Ecological Classification of Pristine Premontane Vegetation in the Alto Mayo Valley, Peru

Clasificación ecológica de la vegetación natural pre-montana en el valle del Alto Mayo, Perú

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Abstract
An ecological classification for pristine vegetation in the Río Avisado and Río Tioyacu watersheds at the eastern slopes of the North Peruvian Andes has been developed. Emphasis was on characterizing forest structure, biomass and soil properties. The goal was to improve the understanding of interrelations between the topographic and geologic situation of the particular forest types, their biomass storage, the climatic conditions and the soil properties.
Forest plots for intensive structural measurements and soil description (currently > 200) were taken along transects and typical *catenae* in the upper Río Tioyacu and Río Avisado watersheds. Study plots reach from 800 m to 1600 m a.s.l. and cover different topographic and geologic situations. The stand structural, topographic, and soil parameters which were obtained in the field were statistically analyzed by principal component and hierarchical cluster analysis. The vegetation types were characterized by their variation of parameters: e.g. elevation, topographic position, soil organic layers, mineral soil, tree size, stand density, life forms, canopy density as well as dead and living biomass.
The classification resulted in a statistically confirmed separation of major vegetation types: Amphibiomes like Aguajales, Renacales, valley forests and alluvial plain forests, and terra firme forests like hill forests, dense heath forests, open heath forests and montane rain forests. All these major vegetation types showed significant differences in site climate, soil and plant nutrient status, and growth patterns. Biometric properties which were used for subsequent biomass calculation of all vegetation types. Biomass ranged from 26 23 tons per hectare in the open heath forest type to 245 147 t/ha in montane rain forests.
By combining aerial photographs, satellite imagery, a digital elevation model and geologic information in a Geographic Information System it was possible to derive a detailed forest type map for the study area. The classification of pristine vegetation of the two watersheds provides the base for an ecological sensibility analysis of forests and soils and the development and implementation of an environmental monitoring system at the Margen Izquierda (Bosque de Protección) of the Alto Mayo Region.

Resumen
Se elaboró una clasificación ecológica de la vegetación natural de las cuencas de los ríos Avisado y Tioyacu, localizadas en las pendientes nororientes de los Andes peruanos. El objetivo fué de mejorar el conocimiento sobre las interrelaciones entre las condiciones particulares de topografía

y geología de los tipos de bosque, de la acumulación de biomasa, de las condiciones climáticas y de las propiedades del suelo.
En las cuencas estudiadas se establecieron parcelas forestales a lo largo de transectos y *catenae* (actualmente > 200) para las medidas estructurales y para la descripción de los suelos. Las parcelas fueron localizadas entre los 800 y los 1600 m s.n.m. y abarcaron diferentes condiciones topográficas y geológicas. Los parámetros de características estructurales de las parcelas, de la topografía y de los suelos fueron colectados en el campo y posteriormente analizados por el método de componentes principales y de clusters jerárquicos. Los tipos de vegetación fueron descritos usando parámetros tales como: elevación, posición topográfica, profundidad de la capa orgánica del suelo, profundidad del suelo mineral, tamaño y densidad de árboles, densidad del dosel, tipos de formas de vida y la cantidad de biomasa viva y muerta.
Los principales tipos de vegetación diferenciados en esta clasificación fueron los anfibiomas como Aguajales y Renacales, los bosques de la llanura aluvial, los bosques de galeria, y los bosques de terra firme como bosques colinosos, bosques de heath densos y abiertos, y bosques montanos. Todos estos tipos de bosque mostraron diferencias significativas en cuanto a microclima, condiciones de los nutrientes en el suelo y en las plantas, y patrones de crecimiento. Las medidas de biomasa variaron entre un mínimo de 26 23 t ha^{-1} en el bosque de heath abierto y un máximo de 245 147 t ha^{-1} en el bosque montano lluvioso.
Mediante el uso de fotografías aéreas, de imágenes de satélite, de un modelo de elevación digital y de información geológica en un Sistema de Información Geográfica, fué posible elaborar un mapa detallado de los tipos de bosque. La clasificación de la vegetación natural de las cuencas de los ríos Avisado y Tioyacu proporciona una base para la preparación de un análisis de riesgo ecológico de bosques y suelos de la región y para el desarrollo y la implementación de un sistema de monitoreo del Bosque de Protección de la región del Alto Mayo.

