Using plant functional types as climatic indicators in the Cordilleras

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Abstract

Although considered water towers for their forelands mountain ranges are missing appropriate climate data due to insufficient nets of weather stations. Plant functional types can deliver detailed information for an estimation of the amount of humid months at any mountain site. Apart of climatic interpretation by floristic similarity analyses effected in arid mountain ranges of SW-USA and Central Asia the author developed three methods of hygro-climatic phytoindication adapted to the neotropical cordilleras:

1. In the perarid high Atacama of northern Chile checking plant coverage exhibits best results to show up the influence of mass elevation or “Merriam-Effect” on hygric regimes.
2. Within humid mountain regions leaf-size analyses of Melastomataceae are adequate for fine-tuned judgement of the number of humid months of smaller areas (i.e. valley transect with adjacent slopes = mesoclimate), exemplified by results from Zongo Valley (Bolivia) and Sierra Nevada de Mérida.
3. However, similarity analyses by epiphytism on solitary trees are of best profit for giving an overview of hygric conditions of a region with complex climatic structure (i.e. valleys, escarpments, and mountain ranges = macroclimate).

The presentation includes examples from Mexico and points out results of similarity analyses based on 170 relevées in South Ecuador (Nudo de Loja = hot spot of diversity) to complete a hygro-climatic map which for its part allows the completion of maps of natural vegetation and of regional circulation patterns. The method, feasible also for non-botanists, is of practical use providing basic information for agricultural planning as risks and profits can be derived.

Resumen

Interpretación hidroclimática de los Andes considerando los diversos “Plant functional types”

Aunque considerando las arcas del agua para los llanos del alrededor de las montañas datos climaticos son raros por redes insufisientes de estationes climatologicas. “Plant functional types” pueden ofrecer informaciones detalladas para una estimación de los números de meses humedos en qualquier sitio de la montaña. Aparte de interpretationes climáticas a base del análisis de similaridad florística efectuadas en montanas áridas de los EEUU in en Asia Central el autor a desarollado tres métodos de una fitoindicación hidro-climática adaptada para las cordilleras neotropicas:

1. En la alta Atacama perarida del norte de Chile chequear la cobertura de las plantas presenta resultados optimales para mostrar la influencia de la elevación de masas o el llamado « effecto Merriam » por régimes hidricos.
2. En el interior de regiones montañosas húmedas análisis del tamaño de hoja de Melastomataceae son adecuadas para un dictamen fino del número de meses húmedos de areas limitadas (quiere decir transectos de valles con pendientes adyacentes = mesoclima), ejemplificado para resultados del Valle de Zongo (Bolivia) y la Sierra Nevada de Mérida.
3. Pero, análises del epifitismo árboles solitarios son de profito óptimo para prestar una sobrevista de las condiciones hidricas de una region con estruturas complexas del clima (quiere decir valles, vertientes y sierras = macroclima).

La presentación incluye ejemplos de Méjico y destaca resultados de análisis de similaridad basadas en 170 relieves en el sur del Ecuador (Nudo de Loja = hot spot de diversidad) para completar una carta hidroclimática que para su parte permite la elaboración de mapas de la vegetación natural y del tipo de la circulación regional. El método, también factible para non-botanicos, y de uso practico para proveer informaciones básicas concerniente a la planificación agraria porque los riesgos y los profites pueden ser derivados.

Introduction

Mountain areas generally suffer from a lack of climate information due to insufficient nets of weather stations. This is specially true for remote areas with a sub-recent impact of colonisation by internal migration as known from various regions within the Central and South American Cordilleras: Sierra Madre Oriental de México and Sierra Madre de Chiapas, Altos Cuchumatanes and Cordillera Volcanica de Guatemala, Cordillera de Talamanca in Costa Rica, and the semi- up to per-humid western and eastern escarpments of the tropical Andes in Colombia, Ecuador, Peru and Bolivia. An installation of further weather stations is expensive, requires an intensive maintenance, and does not bring significant results basing on long-time data sets before at least one or – in arid environments - even two decades. Thus, methods of indication are much more appropriate for mountain regions situated in marginal areas. To receive details on temperature regimes, i.e. from the so called “tierras calientes” up to the “tierras heladas”, 60 cm below-surface-temperatures give hint on the annual 2 m above-surface-means. Information on rainfall regimes and their correspondent genetic backgrounds different methods of phyto-indication are valuable of which some are demonstrated here.

Methods

Apart from own studies in the Basin and Ranges of Southwest USA and in the high mountains of Central Asia, the following Latin-American regions have been interpreted climatically by means of phyto-indication:

1. The deserts of the High Atacama in the region of Antofagasta (Chile) by coverage values of vegetation in more than 20 transects between 2.500 and 5.500 m a.s.l.
2. Evaluation of leaf-sizes of all available species of Melastomataceae within transects from the lowlands up to the timberline-ecotone in northern Bolivia, southern Ecuador, western Venezuela, Costa Rica, southern and central México.
3. Similarity analyses of epiphytic communities based on an inconsistent classification system including growth-forms as well as taxonomic features evaluated on transects in southern Ecuador, Central and southern México.

Experiences by the author exist from various further study sites in the Cordilleras. All investigations are based on own field work, i.e. all results base on consistent data sets. The following interpretations and results are mainly shown by extended descriptions of the figures.

Fig. 1: Sites of investigation and experiences. Studies elaborating total vegetation coverages were situated at “m”, leaf-size investigations of Melastomataceae were carried out at “d”, “e”, “g” and “k”, and epiphytism was researched at “b”, “d”, and especially in southern Ecuador.

Results

During a three years lasting research project on climate and vegetation in northern Chile five semi-automatic climatological stations situated between 2.950 and 5.820 m a.s.l. provided data on various elements. The document by Schmidt (1999) gives prove of this driest high mountains not only of the Cordilleras but even of the world. Under these extreme circumstances with highest solar radiation values and extreme aridity even slight variations in vegetation coverage show up differences in the amount of given (summer-) rainfall. The overview in three of the transects (fig. 2) reflects the contrast between a respectively dense and diverse coverage at Sairecabur and a scarce and rather homogenous one at Llullaillaco, while Volcán San Pedro shows an intermediate situation (fig. 2).

As a side-product of ca. 500 species relevés coverage values from each study site posed at a vertical distance of 100 m within several transects are given in fig. 3 (for better comparison only optimum states of vegetation at each altitudinal level are evaluated). In case of Sairecabur maximum values peak at 50 % of total coverage around 4.200 m while correspondent values do not pass 20 % at Volcán San Pedro and not yet 15 % at Llullaillaco. Reasons for these differences are to be found in the so called “Merriam Effect” (Richter 1996), an effect of mass elevation, as well as in the southward spatial change from summer towards winter rain-regimes. The Merriam Effect can be best observed E and NE of the Salar de Atacama: Frequency of convective cells providing thunderstorms with downpowers is greater at mountains with extended mass elevation which must not at all coincide with highest summits (as to be seen at Llullaillaco, i.e. the highest summit but not most extended mount of the region).

extended around the Linzor-Sairecabur- and the Miniques-Massifs – just there where highest vegetation coverages go along with higher precipitation amounts. Maximum per-level vegetation coverage as indicator for the degree of hygric conditions (i.e. precipitation minus potential

evaporation, e.g. per month) must be considered the most effective method within arid mountain areas.
Contrasting to arid and semi-arid areas the family of Melastomataceae are concentrated on tropical regions with at least six or seven humid months. However, with an increasing number of humid months these mostly shrubby plants show a considerable high amount of different species which are best suitable for calculating hygric conditions. Their recognition is easy even for non-botanists since in most cases they show a typical leaf-form characterised by a central nerve, two or three pairs of inflected lateral nerves, and a rectangular segmentation of cross-nerves (fig. 4, upper part).

