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### Title

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### Permalink

<https://escholarship.org/uc/item/4qw5r72g>

### Journal

Die Erde, 132

### ISSN

0013-9998

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### Publication Date

2001

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Peer reviewed

• *vegetation mapping - Ecuador - Andean vegetation - floristic composition - páramo*

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## **Classification of tropical montane shrub vegetation - a structural approach**

*Klassifizierung einer tropischen Gebüschvegetation - ein struktureller Ansatz*

With 2 figures and 4 tables

Studies that estimate potential risks and rates of loss in tropical ecosystems always depend on the use of a vegetation classification scheme. Classification can be approached on the basis of floristic or structural data. While floristic approaches are well established for the vegetation of temperate zones (*Braun-Blanquet* 1964, *Cajander* 1909, *Du Rietz* 1932), they are not easily applied in the tropics owing to the enormous number of species in tropical vegetation (*Vareschi* 1980). The present study reviews newer approaches that use a mix of floristic and structural features to characterise vegetation and highlights what 'structure' means in each case. We present the results of a structural analysis of a shrub vegetation on higher elevation of the Ecuadorian Andes on a plot scale (average size 50 m<sup>2</sup>) that is independent of floristic identification. Nevertheless, we registered plant species composition of the plots as a test for our investigation system. Our results contribute to the current discussion in favour of structural approaches.

### **1. Introduction**

The Ecuadorian Andes lost 90 % of their original forest cover owing to human activity (*Hamilton et al.* 1995), and with 1.1 % the annual rate of loss in tropical montane forests is even higher than in tropical lowland forests with 0.8 % (*Doumenge et al.* 1995). To estimate potential risks and rates of loss, and to suggest conservation concepts the vegetation has to be classified. If ecosystem processes such as energy flows, information flows, nutrient exchanges or changing biodiversity are to be documented and understood, vegetation as a central part of the ecosystem has to be investigated (*Ewel and Bigelow* 1996). Even on a global scale the assessment of ecological problems depends always on the use of a vegetation classification scheme (*Adams* 1999).

Approaches to classify vegetation are numerous and can be divided into two major groups: floristic approaches and physiognomic approaches (*Beard* 1973). The floristic approaches use plant species and species composition to describe vegetation or vegetation units for a hierarchical system. The physiognomic approaches use plant architecture, life-form composition or structure to describe and classify physiognomic units.

Most of the floristic classification systems have been developed for temperate zones (*Braun-Blanquet* 1964, *Cajander* 1909, *Du Rietz* 1932) and are not easily applied in the tropics owing to the enormous number of species in tropical vegetation. *Vareschi* (1980) states that about 80 different species of ferns exist in central Europe, whereas Venezuela

alone hosts more than 1000. He concludes that there cannot be a 'botanist of the tropics' who knows the complete flora of a tropical country but that specialisation in taxonomic groups or certain vegetation types is unavoidable. Hence, to describe the species composition of a tropical forest is very complicated and time-consuming, if at all possible. *Madsen and Øllgaard* (1994) undertook this task for two 1-ha plots in an upper montane rain forest in southern Ecuador and found 75 and 90 species respectively. But this study included only trees with a dbh  $\geq 5$  cm and neglected for example epiphytes, not to mention mosses and lichens. *Barthlott et al.* (1996) identify the montane forests covering the eastern slopes of the Andes in Ecuador as a hotspot of biodiversity. A floristic approach therefore might not be the most promising way to classify the vegetation of that investigation area, at least not with current floristic knowledge and in an ecosystem approach, where colleagues from other disciplines (e.g. soil scientists) are waiting for results.

Nor are physiognomic approaches always suitable for the tropics, depending on where they have been developed. The classical life-form concept of *Raunkiaer* (1934), for example, is of little value in the recognition of forest types in the tropics because of the lack of a cold season (*Beard* 1973). It was very much improved by *Mueller-Dombois and Ellenberg* (1974) who created a system of vegetation units suitable everywhere. This system has a global scale and does not allow more distinct subdivisions on a local scale.

*Beard* (1973) gives an excellent overview about the history of important concepts beginning with the ideas about life-forms of *Warming* (1909) and *Schimper* (1898) and discusses the major approaches up to the 1960s. *Webb et al.* (1970: 204) state that 'The close correlations that exist between reproductive structures and

vegetative morphology render the floristic/structural distinction somewhat artificial, and some degree of overlap is unavoidable'. The same authors admit that the number of structural features that could be described is unlimited and therefore those actually used must be listed. So the present study reviews those newer approaches that use a mix of floristic and structural features to characterise vegetation and highlights what 'structure' means in each case (especially for the tropics). These mixed approaches are grouped according to the growing degree they consider structure and get independent of plant species identification. Finally we present the results of a structural analysis of a shrub vegetation on higher elevation of the Ecuadorian Andes on a plot scale (average size 50 m<sup>2</sup>) that is independent of floristic identification. Nevertheless, we registered plant species composition of the plots as a test for our investigation system. The shrub vegetation was chosen to ensure a comparatively low number of species that are fairly well documented already (*Balslev and Luteyn* 1992, *Baruch* 1984, *Beard* 1955, *Ramsay and Oxley* 1996, 1997). For the definition of 'structure' we followed *Barkman* (1979), who defined structure as the 'horizontal and vertical arrangement of vegetation'.

