bangae	1140-2150
F. kegelianus	1350	I. phlyctitheca	1800-2800
F. latifolius	1130-2440	I. sericifolium	2850-2900
F. leucocinctus	1900	Leiomela africana	1830-2510
F. longelimbatus	1620-2100	Lepidopilidium hanningtonii	1800-2850
F. longidens	-1600	Leptodon smithii var. beccarii	1600-2750
F. malacobryoides	1370	Leptodontiopsis fragilifolia	3300-4500
F. marginatus	3260-3600	Leptodontium flexifolium	2970-3800
F. nitens	1800-2000	L. joannis-meyeri	3700-3950
F. ovatus	1350-3360	L. luteum	2600-3500
F. purpureocualis	1350-2850	L. pungens	2850-4500
F. rufescens	1130-2700	L. stellatum	1700-1800
F. smilioides	-1260	L. viticulosoides	1600-3800
F. spinosolimbatus	-2900	L. wallisii	3800
F. stellenboschianus	-2750	Leucobryum isleanum var. molle	1000-2530
F. splendens	1900	Leucodon dracaenae	2000-3800
F. subcongolensis	-1900	L. laxifolius	2530-2700
F. undifolius	2150	L. rutenbergii	-2700
F. vesiculosus	1260-1450	Leucoloma aspericupsis	1130-2200
F. vogelianus	1800-1900	L. bifidum	1700-1900
Floribundaria floribunda	-1440	L. holstii	1700-2700
Forsstroemia producta	1500-1700	Levierella perserrata	-1700
Funaria calcarea var. convexa	-2985	Lindbergia patentifolia	1000-1700
F. hygrometrica var. calvescens	1000-3800	Macrocoma abyssinica	2150-3800

M. tenue	1500-1800
Macromitrium levatum	1750-3470
Mittenothamnium cavifolium	-2500
M. cygnicollum	1750-2950
M. overlaetii	-2700
M. pseudoreptans	-2000
Mniobryum pergracile	1520-
Neckera platyantha	1700-3000
Neckera remota	2150-2600
N. submacrocarpa	2600-3250
Oligotrichum afro-laevigatum	-2950
O. cavallii	2150-3050
Orthodontium lineare	2150-3300
O. loreifolium	1900-3600
Orthotrichum affine	3800
O. rupestre	3480-4800
Oxyrrhynchium hians	1600-1800
Oxystegus tenuirostris	-2410
Papillaria africana	1540-2870
Philonotis dregeana	2750
Ph. fontana	3350-3950
Ph. hastata	1130-3800
Ph. platyneura	3850-
Ph. tomentella	2500-4400
Pilotrichella ampullacea	1700-2800
P. cuspidata	1700-2150
P. imbricatula	-2000
P. isleana	1900-2100
P. pentasticha	-2250
P. profusicaulis	1500
Pinnatella flagellacea	-1830
Plagiomnium rhynchophorum	2150-2750
P. r. var. reidii	2530-2900
Plagiothecium milbraedii	2200-3800
P. nitens	1800-2700
Plasteurhynchium rusciforme	3900-4000
Pocsiella hydrognioides	2900-2920
Pogonatum aloides	1460-2620
P. molleri	1000-2570
P. rubenti-viride	1850-2350
p. urnigerum	2700-3800
Pohlia afrocruda	3600-
P. elongata	2900-3600
P. nutans	2600
Polytrichum commune	2730-2900
P. piliferum	2200-3900
P. subpilosum	1700-3800
Porothamnium stipitatum	1140-3000
Porotrichum elongatum	1800-2800
P. madagassum	1800-3500
P. molliculum	1800-2600
Prionodon ciliatus	1900-2900
Pseudoleskea leskeoides var. macowaniana	1280
Pterogonium gracile	1680-3000
Pyrrhobryum spiniforme	1830-2440
Racomitrium alare	2950-4500
R. lamprocarpum	2800-3800
Racocarpus purpurascens	2750-3800
Racopilopsis trinitensis	1830-2630
Racopilum capense	1450-3760
Rauiella subfilamentosa	1500-2750
Regmatodon secundus	1800-2100
Renauldia hoehnelii	1800
Rhabdoweisia africana	2900-
R. lineata	2850-3400
Rhachithecium perpusillum	900-1350
Rhizofabronia perpilosa	2600-4500
Rh. personii var. sphaerocarpa	2080-2630
Rhynchostegiella holstii	1140-3900
Rhyncostegium bello-intricatum	1800-2800
Rh. comorae	1520-3000
Rh. horridum	1800-2900
Rh. riparioides	3440-3800
Rh. volkensii	1140-2150
Rigodium kilimandscharicum	1700-3500
Sanionia uncinata	2700-4400
Schimperella atrotheca	1700
Schistidium alpicola	3440-3850
Sch. apocarpum	3450-3800
Sch. apocarpum ssp. confertum	4800-5050
Sch. perichaetiale	4320-4500
Schizomitrium usambaricum	1900-2200
Schizomitrium cratericolum	3250-3800
Sch. elgonensis	2850-2900
Sch. mildbraedii	3800-3950
Sch. ruwenzorense	3250-3800
Schoenobryum robustum	1600-3000
Sematophyllum caespitosum	1400-1500
S. elgonense	1460-3000
S. fulvifolium	1800
S. obtusifolium	-2130
S. subbrachytheciforme	1470-3800
S. subpinnatum	1460-1830
Sphagnum ceylonicum	2290-3050
Sph. davidii	2900-3300
Sph. strictum ssp. pappeanum	3300
Squamidium brasiliense	1860-2100
Stereophyllum brunnthaleri	750-1470
S. nitens	2600-2850
S. radieulosum	1130-1500
Streptopogon erythroontus var. rutenbergii	2130-2750
Syrrhopodon asper	1800-2350
S. gaudichaudii	1700-2350
Taxiphyllum gabonense	1800-3000
Tayloria kilimandscharica	3100
Tetraplodon mnioides	2740-3900
Thuidium matarumense	2600-2950
Th. ramusculosum	-1700
Th. varians	1000-1700
Tortella fragillima	-4800
Tortula cavallii	3320-4500
T. cochlearifolia	3800-4800
T. fragilis	1280-3800