Fig. 4 shows typical leaves of Melastomataceae along an altitudinal transect at the south-western escarpment of the Sierra Madre de Chiapas. The same profile between 0 and 2.800 m a.s.l. was selected for an evaluation of mean sizes of well developed leaves of all species of Melastomatacea found at each 250 m-level in vertical direction. Analyses of the mean and the median of leaf-sizes give reason to presume a broad belt of extended rain periods between 500 and 1.800 m a.s.l. on the monsoon-influenced Pacific escarpment of the Sierra. In contrast to the humid Soconusco Melastomataceae do not exist in the semiarid leeward Valley of Motozintla below 2.200 m a.s.l.

Best suited for calibrating the correlation between leaf-size of Melastomataceae and humidity patterns is the Valley of Zongo near La Paz where 11 rain gauges are located at electric power plants delivering the capital´s power supply. Although precipitation amounts decrease considerably at around 3.200 m a.s.l. the number of humid months, once more calculated by the balance between precipitation and potential evaporation, decreases only slightly due to cooling and thus, to minor evaporation. But even small differences of local rainfall inputs are reflected by leaf-sizes. By various calculations of leaf-size gradients a reduced mean (i.e. a mean neglecting the species with the biggest and smallest leaf-size) correlates best with precipitation and with the amount of humid months.

Fig. 2: Different types of vegetation belts in the northern Atacama: Due to specific precipitation regimes the altitudinal zonation between the three volcanoes (location in fig. 3) varies considerably.

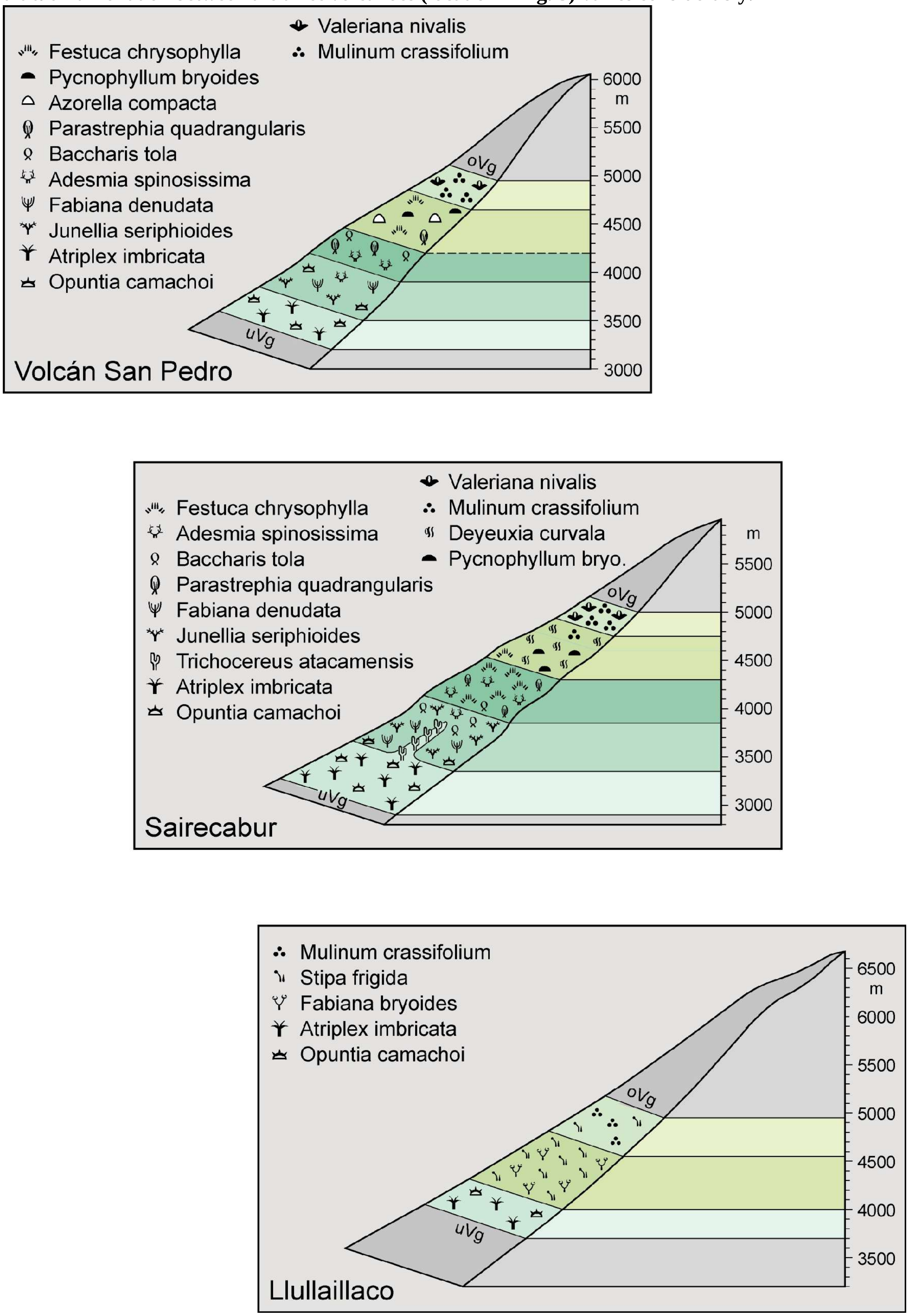


Fig. 3: Ten transects of vegetation coverage in the High Atacama indicating different precipitation patterns which are principally influenced by different degrees of mass elevation (this "Merriam Effect" is typical for mountains of arid environments).