## 2. Newer approaches

The nine studies listed in *table 1* were conducted in different forest types and in different altitudes. Most of them (*Valencia and Jørgensen* 1992, *Valencia* 1995, *Valencia et al.* 1998, *Young* 1998, *García* 1998) aimed just to describe the forest in the sense of an inventory. *Condit* (1998) proposed a forest census for demographic studies and emphasised that the identification of species requires specialists and cannot be done while measuring the trees. *Korning et al.* (1990) tested different designs in one area and concluded that results

Tab. 1 Synopsis of nine approaches that use a mix of floristic and structural features to characterise tropical vegetation / Übersicht über neun Ansätze, die sowohl floristische als auch strukturelle Merkmale zur Charakterisierung tropischer Vegetation heranziehen

Authors	<i>Proctor et al.</i> 1988	<i>Popma et al.</i> 1988	<i>Korning et al.</i> 1990	<i>Valencia &amp; Jørgensen</i> 1992	<i>Valencia</i> 1995
Investigation area	Sabah/Malaysia	Los Tuxtlas/Mexico	Anangu/Ecuador	Pasochoa/Ecuador	Baeza/Ecuador
Vegetation type	Lower montane forest	Lowland forest	Lowland forest	Montane forest	Montane forest
Altitude in m a.s.l.	280-870		250-370	3260-3300	2000
Plot size	0.04-0.4 ha	1ha	1ha	1ha	1ha
Number of Plots	10	1	1	1	1
Determination of species	+	+	+	+	+
Counting of individuals	+	+	+	+	+
Co-ordinates of individuals		+			
Tree height	+	+	+	+	+
Tree diameter	+	+		+	+
Lowest ramification height		+			
Lowest crown limit	+	+			
Crown diameter		+			
Leaf area					
Leaf size					
Presence of epiphytes	+			+	+
Gaps					
Aims	Comparison of soil conditions and vegetation	Search for stratification and distinct layers	Comparison of a plot design to a line transect design	Description of the forest	Description of the forest
Results	Changes in forest structure and species composition not explained by soil conditions	Vertical structure is a gradient of many structural features. Stratification is a special case	Results from different forests should only be compared if obtained by the same method	Species composition, average height and basal area	Species composition, average height and basal area

Authors	<i>Valencia et al.</i> 1998	<i>Young</i> 1998	<i>García</i> 1998	<i>Condit</i> 1998
Investigation area	Ecuador	Abiseo/Peru	Loma de Hierro/Venezuela	
Vegetation type	Different forests	Montane forest	Montane forest	Tropical forests
Altitude in m a.s.l.	50-3300	3350	1355	
Plot size	1ha	1ha	0.002ha	0.01ha
Number of Plots	18	1	45	as much as possible
Determination of species	+	+	+	+
Counting of individuals	+	+	+	+
Co-ordinates of individuals			+	+
Tree height	+	+	+	
Tree diameter	+	+	+	+
Lowest ramification height			+	
Lowest crown limit				
Crown diameter				
Leaf area			+	
Leaf size		+		
Presence of epiphytes	+			
Gaps		+		
Aims	Comparison of forests in different altitudes	Description of timberline forest	Description of the forest	Forest census
Results	Species richness and composition follow geographical patterns	Species composition, regeneration patterns and occurrence of gaps	Species composition, density, height frequency and basal area	Demography, growth rates, density

from different forests should only be compared if they were obtained by the same method. *Proctor et al.* (1988) could not explain the changes they found in forest structure by soil conditions and *Popma et al.* (1988) concluded that vertical structure is a gradient of many structural features. All these studies considered identification of species for each tree

individual as necessary information and the investigation of structure is restricted to the classical parameters of forest inventories, i.e. height, diameter at breast height and number of individuals per area, sometimes enriched by the recording of epiphytes or leaf characters.

The following approaches investigated struc-



ture in more detail:

*Vareschi* (1980) described tropical vegetation types on the basis of formations. He characterised each formation by climatic and edaphic data, species per area rates and morphological features especially of leaves. To obtain this information, the number of different species has to be determined (species do not necessarily have to be identified) and for each species the leaf category has to be chosen out of a catalogue of different types. Thus a leaf type spectrum can be constructed for each formation.

*Parsons* (1975) used a set of 24 structural and functional characters such as life-form, growth-form, height, leaf size and shape, and bark texture to describe each woody species he found in Mediterranean scrub communities of California and Chile. He concluded that floristically distinct communities of comparable climatic regions display similarities in vegetation structure.

On the basis of the concept of *Hallé* and *Oldeman* (1970) *Tomlinson* (1983) suggested a method of classifying tropical forest trees using their architecture. Each species has to be placed in one of 23 basic architectural models that reflect different branching patterns. This idea seems somewhat artificial because it requires optimal growing conditions so that each tree can develop its typical architecture. These conditions will hardly be met under competitive conditions in a dense tropical forest, and *Ewel* and *Bigelow* (1996) observe that trees are so plastic that different tree architectures can converge on the same crown morphology.

*Orshan* (1986) proposed an extended catalogue of physiognomic features describing the above-ground shoot system, the photosynthetic organs, the below-ground organs, longevity and regeneration to be recorded for

each species. A kind of 'passport' should be established for each species to classify the structure of a plant community if the species composition is known.

*Lux et al.* (1994) (based on the ideas of *Barkman* 1979) classified bush vegetation in two European regions and compared the results based on floristic data and structural data. The latter contain especially information about strata and growth-form spectra. The authors stated that the investigation of structures allowed more conclusions about processes of succession that do not necessarily go along with a change of species composition.