Introduction

The slopes of the eastern Andes harbor the most dynamic and ecologically diverse ecosystems in South America with some of the greatest species diversity on Earth. This spectrum of ecosystems is generated by a high variability of climate, geomorphology and soils in the region. (Gentry & Ortiz 1993).

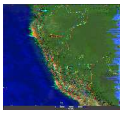


Fig. 1: Edited NOAA-AVHRR satellite image of Perú, reaching from 63°W to 78°W and from 18°S to 1°S

(Source: Axion 1997)

In this region between 400 and 2000 m a.s.l., in Peru alone, live 1.5 million people from pasture and agriculture. Immigration of settlers from central Peru creates a mounting pressure on the previously pristine submontane and montane regions of tropical humid forests. There is little to no sustainable use of the plant resources and most lower elevation forests near rivers and roads have been severely affected or entirely been destroyed. Natural forests suffer from large scale destruction through settlers since the construction of the Carretera Marginal in 1975, which is the major road connecting the studies region with the highlands. Most of the study area is still covered with primary forest today and belongs to native indian Aguaruna tribes (Elliot 1998).
The project Desarrollo Integral Alto Mayo of the German Society for Technical Cooperation (GTZ-DIAM) in Moyobamba, Dept. San Martín, Perú, supports and advices the Peruvian government and the local administration in the rural development of the areas around Moyobamba with emphasis on the Río Tioyacu and Río Avisado watersheds. The GTZ considered the classification and mapping of the remaining natural forest areas a prerequisite for a rural development plan.

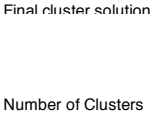


Fig. 3: Diagram depicting the graphical solution (elbow criteria, Backhaus et al. 1996) for the final number of valid clusters.

Materials and Methods

The study site is located in north-central Perú, in the Alto Mayo Valley, north of Moyobamba, Depto. San Martín (Fig. 1). It includes the watersheds of the Río Tioyacu and Río Avisado, both black-water tributaries to the Río Mayo. The elevation gradient is 800-1600 m a.s.l. which includes the NW valley flanks with the Cordillera Cahuapanas. Landforms comprise of two different units, the mountainous zone of higher elevations and the piedmonts including floodplains at the lower end of the watersheds. Geological formations present are mainly Cretaceous and Jurassic sandstones in the mountainous region and Quaternary fluvial deposits in the lower hillside and floodplains (Fig. 4). The hillsides display a tendency to landslides on steep slopes. All formations provide nutrient poor substrate for soil development. Soils have been classified by ONERN (1982) as poor tropic inceptisols, partly under aquatic moisture regime. The precipitation regime according to Walter (1975) is per-humid from October to April with a pronounced dry season from June to August (Fig. 2). In much of the inaccessible native community territories the vegetation cover has remained untouched and typical tropical rain forest vegetation has developed. Natural dynamics and variation in abiotic factors formed different vegetation types in the study area. The obvious distinction between the mountainous regions and the lowlands lead us to analyze the vegetation of these regions separately.

More than 200 sampling plots were described, chosen after predetermined criteria from remote sensing data or arranged along *catenae* and transects. Biometric measurements for the description of the vegetation focused on biomass assessment (e.g. stand density, stem diameter at breast height, tree height; c.f. Ogawa 1965) and stand structure parameters (e.g. dead wood volume, foliage characteristics, canopy coverage; c.f. Richards 1940, Webb 1970). Soil investigation included conventional sampling of soil pits and subsequent analysis of soil texture and nutrient content for soil horizons as described in Dempewolf (2000) and Börner (2000). Geomorphology was derived from topographic maps 1 : 100000 and from stereoscopic aerial imagery. For data reduction either principal component analysis for the extraction of factors or a correlation analysis for detection and exclusion of redundant parameters was applied. Subsequently, the dataset was submitted to hierarchical cluster analysis. Final classes were separated according to the elbow criteria (Backhaus et al. 1996) as described in Fig. 3 and correlated to topographic and soil site conditions.