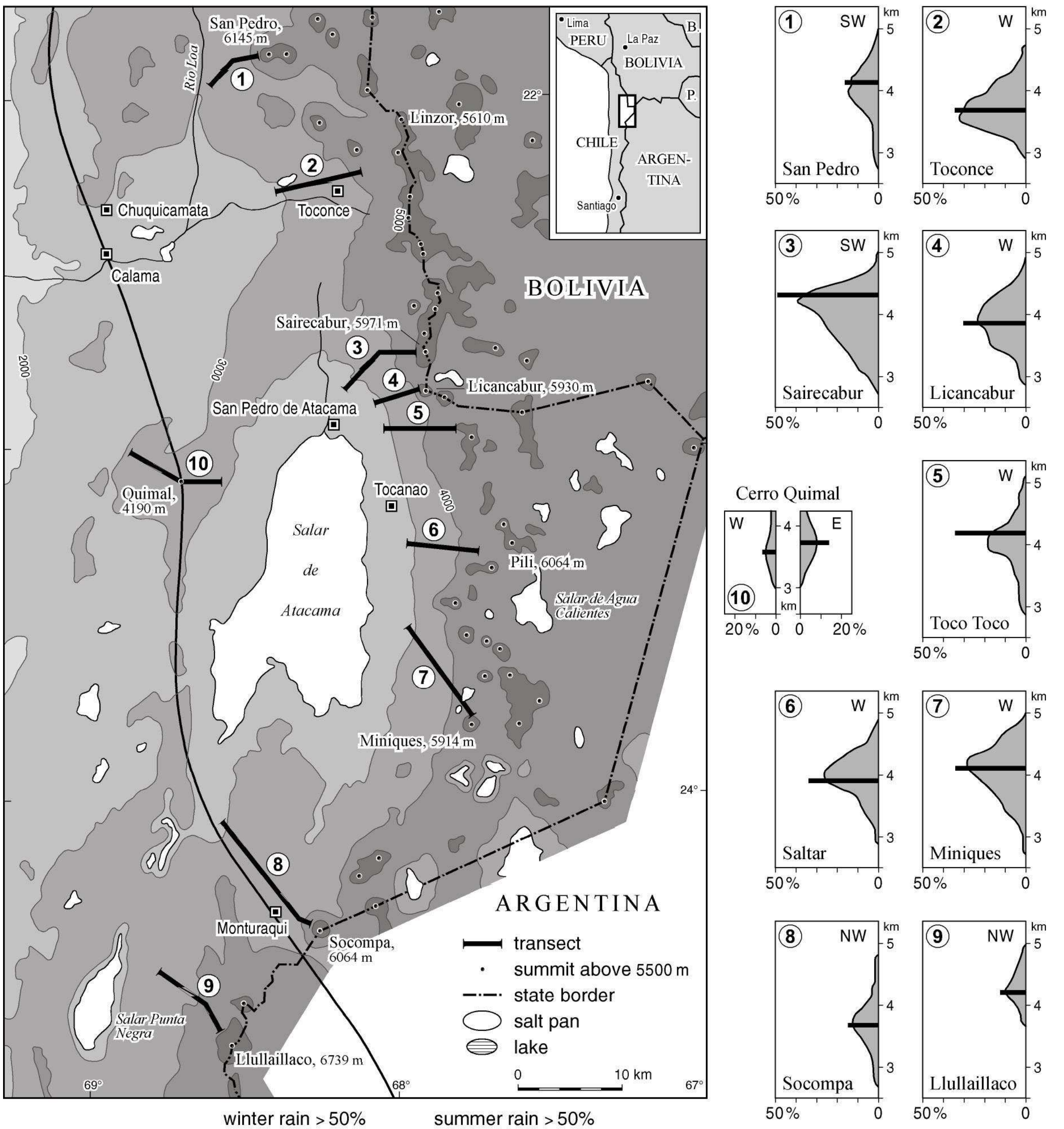


Fig. 4 : Typical species of Melastomataceae (upper part) and the distribution of their species (lower part; each dot indicates one species) at both escarpments of the Sierra Madre de Chiapas / southern México.

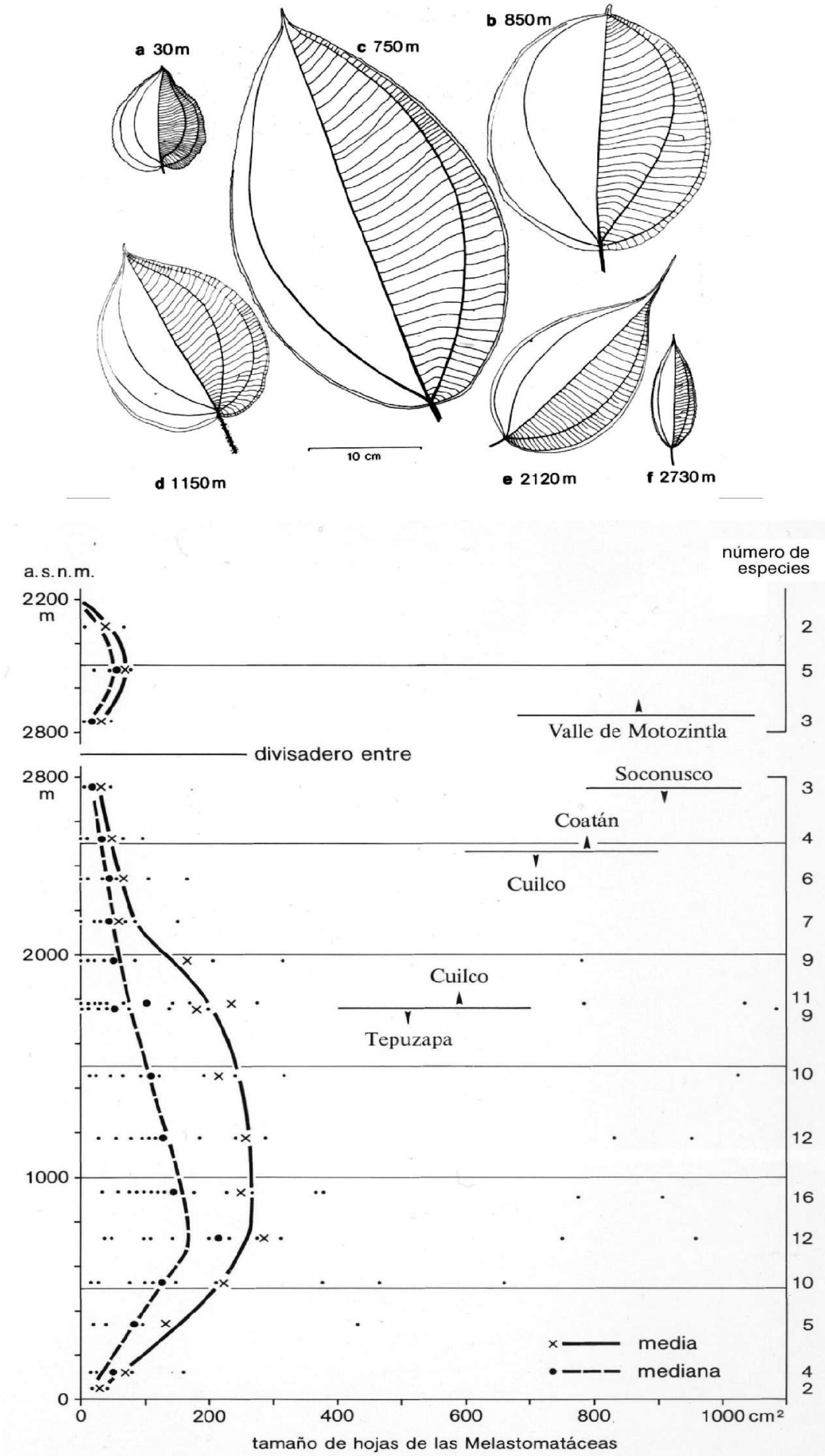
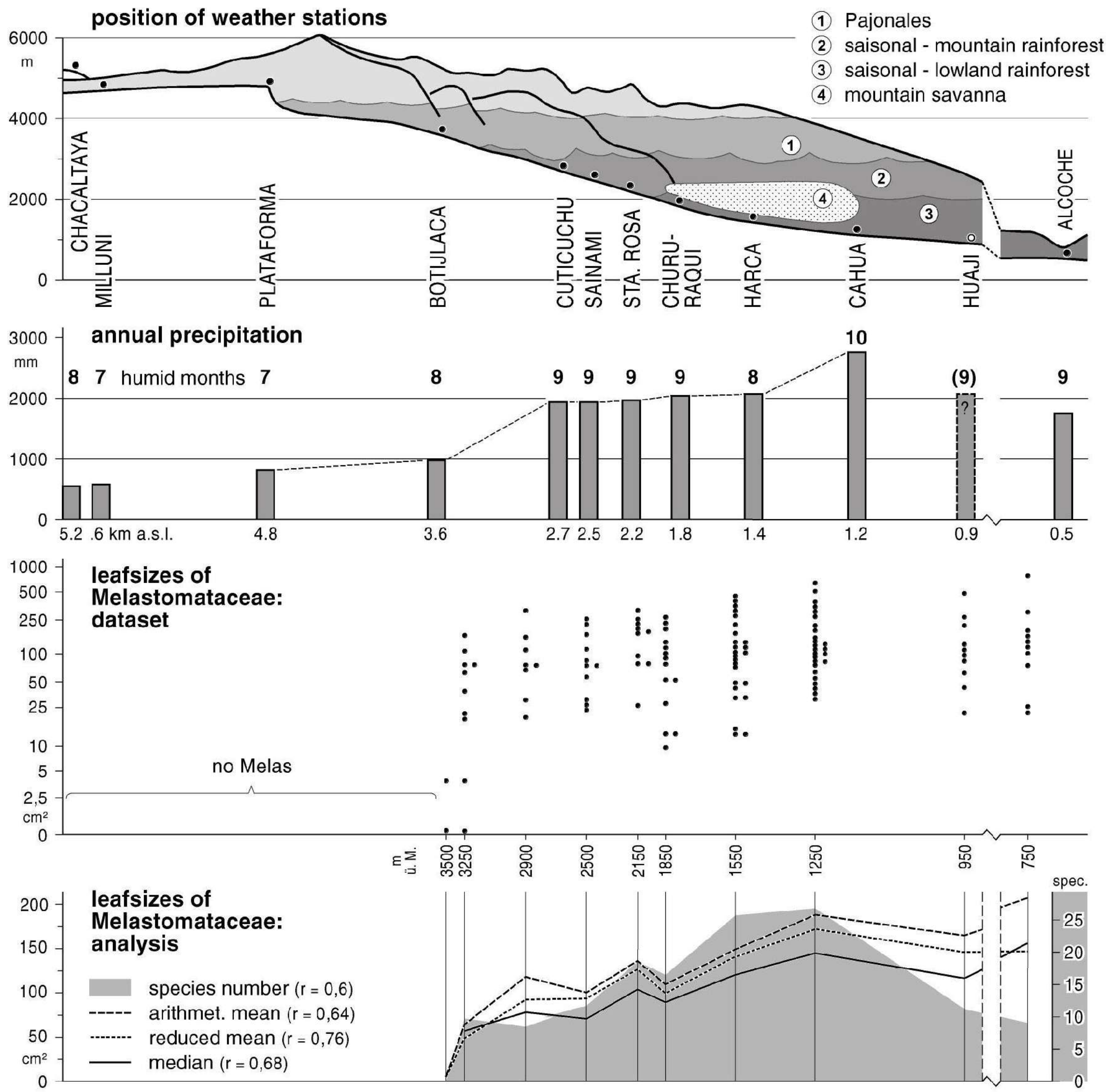