*Le Brocque* and *Buckney* (1997) investigated the relationships between floristic composition and stand structure in Australia with multivariate methods. Structure in this case meant foliage projective cover of 8 different strata. The comparison showed that floristic composition gradients were well recovered by the structure data, although two floristically dissimilar communities exhibited very similar multivariate structural characteristics.

*Webb et al.* (1970: 222) compared the results of a floristic and a structural investigation of an Australian rainforest where 513 tree species were determined and a set of 33 structural features such as canopy height, existence of emergents, bark consistency and leaf size were registered per plot. They summarise: 'The results presented [...] suggest that a classification based on a limited number of physiognomic features noted by untrained observers can prove as useful as a floristic classification'.

*Werger* and *Sprangers* (1982) carried out a comparative study of floristic and structural data from a tropical dry forest in India. On 63 plots they found 192 species and mapped the abundance of 128 structural features such as life-form, form of branching, leaf and crown

characteristics. They conclude that the results of a floristic and of a physiognomic classification are strikingly similar with the latter being far less time-consuming. The authors remark that advanced calculation facilities are necessary to obtain these results, but today this problem seems to be solved by modern software packages.

To summarise the listed approaches it can be said that in many cases the investigation of structure is restricted to the classical parameters of forest inventories, that is height, diameter at breast height and number of individuals per area, sometimes enriched by recording of epiphytes or leaf characters (*García* 1998, *Valencia* 1995, *Valencia* and *Jorgensen* 1992, *Valencia* et al. 1998, *Young* 1998, *Proctor* et al. 1988, *Popma* et al. 1988, *Condit* 1998, *Korning* et al. 1990). In these studies identification of species is the main tool to describe the forest vegetation.

Only a few approaches go into more detail with respect to the structure, recording growth-forms, architecture, or a longer catalogue of physiognomic features. Still, the identification of species is a central point of the study (*Parsons* 1975, *Vareschi* 1980, *Orshan* 1986, *Tomlinson* 1983).

There are only some approaches that compare floristic classifications with the results of structural investigations and thus develop a tool to describe structure independent of species composition (*Webb* et al. 1970, *Wenger* and *Sprangers* 1982, *Lux* et al. 1994, *Le Brocq* and *Buckney* 1997). They all conclude from their data that the investigation of structure leads to comparable results, but is much easier to achieve.

### 3. Methods

Structural and floristic composition of pristine shrub vegetation were sampled on a mountain ridge of the eastern Andean range in southern Ecuador. The sampling area was located in the Podocarpus National Park (province of Zamora Chinchipe, 4°00' S, 79°05' W) at an altitude between 2730 and 2820 m a.s.l. To describe the shrub vegetation, first the vegetation was subdivided by height (<0.5 m, 0.5 to <1 m, 1 to <2 m, >2 m). Then, for each height, a minimum of three representative plots was chosen to ascertain structural and floristic composition of each unit. To obtain homogeneous height per plot, the size of each single plot was adjusted to maximize height homogeneity (average size 50 m<sup>2</sup>). Overall, structural and floristic composition, altitude, slope, and aspect of 27 plots were ascertained.

To describe vegetation structure, we used a new classification system developed by *Paulsch* (in prep.). Vegetation structure is characterised by estimating frequency of occurrence of 134 features per stratum. Features are combined into 28 feature classes, representing seven units of characteristics. One unit describes characteristics of the whole vegetation stand, the other six units describe characteristics of individual plants (shape, ramification, leaves, stem, distribution of epiphytes, and cross-linkage to neighbouring plant individuals). Units and feature classes are further explained in *table 2*. The system for classification of vegetation structure used here, combines the above-discussed structural classification approaches by *Richards* et al. (1940), *Parsons* (1975), *Barkman* (1979), *Wenger* and *Sprangers* (1982), and *Orshan* (1986). Structural features were selected after testing the applicability of previous approaches on the plot level for tropical mountain vegetation, and were supplemented with characteristics describing distribution of epiphytes and cross-

Tab. 2 Units of characteristics and feature classes of the classification system developed by Paulsch (in prep.) based on structural composition of vegetation. Units and classes combine 134 features of vegetation structure, whose frequency of occurrence are estimated per vertical strata (not shown) / *Untersuchungseinheiten und Merkmalsklassen des auf Strukturmerkmalen der Vegetation basierenden Klassifikationssystems von Paulsch (in prep.). Einheiten und Klassen beinhalten 134 Merkmale der Vegetationsstruktur, deren Frequenz pro Vegetationsschicht abgeschätzt wurde (nicht einzeln aufgeführt)*