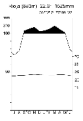


Fig. 2: Climate diagram of Rioja in the Alto Mayo valley, Perú. Mean monthly temperature and precipi- are shown. re measureents are -83, preci-pitation -93. rce: Ohando 1995)

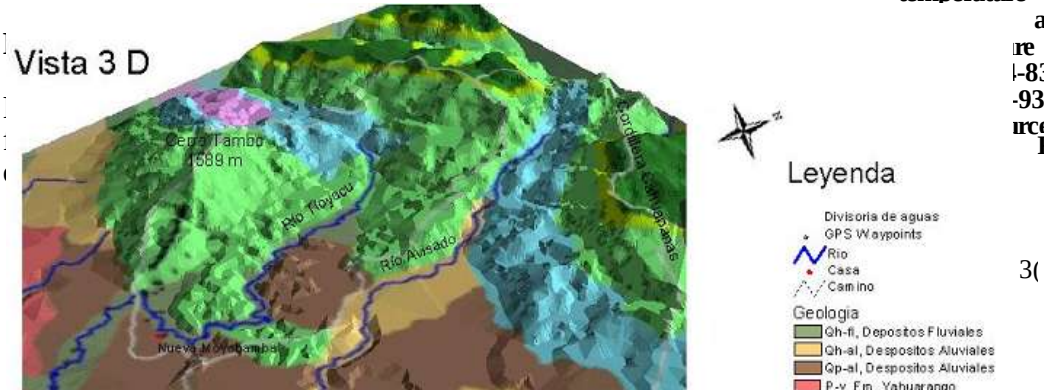
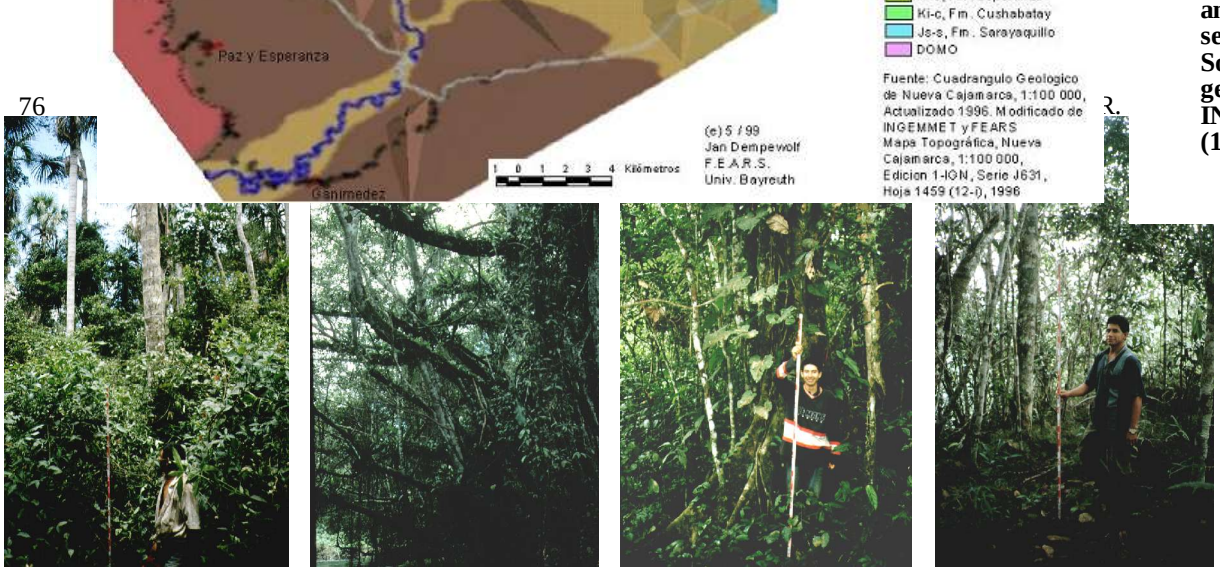


Fig. 4: Topography and geology of the upper Río Tioyacu and Río Avisado watersheds. The older mountainous and Quarter- nary low land



analyzed separately Source of geology: INGEMMET (1996)

Fig. 5: Forest structure types in the Río Avisado lowlands. From left to right:
„Aguajal“ on permanently flooded lowland sites (open stands, dominated by *Mauritia flexuosa*, with dense understory)
„Renacal“ on periodically flooded lowland sites (dense stands, rich in epiphytes, dominated by *Ficus trigona* and *Ficus* ssp.)
„Premontane rain forest“ in the lower hill region (dense, structural homogeneous stands with emergent trees above the canopy layer; buttresses frequent; climbing Araceae at stems)
„Impoverished premontane rain forest“ in the upper hill region (little stratified and rather homogeneous stands with large numbers of stems; Selaginellaceae, Lycopodiaceae and ferns on the ground)