Trachyphyllum inflexum	1140-1500	W. jungneri	-1830
Trachypodopsis serulata var. serrulata	2000-3000	W. trichocolea	1140-2950
Trichosteleum humbertii	2380-2850	Zygodon barbuloides	3740-4800
T. mamillipes	1830-2200	Z. intermedius	1280-3600
T. lorifolium	-2700	Z. reinwardtii	2700-3800
Trichostomum tenuirostre	2810-2900	Z. robustus	3650-3850
Trischium mirabile	3350-4000	Z. runcinatus	2560-3000
Ulota tanganyikae	4800	Z. seriatus	1800-3600
Warbugiella leptorrhyncha	1800-2800	Z. trichomitrius incl.	
Wijika cuynetii	1700-1800	var. mildbraedii	1130-3000

ZONE I, 750-1800m

The number of species gradually increases within this zone from almost zero to about 100. Characteristic species (of which the majority reaches its highest altitudinal limit within this belt), are either lowland tropical bryophytes, as *Anthoceros myriandraceus, Cololejeuna cardiocarpa, Cyathodium africanum, Lejeunea rhodesiae, Lopholejeunea laciniata,* L. *arbotiva* var. *fragilis, Marchantia parviloba, M. wilmsii, Mastigolejeunea auriculata, Notothylas flabellata, Taxilejeunea pulchriflora; Anoectangium hanningtonii, Bryum huillense, Erythrodontium subjulaceum, Fissidens angolensis, F. helictocaulos, F. vesiculosus, Haplocladium angustifolium, Hyophila potieri, Hypopterygium laricinum, Pinnatella flagellacea, Sematophyllum caespitosum, Stereophyllum brunnthaleri, Wijkia cuynetii*; or xerophytes, which cannot find suitable habitat higher in these wet slopes of Mount Kilimanjaro, or they are not competitive, as *Exormotheca pustulosa, Marsupidium limbatum, Plagiochasma eximium, P. rupestre, Erpodium beccarii, Fabronia leikipiae, F. longipila, F. pilifera, Forsstroemia producta*, and others. These xerophytes ascend to much higher altitude on the northerly, dry slopes of the mountain.