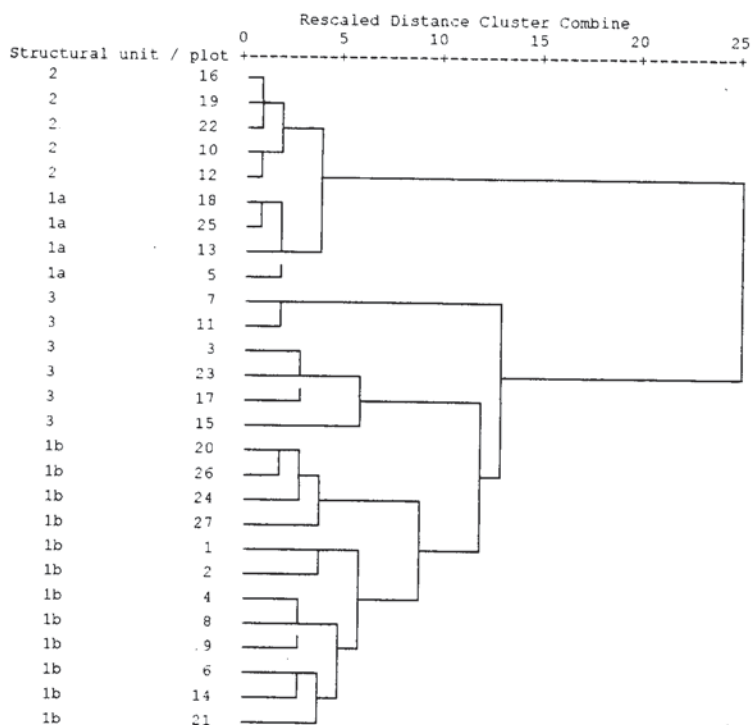
Unit of characteristics	Feature class
Stand	Stratification, average height, cover (expressed as percentage of plot area), number of plant individuals, overlapping of branches or crowns of neighbouring individuals within one strata
Shape of individual plant	Diameter and shape of crown, degree of deviation from typical shape (free standing and under optimal growing conditions)
Ramification of individual plant	Growth direction of branches, degree of ramification on branches' tops, height of ramification relative to height of individual plant
Leaves of individual plant	Size, colour, shape, thickness, angle relative to the ground, height, where leaves occur relative to height of individual plant
Stems of individual plant	Degree of woodiness, colour and thickness of bark
Distribution of epiphytes per individual plant	Number and distribution of epiphytic bromeliads, orchids, other higher plants, ferns, mosses, and lichens
Cross-linkage of neighbouring plant individuals	Amount and height of bamboo and number and height of lianas relative to height of individual plant

linkage of neighbouring plant individuals. For each feature, the frequency of occurrence on each plot was estimated per vertical stratum on a scale with four steps: 0 = missing, 1 = rare, 2 = abundant, 3 = very abundant, following the concept of Webb et al. (1970). Each category relates to the number of plant individuals in the considered plot. To evaluate data, first a principal component analysis (PCA) was carried out to reduce the number of features, followed by a hierarchical cluster analysis to group plots into units of similar feature combination, using the SPSS software package. Since plots differed in number of vertical strata (one or two) and thus number of features, in plots with only one stratum, the missing stratum was interpreted as the upper stratum, with all features set zero. Otherwise it would not be possible to compare plots with different numbers of strata. To avoid over-interpretation of a single characteristic described by several features, for the PCA (varimax rotation) features with zero variance within plots, or an internal correlation smaller than 0.4 were excluded from the data set. For the cluster anal-

ysis (Ward's algorithm, with Euclid's squared distance as proximity measure), features with zero variance within plots, or an internal correlation higher than 0.8 were excluded from the data set for the same reason.

To describe floristic composition of shrub vegetation, a species list for each plot was provided by sampling specimens of all plant individuals per plot after finishing the estimation of structural features. (Plant species frequency of occurrence and distribution within vertical stratification could not be considered within the given time owing to very high species number). Epiphytes and ground-living lichens were not considered. Plant specimens were dried and species were identified in the herbarium of the University of Loja (Ecuador). For plant nomenclature, we followed Index Kewensis (1997). Plots were grouped into units with similar species composition using hierarchical cluster analysis (Ward's algorithm, with Euclid's squared distance as proximity measure). Species with a frequency of occurrence in all plots lower than 10% or higher than 90%





*Fig. 1* Dendrogram of structural vegetation units obtained by hierarchical clustering using Ward's algorithm with Euclid's squared distance as proximity measure. Clustering was calculated for 27 plots using 211 out of 268 features, excluding features with an internal correlation of 0.8 or higher variance within plots. Clustering resulted in four groups, interpreted as three major structural vegetation units (1, 2, and 3), unit 1 with two sub-units (a and b) / *Dendrogramm der Vegetationsstruktur-Einheiten nach hierarchischer Clusteranalyse mit Ward-Algorithmus und quadrierter euklidischer Distanz als Proximitätsmaß. Die Analyse wurde für 27 Plots und 211 von 268 Strukturmerkmalen durchgeführt. Merkmale, die untereinander mit 0.8 oder höher korrelierten oder keinerlei Varianz zwischen den Plots zeigten, wurden ausgeschlossen. Die Clusteranalyse führte zu vier Gruppen, die als drei Vegetationsstruktur-Einheiten interpretiert wurden (Einheiten 1, 2, 3.), von denen eine (Einheit 1) in zwei Untereinheiten (a und b) gegliedert wurde*

were excluded from the data. The use of rare species resulted in a too high (and thus not reasonable) number of floristic units, while very abundant species did not contribute to group differentiation.