Fig. 5: Leaf-size of Melastomataceae along a longitudinal profile in the Valley of Zongo (Bolivia) connected with altitude and annual precipitations given at 11 rain gauges (columns).

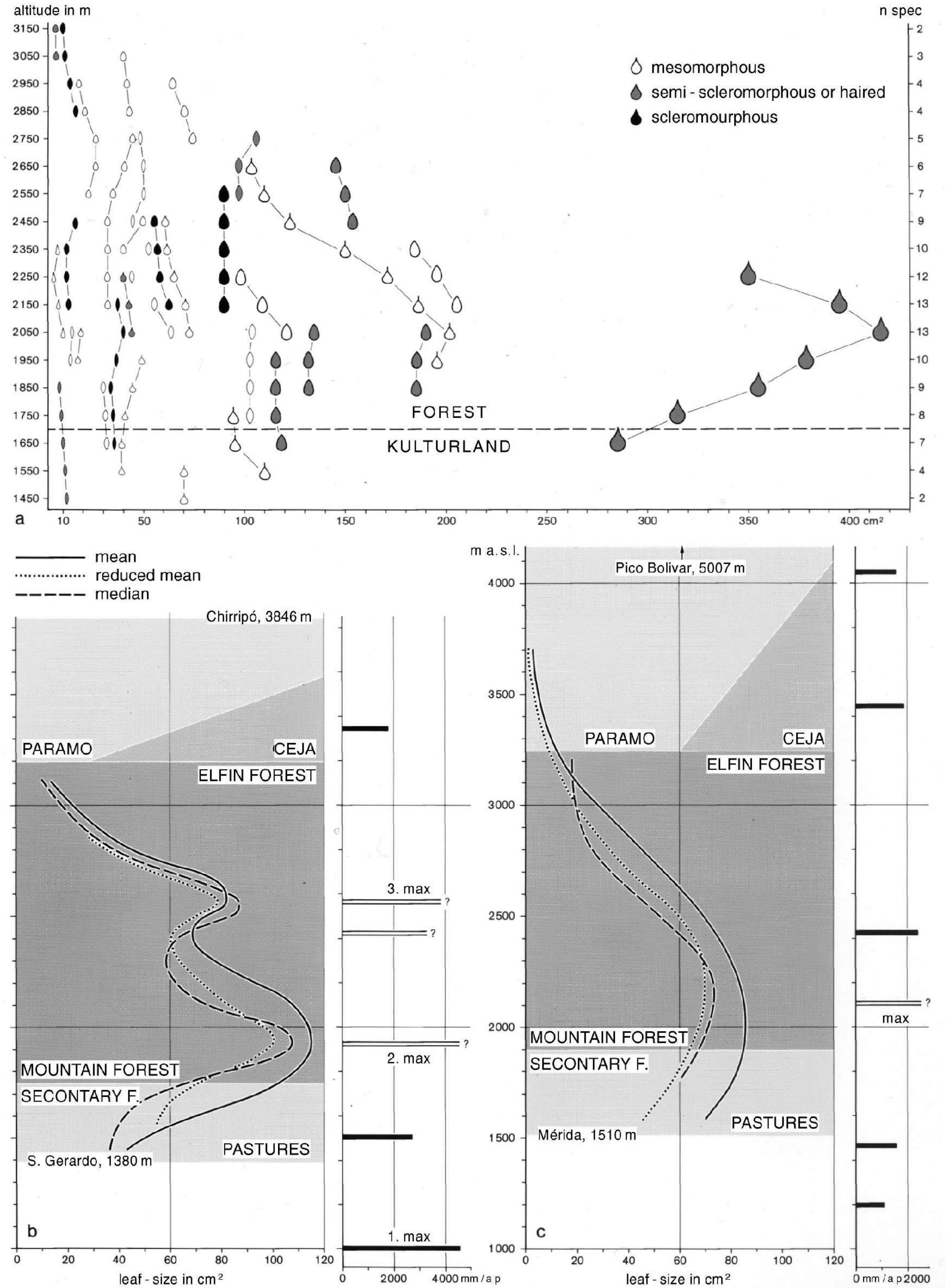


Instead, the extension of elevated parts must be considered a major trigger for convergent air streams; in fig. 3 those elevated parts are shown by areas above 5.500 m a.s.l. which are indeed