This bryological zone nowadays is very densely populated and mostly cultivated. On these lowermost slopes the original vegetation was a continuous transition from dry, open savanna woodland through dry semideciduous forest to the wet, evergreen tropical submontane forest belt. On figure 4 the first, smaller peak of the graphs at 1200m most probably indicates the boundary between the former savanna woodland and closed dry forest belts, where a number of forest bryophytes first appear. Only rocky slopes, stream valleys (submontane riverine forests with *Newtonia buchananii* and *Albizia schimperiana*) and waterlogged areas (e.g. swamp and riverine forests of Rau Forest Reserve) remained in more or less natural condition. These original vegetation types are not rich in bryophytes (Pócs 1982). On the other hand, coffee plantations with their shade trees offer a relatively good bryophyte habitat.

ZONE II, 1800-2600m

After a sharp increase the species number is high, above 2000m reaching 180 in every 100m sections. The species are typical orophytes, in many cases with Afromontane or East African montane, sometimes with southern temperate distribution. A few examples of species typical here: *Acanthocoleus madagascariensis, Adelanthus decipiens, Bazzania nitida, Cololejeunea grossidens, Leptoscyphus infuscatus, Radula boryana, Telaranea nematodes; Bryohumbertia flavicoma, Calyptothecium hoehnelii, Dicranella usambarica, Hylocomiopsis cylindricarpa, Leiomela africana, Leucoloma holstii, Neckera remota, Papillaria africana, Plagiothecium nitens, Porotrichum molliculum, Rhizofabronia personii var. sphaerocarpa, Rhynchostegium horridum, Squamidium brasiliense, Syrrhopodon asper.* This zone is the upper limit of many tropical species (like most *Meteoriaceae*).

This bryological zone corresponds to the structurally most complex lower tropical montane belt of Mount Kilimanjaro, dominated by *Ocotea usambarensis* and *Podocarpus latifolius* in the canopy accompanied by *Rapanea melanophloeos*, in the lower layers with many tree ferns (*Cyathea manniana*). The ground layer is usually densely covered by *Selaginella kraussiana*, often accompanied by *Impatiens kilimanjarica*. The climber *Begonia meyeri-johannis* is typical in these forests.

The canopy of once logged, secondary stands is dominated by *Macaranga kilimanjarica* and by *Polyscias fulva*. Secondary stands, lacking the old *Ocotea* (East African camphor) specimens are usually much poorer in epiphytic bryophytes, *Ocotea* bark being a very suitable epiphytic substrate.

ZONE III, 2600-3000m

This zone is the richest in bryophyte species. This richness end abruptly at 3000m altitude, with the upper forest line. There are many forest elements which occur only to this limit throughout the forest belts: e.g. *Aphanolejeunea exigua, Bazzania decrescens, Cololejeunea malanjae, Dumortiera hirsuta, Leucolejeunea xanthocarpa, Porella subdentata; Aerobryidium subpiligerum*, all *Daltonia* species, *Dicranoloma billarderi, Ditrichum difficile, Hypnum aduncoides, Neckera platyantha, Pilotrichella ampullacea, Porothamnium stipitatum* and many others. On the other hand in this zone already appear a number of the Afroalpine species, often in open ravines, rocky gorges (see at the end of chapter).

Typical elements of this zone are: *Adelanthus lindenbergianus, Cephalozia bicuspidata, Colura kilimanjarica, Kurzia irregularis, Pallavicinia serrata; Brachymitrion pocsii, Brachythecium gloriosum, Bryum leptoneuron, Campylopus dicranoides, Pocsiella hydrogonioides, Thuidium mataramense* and a few others. The very high species diversity of this zone is much more the result of its transitional position and special vegetation (see below), than the high number of its own typical elements, although a few of most isolated endemics are restricted to this zone (*Brachymitrion, Pocsiella*).