#### 4. Results

To describe vegetation structure, 134 structural features were examined per vertical stratum

of 27 plots. Principal component analysis did not lead to a decisive reduction of features. Six features showed zero variance within plots, 10 had an internal correlation of 0.4 or lower, all belonging to 6 out of 7 units of characteristics. The first three principal components (PC), explaining 34% of variance, were determined by a variety of features of all seven units of characteristics and 17 feature classes. Feature classes were not specific for PCs, but cross-linkage of neighbouring plant individu-



Tab. 3 Structural units of a shrub vegetation in Southern Ecuador / Struktureinheiten einer Gebüschvegetation in Südecuador

	Unit 1			Unit 2		Unit 3	
	Subunit 1a	Subunit 1b	Stratum 1	Stratum 2	Stratum 1	Stratum 2	
Height	<0.5m	<1m	<1m	<0.5m	<1m	<3m	<1.5m
Dominant life-forms	dwarf shrubs, herbs	shrubs, herbs, grasses	shrubs, herbs	dwarf shrubs, herbs	shrubs, herbs	shrubs, trees	shrubs, trees
Abundant crown shape	umbrella, funnel, cushion, irregular	umbrella, irregular	cylindrical, funnel, irregular	cylindrical, funnel, irregular	umbrella, spherical	umbrella, irregular	umbrella, spherical
Ramification	upper third	lower half	upper third	upper third	upper third	upper third	upper third
Leaf consistency	semisclerophyllous, malacophyllous	semisclerophyllous	semisclerophyllous	malacophyllous	semisclerophyllous	semisclerophyllous	semisclerophyllous
Mosses and lichens	abundant	abundant	abundant	abundant	abundant	abundant	abundant
Vascular epiphytes	rare	rare	rare	missing	rare	abundant	abundant
Bamboo and lianas	rare	rare	rare	rare	abundant	rare	rare

als and distribution of epiphytes dominated one principal component. Cluster analysis resulted in four groups (fig. 1).

However, an illustrative description of the groups was hard to obtain by comparing the units of characteristics per group, since four trends became evident from the multivariate evaluation:

- i) the four structural units hardly differed in presence or absence of features and
- ii) most decisive features for each structural unit derived from all seven units of structural characteristics, but
- iii) structural units differed in frequency of features occurrence, with
- iv) small differences in frequency of feature occurrence between units.

The groups obtained by the cluster analysis can be described more illustratively by comparing the dominant life-forms (Mueller-Dombois and Ellenberg 1974). Thus these groups were interpreted as three structural units (unit 1, 2, and 3), unit 1 with two sub-units (1a and b) (fig. 1). Unit 1 consisted mainly of dwarf shrubs with (1a) herbs, or (1b) shrubs, unit 2 consisted of shrubs only and unit 3 of shrubs and trees. Table 3 describes the structural units using selected features of all seven units of characteristics.

Geographical distribution of structural units followed a distinct pattern, and was presumably mainly controlled by slope, soil depths and exposition to wind. A typical transect through shrub vegetation is shown in figure 2.

In the 27 plots, 142 vascular plants from 46 families were found (average  $0.7 \pm 0.5$  species per  $m^2$ ). Vegetation was dominated by shrubs (79 species), followed by herbs (26 with 4 lianas), grasses (8), and trees (5). Most shrubs belonged to the *Melastomataceae* (21 spe-

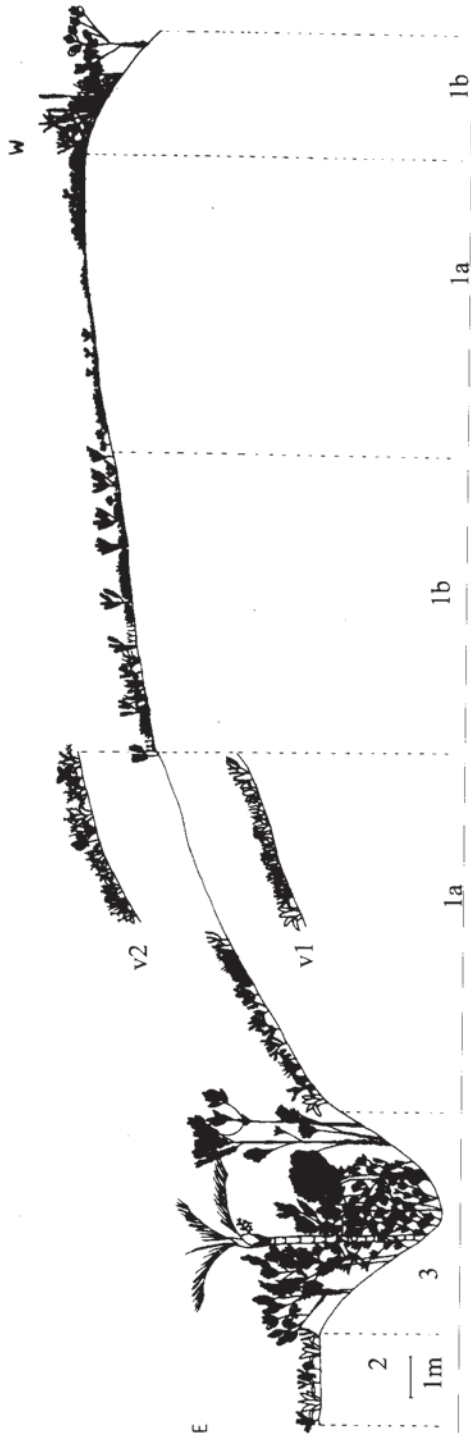


Fig. 2 East to west transect through shrub vegetation in the investigated area (Southern Ecuador, 2800 m a.s.l.). Unit 1 (a and b) is found on steep, wind exposed slopes and ridges, unit 2 occurs on steep, but wind safe slopes, and unit 3 is found in wind safe depressions. Main wind direction is east. Sub-unit 1a may occur in two variations, as mixed stand (v1), or dominated by *Puya nitida* Mez (v2) / Ost-West-Transsekt durch Gebüschvegetation im Untersuchungsgebiet (Südecuador, 2800m ü.N.N.). Einheit 1 (a und b) wurde auf steilen, windgeschützten Hängen und Graten gefunden, während Einheit 2 auf ebenfalls steilen, aber windgeschützten Hängen auftrat und Einheit 3 in windgeschützten Muldenlagen anzutreffen war. Untereinheit 1a kann in zwei Variationen auftreten: als gemischter Bestand (v1) oder dominiert von *Puya nitida* Mez (v2)