Similar results can be derived by a profile running parallel of the funicular lift from Mérida to the Pico Espejo in the Sierra Nevada. Fig. 6 illustrates the correlation between leaf-sizes of Melastomataceae and the mean annual precipitation. In all three statistical analyses, an uncomplicated vertical gradient exists in form of an exponential function from which it is possible to derive a belt of maximum rainfall. It is correlated with the bulge in the leaf-size curve at an altitude of 2.100-2.200 m a.s.l. Instead of this regular form of the bulge, the vertical change

Fig. 6: Vertical gradient of leaf-types of different taxa of Melastomataceae along the path San Gerardo – Rio Talari at Mount Chirripó (Costa Rica; upper part). Means and medians of hypsometrical change of leaf-sizes at Chirripó (bottom left) and in the Sierra Nevada de Mérida (Venezuela, bottom right) combined with "real" annual

precipitation of nearby weather stations (black columns), and supposed annual precipitation at the respective altitudes (white columns).



along a vertical profile on the SW slope of the Cordillera de Talamanca in Costa Rica deviates significantly from this model. Here, the calculations of leaf-sizes, which in this case are individually coded in the upper diagram (fig. 6)), give at least two maximum ranges. Only the upper and lower boundaries of the vertical section shown are confirmed by precipitation data from in each case one weather station; the absolute peak value occurs lower down at another station situated at 1.000 m a.s.l. Thus, the Melastomataceae studies indicate that on the selected normal route over an exposed spur (Fila Cimiterio) towards Chirripó there is reason to believe that two more concentrations of maximum rainfall input occur. This more complicated situation is not at all surprising since in narrowly dissected terrains the precipitation patterns can be extremely variable within small space.

Taking up the example of leaf-sizes of Melastomataceae one specific feature of the humid escarpment of the Sierra Madre de Chiapas becomes obvious: There does exist an indicative differentiation between the lowlands, slope regions, and crest-line, however, major variation in general aspects of epiphytism is less significant. This is specially true for the group of bromeliads which normally can be used best for separating semi-arid and semi-humid regimes. In the case of Chiapas regional parts with nine and more humid months are dominated by cistern-formed bromeliads while those with six to eight humid months are characterised by globe-, bulb-, or grass-forms (fig. 7 and 8). Thus, at least in this case of southern México hygric interpretation within dry regions can be given by epiphytism while leaf-sizes of Melastomataceae are suitable for wetter ones (Richter 1993).

Epiphytism must be regarded as an optimal climate indicator in southern Ecuador where it has been investigated in detail (fig. 9 to 13). Once again the hygric differentiation between semi- and perhumid areas is less obvious as between semi-arid and semi-humid regions: Fig. 9 indicates that mosses, various orchids, and cistern-formed bromeliads characterise the wetter environments at Cajanuma and Zamora whereas lichens, grass- and globe-formed bromeliads are significant for the drier surroundings of Vilcabamba.

Such very obvious differences in epiphytic communities sampled on solitary trees are usable for numerical classifications by similarity analyses in the sense that in southern Ecuador the examples from Cajanuma and Zamora show rather similar aspects, whereas both differ considerably from that one at Vilcabamba. Basing on the classification system combining growth-form features and taxonomic groups such as presented below the sketch of Cajanuma (fig. 9) a canonical correspondant analysis (CCA with root transformation of coverage values) of 140 epiphytic relevés is helpful to illuminate regional hygric differences (Fig. 10).

Southern Ecuador was selected since the three Andean mountain chains splitting up south of the "Nudo de Loja" are considered as one of the South American "hotspots of diversity". The extreme variety of plants including endemic species swarms as well as widespread taxa and of plant-formations goes back to different causes:

1. extreme orographical dissection including remote and isolated areas,
2. different disturbance regimes of various dimensions (burrowers, landslides, fires, droughts etc.) and with specific (micro-)successions,
3. and, above all, an extraordinary hygrothermical complexity, extending from the tierra caliente to fria as well as from perhumid to semi-arid sections within short distances. The driest point of the region is situated nearby to the Peruvian border (about 250 mm a^{-1}) while the highest amounts of precipitation accumulate up to probably 6.000 mm a^{-1} on the Amazonian escarpment of the eastern Cordillera.

Since within this extremely fragmented area only 12 fully equipped weather stations provide climate data phytoindication must be considered an inevitable tool to understand the dynamic processes supporting rainfalls, fog, or dry fall winds (eight supplementary automatic weather stations between Loja and Zamora are active since Oct. 97 as part of an ecological project by the author). In a first step, existing hygric data of continuously running stations are assigned to the epiphytic similarity analyses. In a next step the resulting hygric subdivision based on the carefully selected locations of relevés is transferred to a topographical map. The succeeding map of the number of humid months serves as an important foundation to explain the extraordinary climatic complexity (fig. 11). In a last step, a synthesis of regional circulation patterns can be delivered.

As the crest-lines of the eastern cordillera (Cordillera de Loja and de Sabanilla) receive quasi-permanent and constantly directed stormy winds, easterlies' impact seems to be a main trigger for this section. These strong currents cause a strong uplift of air masses diverging from the trades that pass the Amazone forelands from N towards S in the southern summer and from S towards N in the southern winter (red streamlines in fig. 12 and 13). Continuous uplift results in a more or less continuous humid situation at the eastern escarpment and in the crest-region. The same air flows cause the frequent occurrence of a whirl-cloud in the summit region of the cordilleras which releases a latent heat flux and strong fall winds, i.e. the desiccating foehn of the Valleys of Loja, Malacatos, Vilcabamba, and Yangana (yellow and orange arrows).

Similar effects can be observed at the western cordillera, promoted by winds overlaying the Peru Current southwest of the area. During summer the western air flows converge with the eastern ones, causing high thunderstorm clouds above the Inner Andean mountain summits. In contrast, steady easterlies promote the local dry period in winter.

The method allows a reconstruction of the former vegetation destroyed within the last 50 years by extremely expanding land-use. Relics of nature-near vegetation still can give an idea of the original distribution of plant-communities within of a region formerly untouched by man (evaluation not presented here).

Discussion

The method's use is even more important in a practical sense for agricultural planning. Inadequate land-use practices with subsequent effects on soil-erosion, changes in thermic and hygric meso-climate respectively in energy fluxes, and in hydrologic regimes can be avoided by better knowledge of the regional climate. Phytoindication must be considered an adequate tool for getting such detailed climate information for a sustainable land-use management.

Up to now, presentations of the described methods received a high acceptance by the scientific community, agro-engineers included. However, since in some of the Andean countries agricultural planning is still based on political decisions of personal interest a need of adequate scientific experiences and transference seems to be evident...

Fig. 7: Vertical distribution of plant-formations (upper part) and of epiphytism in the Sierra Madre de Chiapas between the leeward semiarid escarpment (left side) and the windward humid escarpment (right side). Epiphytes are split up in taxa by the upper columns and in growth forms of bromeliads by the lower columns.
Fig. 8: Hygric and thermal ordination of growth-forms of bromeliads in the same region.