Photos: A. Börner

species *Mauritia flexuosa* and *Ficus trigona*, locally named as “Renacales” and “Aguajales” (c.f. Fig. 5). In the hillside no characteristic species were assigned to premontane rain forest and impoverished premontane rain forest types (accounting for the simpler layer structure and relative absence of epiphytes and emergent trees). Biomass and soil parameters were classified

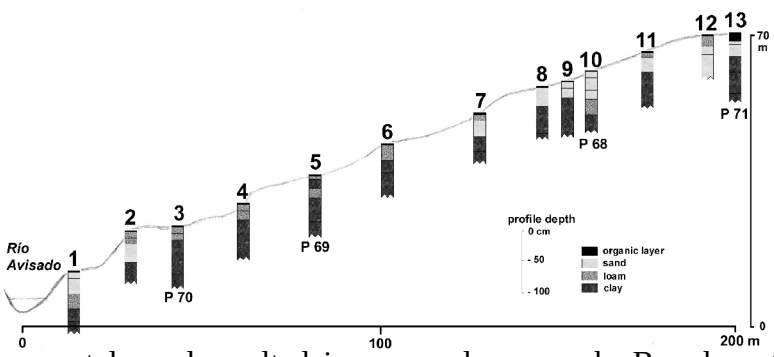


Fig. 6: Soil *catena* of 200 m length and 70 m elevation gradient in the hill region on a slope that rises above the Río Avisado. The soil profiles show the depth of different horizons and their dominating soil texture.

separately and resulted in seven classes each. Based on the numeral differences between the classification results no direct assignment of structure with biomass or soil classes was conducted. However, several biomass cluster were only to be found in distinct structure classes. Yet soils in the at least seasonally inundated floodplains were represented in one single, fairly nutrient rich soil class. The remaining six classes were distributed ± evenly throughout the hill region as soil properties were highly variable on a small scale and depended largely on the topographic position and the associated variation of clay content (Fig. 6).
Studies of the vegetation in the upper part of the watershed extended over an altitudinal gradient of 600 m, compared to a maximum of 100 m gradient in the lowlands. Seven forest type classes were distinguished by statistical analysis from the variables recorded in the field and subsequently mapped. The classes
were named after their topographical characteristics such as valley, alluvial plain, hill and montane forests. Valley and alluvial plain forests occurred in the depressions (distinguished by the width of the valleys) and hill forests were found on ridges and on lower slopes of the

Fig. 7: Forest structure types in the hill and mountain regions of the Río Tioyacu and Río Avisado watersheds. From left to right:

"Valley forest" in a broad valley below the Cerro Tambo mountain range at 975 m a.s.l.
"Hill forest" on a mountain side of the Cerro Tambo range at 1210 m a.s.l.
"Dense heath forest" on a ridge of the Cerro Tambo mountain range at 1330 m a.s.l. (Note the low tree heights and the low canopy density)

Photos: J. Dempewolf & E. Gamonal

cordillera. Montane forests covered mainly the higher elevations. Thickness of the soil organic layers increased with elevation. Within the montane forests, and under similar topographic and edaphic conditions, two more forest types were found. These were

islands of unusually low and open, shrub-like vegetation (c.f. Fig. 7), which were termed open and dense heath forests. The heath forest soils were comparable to the ones developed under

Fig. 8: Typical soil profiles of forest types found in the mountainous region. Stratification was grouped into organic and mineral soil horizons. Texture is labeled according to German soil taxonomy (AG Boden 1994): "Tu3" stands for very silty clay, "Ts2" for sandy clay, "Ts3" for very sandy clay and "Su3" for very silty sand. "Ol" is the litter layer, "Of" is the organic layer.

montane forests, but stand structure and biomass (26 23 t/ha in the open heath forest type and 245 147 t/ha in the montane rainforest type) were very different.

Heath forest soils in the mountainous region were characterized by a pronounced organic layer. This was in contrast to in the lowlands, where soils of the valley, floodplain and hill regions

featured small organic layers. Differences between soils of the forest types were found in the texture of the mineral horizons (Fig. 8).

Mapping of the forest types in the upper Río Avisado and Río Tioyacu watersheds was performed by combining readily available data with data obtained from the field. Field data were referenced against the statistical classification of the vegetation as recorded on the investigation plots. Basis for the creation of the map pictured below (Fig. 10) was panchromatic aerial photography which was overlaid with a digital elevation map and geology in a geographic information system. Interpretation followed a decision scheme developed for the data available (Fig. 9).