Tab. 4 Species composition (species and family) of floristic groups obtained by hierarchical clustering of 27 plots, using 60 out of 166 species with a frequency of occurrence higher than 10% within all plots. Only species with a frequency of occurrence higher than 50% within each group are shown. (Complete list in Czimczik 1999) / *Artenzusammensetzung (Art und Familie) der durch hierarchische Clusteranalyse von 27 Plots erhaltenen floristischen Gruppen, zu deren Bildung die 60 von 166 Arten herangezogen wurden, die in allen Plots mit mindestens 10% Deckung vorkamen. Nur Arten mit mehr als 50% sind aufgelistet (komplette Liste in Czimczik 1999)*

Floristic group 1	Floristic group 2
<i>Blechnum lima</i> Rosenst. (Blechnaceae)	<i>Chusquea loxensis</i> L.G. Clark (Poaceae)
<i>Brachyotum rotundifolium</i> Cogn.,	<i>Clusia multiflora</i> HBK (Clusiaceae)
<i>Miconia caelata</i> DC. (Melastomataceae)	
<i>Clethra fagifolia</i> HBK (Clethraceae)	<i>Cybianthus marginatus</i> (Bentham) J.J. Pipoly (Myrsinaceae)
<i>Disterigma pentandrum</i> Blake,	<i>Disterigma pentandrum</i> Blake,
<i>Gaultheria erecta</i> Vent. (Ericaceae)	<i>Disterigma acuminatum</i> Niedenzu (Ericaceae)
<i>Eriosorus aureonitens</i> (Hooker) Copel. (Pteridaceae)	<i>Peperomia hartwegiana</i> Miq. (Piperaceae)
<i>Hieracium frigidum</i> Wedd. (Asteraceae)	<i>Tillandsia rubella</i> Baker (Bromeliaceae)
<i>Hypericum aciculare</i> HBK (Hypericaceae)	
<i>Ilex</i> spec. (Tourn.) Linn. (Aquifoliaceae)	
<i>Paepalanthus ensifolius</i> Kunth (Eriocaulaceae)	
<i>Puya nitida</i> Mez (Bromeliaceae)	
<i>Rhynchospora locuples</i> V.B. Clarke (Cyperaceae)	
<i>Sticherus revolutus</i> HBK (Gleichniaceae)	
<i>Tillandsia rubella</i> Baker (Bromeliaceae)	
<i>Xyris subulata</i> Ruiz and Pav. (Xyridaceae)	

cies), *Ericaceae* (11), or *Asteraceae* (9). Within herbs, species from the *Asteraceae* (8 species), and *Orchidaceae* (4) were most abundant, however it was observed that species from the *Bromeliaceae* (3) and *Eriocaulaceae* (1) were dominant if found in the plot. Non-vascular plants were represented by ferns (16 species, 6 families) and club mosses (8 species). Species composition was highly diverse, with a high degree of endemism and some not yet described species, as further investigated by Jørgensen and Ulloa Ulloa (1994) and Ulloa Ulloa and Jørgensen (1995).

Cluster analysis considering 60 species with a frequency of occurrence within all plots higher than 10% or lower than 90% resulted in two groups. From the 60 species, 58 were found in group 1, 49 in group 2. For each group, species with a higher frequency of occurrence than 50% within each group are given in table 4. Species composition of group 1 is typical for

vegetation above tree line, shrub and grass páramo, that of group 2 for tree line vegetation with ceja andina and upper montane forest (Jørgensen and Ulloa Ulloa 1994). Stem-rosettes (*Espeletia*, *Asteraceae*), which are found in the páramo El Angel of northern Ecuador, are lacking in the investigated area, however, rosettes of *Paepalanthus* (*Eriocaulaceae*) reached a total height of 0.5 m. Further south of the investigation area in northern Peru, vegetation above tree line is indicated as grass-dominated puna (Ellenberg 1996). In the puna, however, the genera *Stipa*, *Deeyuxia*, and *Agrostis* dominate, which were missing in Southern Ecuador, where grasses belonged to the genera *Rhynchospora* and *Neurolepis*.

By comparing structural units with floristic groups it became obvious, that the floristic group 1 (páramo) corresponded with the structural unit 1 (dwarf shrub) except for two plots,



and the floristic group 2 (ceja) corresponded with the structural unit 2 (shrubs) and unit 3 (shrubs with trees), except for three plots. Since structural unit 1a and b, and unit 2 and 3 mainly differed in number of strata, similar species composition might lead to the conclusion that structural unit 1a is a younger succession stage of unit 1b, and unit 2 a younger stage of unit 3.

## 5. Discussion

Close correspondence between floristic and structural composition was also found by *Webb et al. 1970*, *Werger and Sprangers 1982*, *Lux et al. 1994*, *Le Brocq and Buckney 1997*. All of them conclude, that the physiognomic approach is much less time-consuming and easier to apply. Our results support this point of view. Especially for the species-rich montane forests of Ecuador the application of a structural classification system is highly recommended.