This belt includes two vegetation types: the upper tropical montane (mossy) rainforest and the tropical subalpine *Erica arborea* forest (giant heath). The mossy montane rainforest occupies more rich soils, often in the damp valleys but also on ridges with deep soil. *Podocarpus latifolius* can be dominant in the canopy, often intermixed with *Hagenia abyssinica*. The most striking feature of this forest is the very dense moss cover. Epiphytic bryophytes cover the trunks making their appearance much thicker than they are. Thick fur or large cushions load all bigger branches too. The commonest epiphytic bryophytes are, which represent the largest biomass: *Herbertus subdentatus, Lepidozia cupressina* and *Dicranoloma billarderi.*

The other forest type within the same belt is the *Erica arborea* forest (giant heath). This forest replaces the previous one on shallow, leached soils, mainly on the ridges. The dominant tree species, *Erica arborea* forms a 6-15m tall, open canopy and therefore much more light reaches the ground. The forest form of the afroalpine giant *Senecio johnstonii* with naked stem without senescent leaves is common in the lower layers and *Lobelia deckenii* also appears. The epiphytic bryovegetation is very similar to the previous type and the dominant species are the same. But in this open community much more afroalpine element penetrate from the zones above, e.g.; *Chandonanthus cavallii.* Even the ground is densely covered by bryophytes, as by the large cushions of *Lepidozia cupressina, Plagiochila boryana* and *P. ericicola, Breutelia stuhlmannii* and other *Breutelias,*

Campylopus jamesonii, Sphagnum ceylonicum, Sph. davidii, Thuidium matarumense, intermixed with *Leptodontium luteum, Bryum leptoneuron or Cyclodictyon borbonicum.*

Within this belt are the rocky gorges and cliffs are the habitat richest in afroalpine bryophytes. On the rock surface many species which live generally at higher elevation, occur. Bryophytes in the forest belts only in these habitats: *Anastrophyllum auritium, Andrewsianthus kilimanjaricus, Asterella volkensii, Chandonanthus hirtellus*ssp. *giganteus, Colura hedbergii, Diplophyllum africanum, Lethocolea congesta, Riccardia compacta; Amphidium tortuosum, Batramia afro-ithyphylla, B. ruwenzorensis, Bryum laevigatum, Funaria kilimandscharica, Grimmia laevigata, Racomitrium alare* and *R. lamprocarpum.*

ZONE IV. 3000-3800m

As most sciophilous forest species disappear at 3000m, the number of species drops rapidly, although a large number of alpine species appears. Above this altitude the species richness decreases gradually from 140 to 110 at 3700m, then again increases at 3800m before rapidly falling to the altitude of 4000m. Afroalpine species are typical as: *Chandonanthus cavallii, Diplophyllum africanum, Gongylanthus richardsii, Metzgeria elliotii; Andreaea cucullata, A. firma, A. obovata, Bartramia hampeana, B. jungneri, Breutelia humbertii, B. muhavuren-sis, Bryum afro-calophyllum, B. hedbergii, Campylopus johannis-meyeri, Didymodon paucidentatus, Enthostodon volkensii, Fissidens marginatus, F. caloglottis, Funaria perlaxa, Hygrohypnum hedbergii, Leptodontium johannis-meyeri, Schizimenium craericolum, Sch. mildbraedii, Sch. ruwenzorense, Zygodon robustus* and others. Certain northern or southern (*) temperate elements on Mount Kilimanjaro occur exclusively in this belt, like *Anastrophyllum minutum, Marchantia polymorpha, Marsupella emarginata, Distichium capillaeum, Encalypta ciliata, Hedwigia ciliata, Hymenostylium recurvirostre, Leptodontium flexifolium, Philonotis fontana, Schistidium alpicola, Tristichium mirabile**. (Compare Gradstein & Vána, 1987).

This bryological zone coincides with Hedberg's (1951) Afrosubalpine Ericaceous shrub zone formed on this side of the mountain mostly by the *Philippia* species, sometimes by stunted, 1-3m tall *Erica arborea* bushes or by the dwarf *Blaeria* species. With altitude this subalpine bush, which is the analog of subparamo belt in the Andes, becomes more and more open and the shrubs smaller and smaller, slowly giving place to the Afroalpine tussock vegetation. The bryophytes given above occur only partly on the floor of this heath vegetation. Some elements inhabit the more open grounds, like small *Gongylanthus, Entostodon, Schizimenium* species, *Tristichium mirable* or the very disjunct altimontane *Aongstroemia julacea*. Even more bryophytes occur in rocky gorges, on boulders, in the giant *Senecio* moorlands or in spring bogs. The latter two communities occur on Mount Kilimanjaro mostly in valley bottoms at an altitude around 3800-3900m and their presence causes the small increase of species number visible on the graphs.