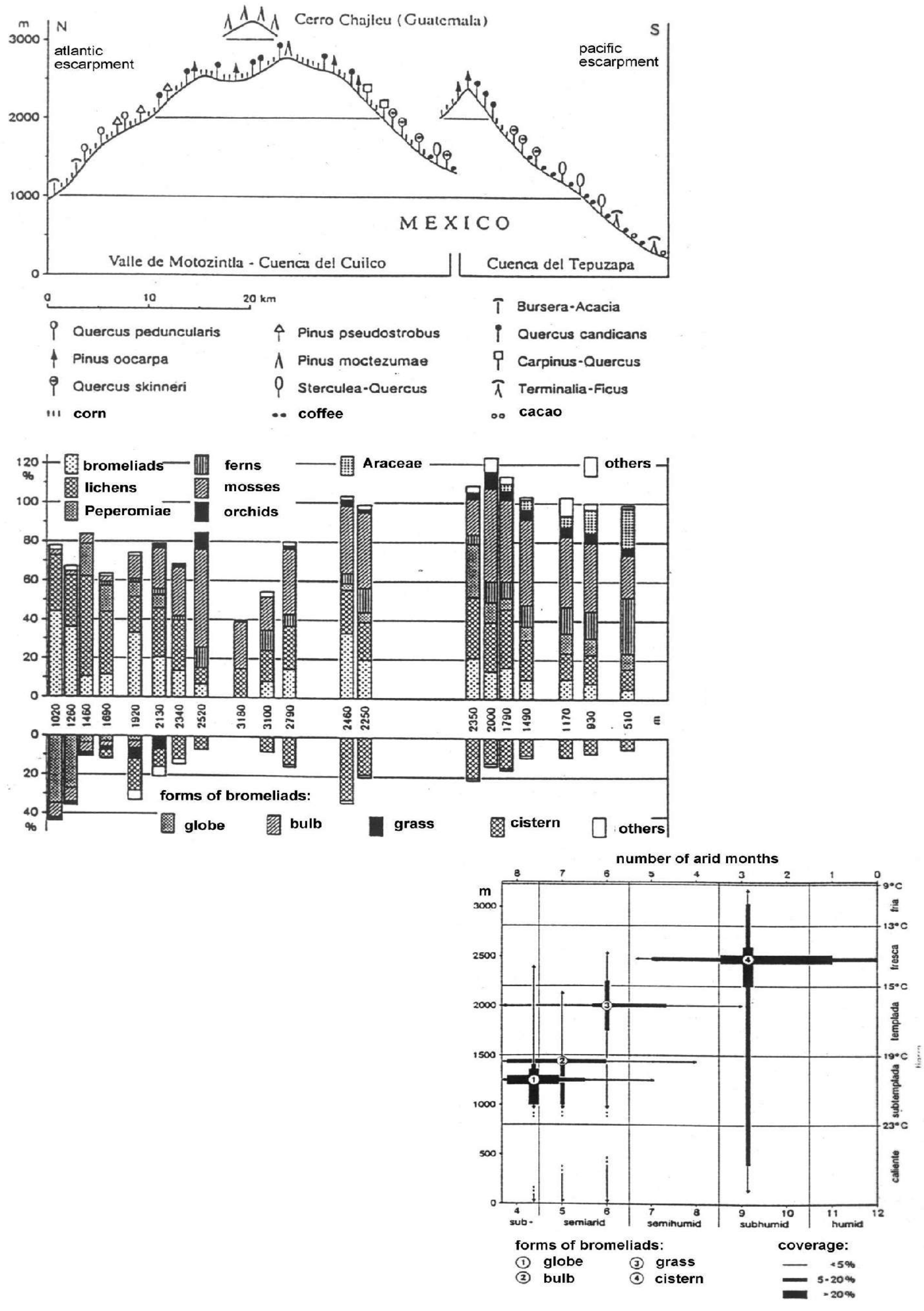


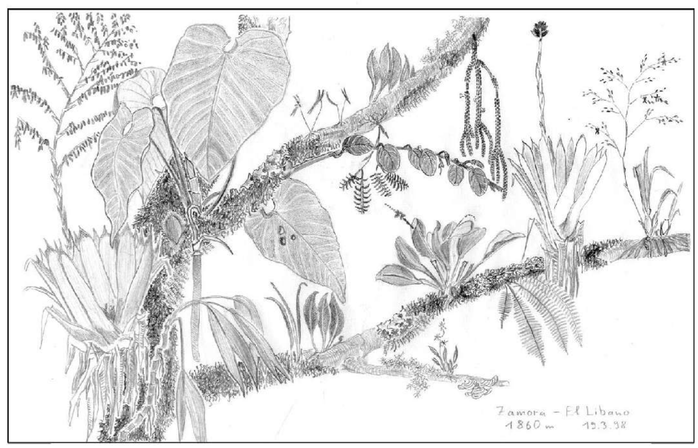
Fig. 9: Three examples of epiphytism in different hygric environments in southern Ecuador.

3

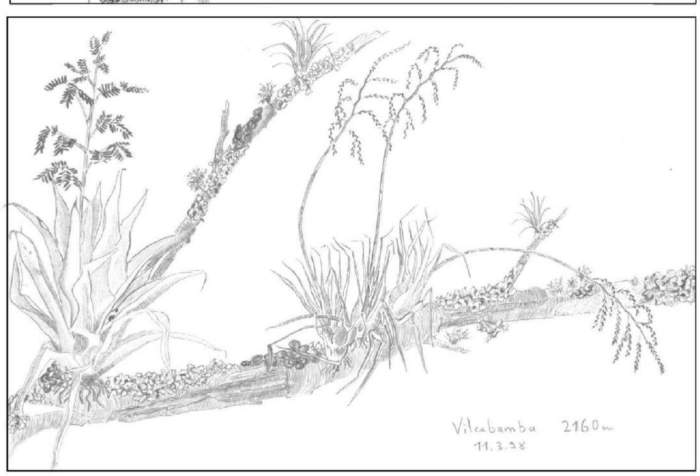
Plant forms for CA-Classification:

fungi	*2%*
mooses	*35%*
crust-lichens	*45%*
shrub-lichens	*8%*
Hymenephyllae	*10%*
pinated ferns	*2%*
not-pinated ferns	*2%*
Orchids (with bulb)	*2%*
Orchids (without bulb)	*8%*
Bromeliads (cistern form)	*6%*
Bromeliads (grass form)	*4%*
Bromeliads (bulb form)	*5%*
Begonia (Begoniac.)	*1%*
Peperomia	*1%*
Ericacea	*1%*
others	*1%*
total coverage	*= 133%*

CAJANUMA, 2600 m
type: semihumid



ZAMORA, 1860 m
type: perhumid



VILCABAMBA, 1860 m
type: semiarid

Fig. 10: Similarity analysis of 140 relevés of epiphytism by CCA and assignment to given data of humidity.