But not only practical reasoning recommends structure as a basis for classification: If there is redundancy among higher plants, and species can replace each other, it is likely that the loss of a species has only minor effects on ecosystem functioning. The loss of a life-form or a functional type on the other hand can be the loss of a function and therefore have much more effect on the system. *Ewel and Bigelow (1996)* state that 'it is the assemblage of life-forms that gives forests their characteristic structure, and structure, in turn, dictates whole system functioning'.

We conclude that if the functioning of the Ecuadorian montane forest ecosystem is to be understood - and this has to be done quickly considering the immense destruction rate - a structure-based classification is the most effective way to describe the vegetation as a

basis for further ecosystem research.

## Acknowledgements

We thank the Deutsche Forschungsgemeinschaft (DFG) for financial support. Further, we thank the Instituto Ecuatoriano Forestal y de Areas Naturales y Vida Silvestre (INEFAN, Ecuador) for providing work permits, Sr. *Bolivar Merino* (Herbarium, University of Loja, Ecuador) for helping us to identify the plant species, and the Fundación Científica San Francisco (FSCF, Loja, Ecuador) for logistics.

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*Summary: Classification of tropical montane shrub vegetation - a structural approach*

The montane forests of the eastern part of the Ecuadorian Andes are considered as a hotspot of biodiversity threatened by human activity. Vegetation classification is a central part of ecosystem studies that estimate potential risks and rates of loss, and suggest conservation concepts. Classification can be approached on the basis of floristic or structural data. The present study reviews newer approaches that use a mix of floristic and structural features to characterise vegetation and highlight what 'structure' means in each case (especially for

the tropics). These mixed approaches are grouped according to the growing degree they consider structure and get independent of plant species identification. Only a few approaches compare floristic classifications with the results of structural investigations and thus develop a tool to describe structure independent of species composition (Webb et al. 1970, Werger and Sprangers 1982, Lux et al. 1994, Le Brocq and Buckney 1997). They all conclude from their data that the investigation of structure leads to comparable results but is much easier to achieve. The results of our structural investigation of a shrub vegetation in higher elevations of the Ecuadorian Andes on plot scale are presented. Although the new investigation system is independent of plant species identification, plant species composition of the 27 plots was registered as a comparison. Shrub vegetation was chosen to ensure a comparatively low number of species that are fairly well documented. Cluster analysis of 134 structural features per stratum led to four groups that were interpreted as three structural units (unit 1, 2, and 3), unit 1 with two sub-units (1a and b). Unit 1 consisted mainly of dwarf shrubs with (1a) herbs, or (1b) shrubs, unit 2 consisted of shrubs only, and unit 3 of shrubs and trees. Geographical distribution of structural units followed a distinct pattern, and was presumably mainly controlled by slope, soil depths and exposure to wind. In the 27 plots, 142 vascular plants from 46 families were found and grouped in two groups. Species composition of group 1 is typical for vegetation above tree line, shrub and grass páramo, that of group 2 for tree line vegetation with ceja andina and upper mountain forest. Comparison of structural units with floristic groups made obvious that the floristic group 1 (páramo) corresponded with the structural unit 1 (dwarf shrub), and the floristic group 2 (ceja) corresponded with the structural unit 2 (shrubs) and unit 3 (shrubs with trees). Our results support the point of view that our structural approach leads to comparable results but is much easier to achieve than a floristic classification. We conclude that if the functioning of the Ecuadorian montane forest ecosystem is to be understood - and this has to be done quickly considering the immense destruction rate - a structure-based classification is the most effective way to describe the vegetation as a basis for further ecosystem research.



*Zusammenfassung: Klassifizierung einer tropischen Gebüschvegetation - ein struktureller Ansatz*

Die Bergregenwälder der ecuadorianischen Andenostabdachung gelten als Hotspot der Biodiversität, sind aber in ihrer Existenz bedroht. Klassifizierung der Vegetation ist zentraler Bestandteil von Studien zur Abschätzung von Risiken und Verluststraten und zur Entwicklung von Schutzkonzepten. Dabei kann die Klassifizierung floristisch oder strukturell begründet werden. Die vorliegende Studie stellt neuere Ansätze zusammen, die sowohl floristische als auch strukturelle Merkmale zur Charakterisierung der Vegetation (insbesondere der Tropen) verwenden und hebt dabei hervor, was jeweils unter dem Begriff 'Struktur' verstanden wird. Dabei werden die Ansätze nach zunehmender Unabhängigkeit von der Bestimmung der Pflanzenarten und der größeren Betonung sortiert, die der Vegetationsstruktur zugemessen wird. Nur einige wenige Ansätze vergleichen tatsächlich die Ergebnisse floristischer Klassifikation mit Untersuchungen zur Struktur und entwickeln so eine Möglichkeit, Vegetationsstruktur unabhängig von der Artenzusammensetzung zu beschreiben (Webb et al. 1970, Werger and Sprangers 1982, Lux et al. 1994, Le Brocque and Buckney 1997). Konsens ist dabei der Schluß, daß die Untersuchung der Struktur zu vergleichbaren Ergebnissen führt, aber wesentlich leichter anzuwenden ist als floristische Ansätze. Die Ergebnisse unserer Untersuchung zur Struktur einer Gebüschvegetation der ecuadorianischen Hochanden werden auf der Maßstabsebene von Einzelflächen vorgestellt. Obwohl das dabei verwendete neue Klassifikationssystem von der Pflanzenbestimmung unabhängig ist, wurde auf 27 Einzelflächen die Artenzusammensetzung zu Vergleichszwecken erhoben. Die Gebüschvegetation bot sich aufgrund ihrer relativen Artenarmut und ihrer vergleichsweise guten floristischen Bearbeitung besonders für diesen Vergleich an. Eine Clusteranalyse über 134 Strukturmerkmale pro Vegetationsschicht führte zur Ausweisung von vier Gruppen, die als drei Struktureinheiten interpretiert wurden, von denen eine in zwei Untereinheiten zu gliedern war. Dabei bestand Einheit 1 hauptsächlich aus Zwergsträuchern in Kombination mit Kräutern (1a), bzw. mit Sträuchern (1b), während Einheit 2 sich ausschließlich aus Sträuchern zusammensetzte und Einheit 3 aus Sträuchern und Bäu-