ZONE V. 3800-4500m

At the lower edge of this zone many species reach their uppermost limit and a smaller number of other species appear. The number of moss species decreases gradually up to 4500m altitude and the liverworts almost disappear. The characteristic species of the zone are typical alpine species, as *Marsupella africana, Gymnocoleopsis multiflora; Bryoerthrophyllum recurvirostre, B. rubrum, Bryum ellipsifolium, Cynodontium tanganyikae, Dicranoweisia africana, Grimmia doniana, G. trichyophylla* var. *brachycarpa, Tortula cavallii, Zygodon barbuloides.*

This zone coincides with the lower Afroalpine belt, where tussock (*Pentaschistis borussica - Festuca kilimanjari - Koeleria capensis*) and *Helichrysum* cushion vegetation predominates. The above species occur mostly on the rocks within this vegetation type, but some *Tortula* and *Zygodon* species are epiphytes on giant groundsels (*Senecio cottonii*). It is very noticeable, that certain sciophilous forest species reach their uppermost occurrence in this belt, living in shady lava caves and rock shelters, far from their continuous distribution, as *Brachythecium afro-glareosum, B. mildeanum, Cephaloziella kiaerii, Ectropothecium sericeum, Eurhynchiella decurrens, Hypnum cupressiforme, Rhizofabronia perpilosa*.

ZONE VI. 4500-5050m

The number of bryophytes is very reduced and no liverworts are present. Only a few new elements appear which do not occur below and are typical for this zone, as: *Cratoneurum subcurvicaule, Encalypta hedbergii, Eucladium verticillatum, Grimmia afroincurva, Schistidium apocarpum* ssp. *confertum, Sch. perichaetiale, Tortella fragillima* and *Ulota tanganyikae*. Many of them are Afroalpine endemics (cf. Spence & Pócs, 1991). The highest occurrence of any bryophyte on Kilimanjaro was observed on the Western Breach of Kibo, where *Schistidium apoarpum* ssp. *confertum* lives at 5050m altitude (Pócs, 1991). This altitudinal limit is relatively low for tropical alpine bryophytes and is caused certainly by drought and not by the low temperature, as in moister tropical mountains bryophytes occur much higher.

This bryological zone corresponds with the higher Afroalpine semidesert and desert belt of Kilimanjaro, with no continuous vascular cover. On the bare soil surface disturbed by ice needle formation during night frosts only loosely attached lichens (*Coelocaulon aculeatum, Xanthoria elegans*) and moving moss balls (*Grimmia* spp) are able to survive (cf. Hedberg, 1964). Only sheltered rocks and spring bogs can harbour a bit more rich bryophytic and lichen life.

Many multizonal species occur also in the alpine zones IV-VI similarly to the forested zones I-III. For example species occuring jointly in zones IV-V, are *Diplophyllum africanum, Gymnomitrion laceratum, Andreaea mildbraedii, Aongostroemia julacea, Cratoneurum filicinum, Leptodontiopsis fragilifolia, Sanionia uncinata, Zygodon barbuloides*. A few other species occur in all the three zones IV, V and VI like *Grimmia affinis, Orthotrichum rupestre* and *Tortula cochlearifolia*.

CONCLUSIONS

The comparison of the above zones and vegetation belts with those studied on the other continents by van Reenen & Gradstein (1983), Gradstein & Frahm (1987), Enroth (1990) and Frahm (1990) shows, that they have many similarities in general. However, the Kilimanjaro zones and their boundaries lie slightly lower than the ones in the other continents. Van Reenen & Gradstein (1983, 1984) in the Sierra Nevada de Santa Marta mountains of Colombia and Gradstein & Frahm (1987) observed a very similar double maximum in the abundance and species diversity of bryophytes at 2075-2300 and at 2700-2950m altitudes to the ones observed by me on Mount Kilimanjaro at 1900-2100 and at 2600-2900m altitudes. Van Reenen & Gradstein (l.c.) explain the phenomenon of this "double peak" by the arrangement of climatic "condensation zones". On Mount Kilimanjaro we still need the meteorological proof of more than one condensation zones. At least one condensation zone is present, where the bryophyte vegetation reaches its highest species diversity, at 2700-2800m altitude, in the mossy forest belt.

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