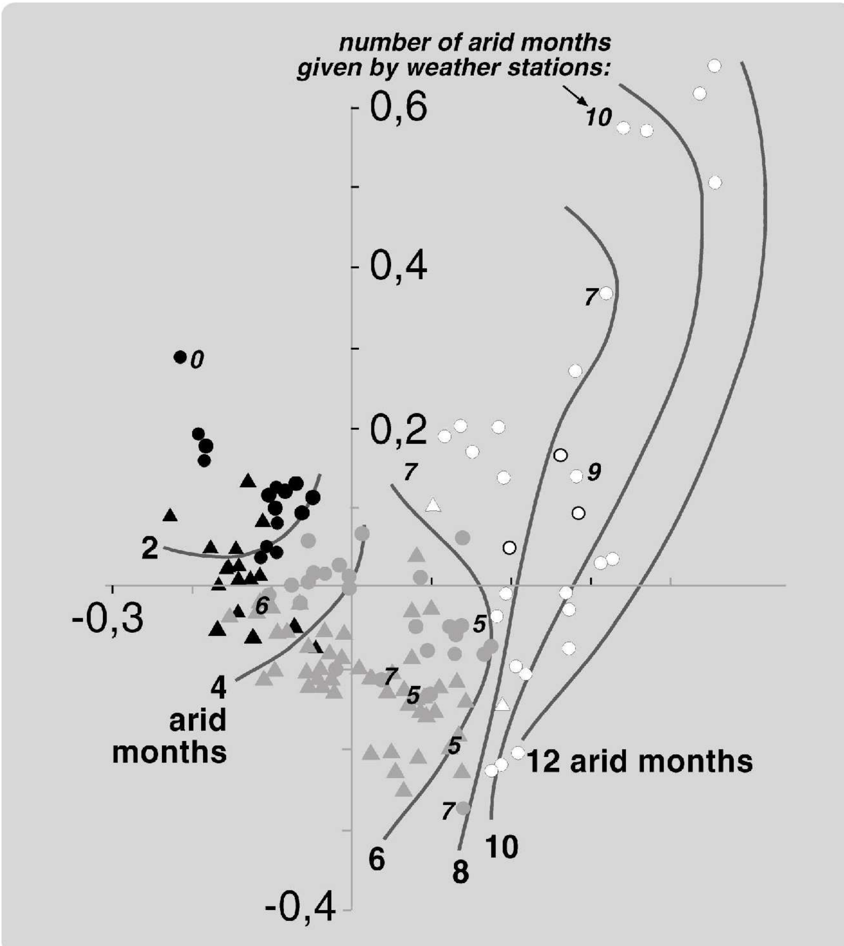


Fig. 12 (page 15): Streamlines and pressure systems in southern Ecuador during the rainy season derived from the humidity pattern in fig. 10 and weather observations.

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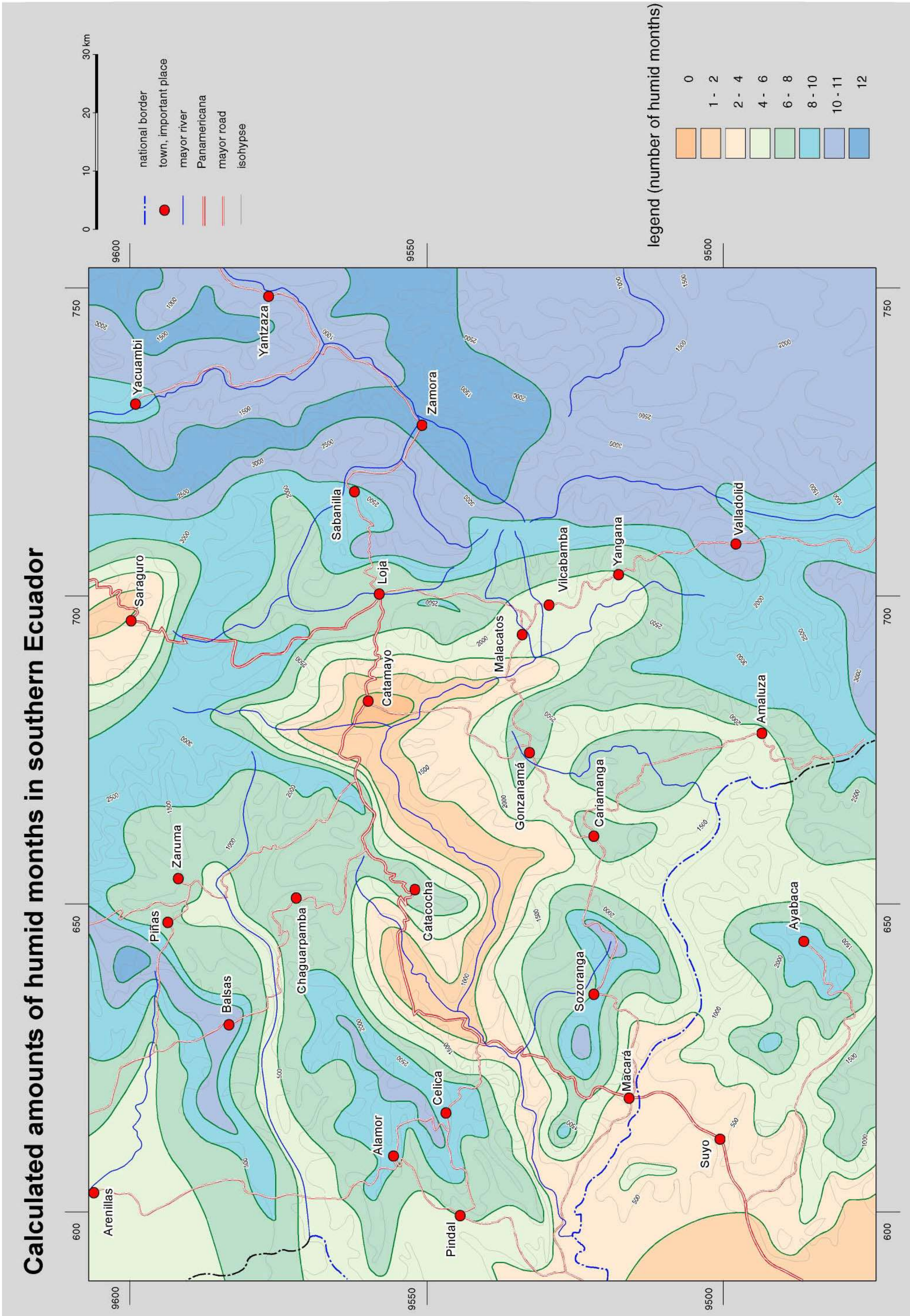

Fig. 11: Amounts of humid months in southern Ecuador based on data of 12 weather stations and similarity analyses of 140 relevés of epiphytic communities.