men bestand. Die räumliche Verteilung der Struktureinheiten folgte einem Muster, welches höchstwahrscheinlich durch Exposition, Neigung, Gründigkeit der Böden und Windexposition bestimmt wurde. In den 27 Einzelflächen wurden 142 Arten höherer Pflanzen aus 46 Familien gefunden, die in zwei Gruppen unterteilt werden konnten. Die Artenzusammensetzung der ersten Gruppe ist typisch für die Vegetation oberhalb der Baumgrenze, den Gebüsch- und Graspáramo, während die zweite Gruppe die Vegetation der Baumgrenze, der ceja andina und des oberern montanen Bergwaldes repräsentiert. Der Vergleich der Struktureinheiten mit den floristischen Gruppen machte deutlich, daß die erste Gruppe mit der Struktureinheit 1 korrespondiert, während Gruppe 2 mit den Struktureinheiten 2 und 3 weitgehend übereinstimmt. Damit unterstreichen unsere Ergebnisse die Erkenntnis, daß ein struktureller Ansatz zu einer vergleichbaren Klassifikation kommt, aber wesentlich leichter zu erreichen ist als eine floristische Einteilung. Daraus schließen wir, daß für das dringend und angesichts der hohen Zerstörungsrate schnell benötigte Verständnis des Bergwaldökosystems ein auf Strukturmerkmalen basierender Ansatz den effektivsten Weg zur Klassifizierung der Vegetation darstellt, auf deren Grundlage weitergehende Ökosystemforschung betrieben werden kann.

*Resumen: Clasificación de una vegetación arbustiva tropical - un estudio estructural*

Los bosques montañosos del parte oriental de los Andes de Ecuador estan conocido como un hotspot de la biodiversidad en peligro. La clasificación de la vegetación es un parte central de los estudios científicos que quieren estimar los riesgos y la cuota de deforestación y que buscan conceptos para la protección. La clasificación puede ser basada en datos florísticos o en datos de la estructura. Este artículo resume estudios recientes los cuales clasifican vegetación con base en datos florísticos y también con base en característicos estructurales y explica que significa 'estructura' en cada caso. Los estudios estan agrupados en orden de creciente independencia de la determinación de plantas y creciente importancia de la estructura. Solamente pocos estudios realmente comparan resultados de clasificaciones

florísticas con investigaciones de la estructura y desarrollan posibilidades para la descripción de la estructura de la vegetación independiente de la composición de especies (*Webb et al. 1970, Werger and Sprangers 1982, Lux et al. 1994, Le Brocque and Buckney 1997*). Todos los estudios concluyen que las investigaciones de la estructura resultan en clasificaciones comparables con investigaciones florísticas. También se concluye que las investigaciones de estructura son más fáciles de conseguir. Los resultados de nuestra investigación de la estructura de una vegetación arbustiva de los Andes altos se presentan en escala de parcelas. Aunque el nuevo sistema de clasificación es independiente de la determinación de especies, se investiga también la composición de especies en 27 parcelas con fin de comparar los resultados. La vegetación arbustiva especialmente se ofrece para una comparación de los dos sistemas, porque la biodiversidad no es tan alta como en los bosques y además la mayoría de las especies es bien conocida. Un análisis estadístico de 134 característicos de la estructura para cada estrato de la vegetación resulta en cuatro grupos los cuales se interpretan como tres unidades estructurales, una dividida en dos subunidades. Unidad 1 consiste de arbustos enanos en conjunto con hierbas (1a) o arbustos, unidad 2 contiene solamente arbustos y en la unidad 3 se encuentran arbustos en conjunto con árboles. La distribución geográfica de las unidades

probablemente está determinado de la exposición y la inclinación de las parcelas. Estos factores corresponden con la profundidad del suelos y la influencia del viento también. En las 27 parcelas se encontraron 142 especies de plantas vasculares de 46 familias que se dividen en dos grupos. La composición de especies del primer grupo es típico para la vegetación sobre el límite del arbolado, el páramo. El segundo grupo representa la vegetación de la ceja andina y del bosque montañoso alto. La comparación de las unidades estructurales con los grupos florísticos hace evidente que el grupo 1 corresponde con la unidad 1 y grupo 2 esta conforme con las unidades 2 y 3. Estos resultados acentan el entendimiento que investigaciones de la estructura resultan en clasificaciones similares pero están aplicadas más fácilmente y en corto tiempo que estudios florísticos. En la conclusión de los resultados una clasificación basada en la estructura es el sistema más efectivo para desarrollar una base para una comprensión del ecosistema del bosque montañoso cual es bien urgente.

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