Fig. 9: Decision tree for forest type determination based on panchromatic aerial photography, a digital elevation map and a geological map.

Conclusions

This study aimed to develop a robust classification method of the pristine rainforests of the Alto Mayo Valley at the eastern slopes of the Peruvian Andes. The classification and mapping were considered a prerequisite for an ecological development plan and monitoring system of the region. The applied classification methods showed the need for a detailed spatial analysis since conditions of the study site varied on a small scale. Aspects of growth dynamics, successional stages and of natural disturbances have not yet been included in the assessment. For the understanding of presently unpredictable vegetation forms such as the heath forests an investigation of such dynamics has been started.

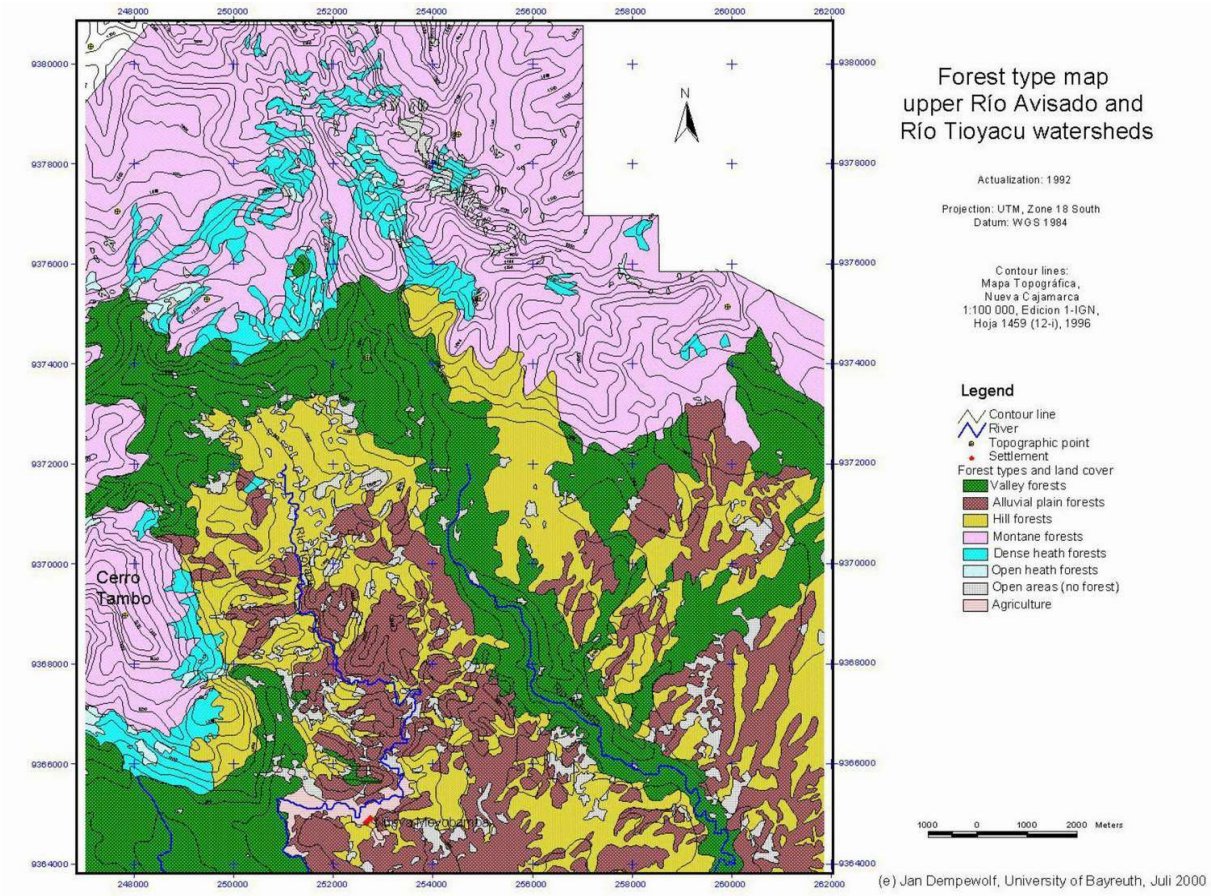


Fig. 10: Forest type map of the upper Río Avisado and Río Tioyacu watersheds derived from panchromatic aerial photography, topographic and geological information, and forest classes defined from soil and forest structure analysis.

Acknowledgements

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