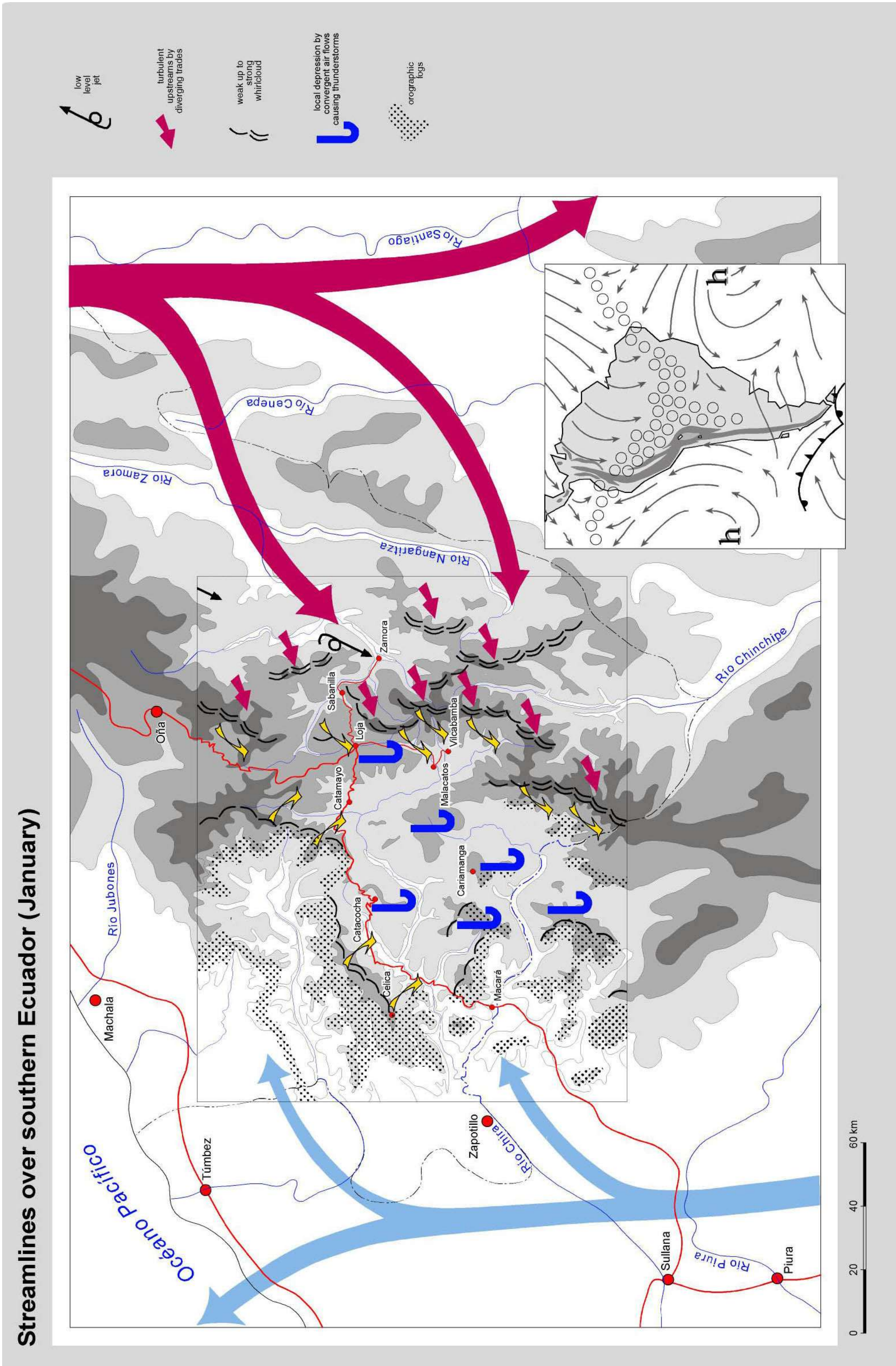

Fig. 12: Streamlines and pressure systems in southern Ecuador during the rainy season derived from the humidity pattern in fig. 10 and weather observations.

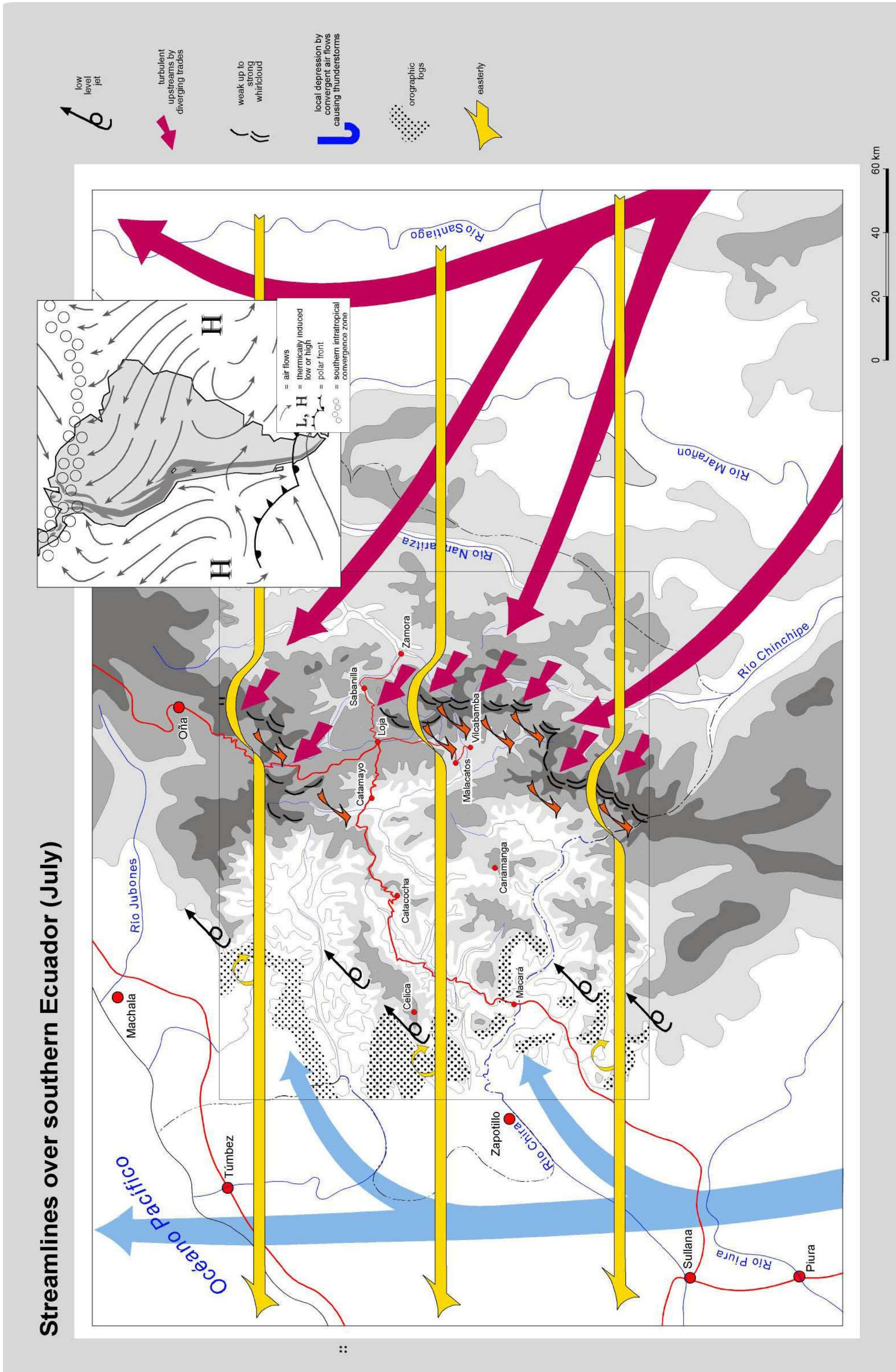

Fig. 13: Streamlines and pressure systems in southern Ecuador during the rainy season derived from the humidity pattern in fig. 10 and weather observations.