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Gradients in a Tropical Mountain Ecosystem of Ecuador

Springer

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Cover illustration: Change of land use from pristine forest to grassland, abandoned pastures and secondary forest as characterized by the ^{13}C signatures of plant and soil matter. The different types and intensities of land use represent one of the gradients analyzed by the research teams. Another ecological gradient presented here is the altitudinal gradient on the slopes of the Andes of southern Ecuador: see Logo of the Research Group above. TMF: Tropical Mountain Forests.

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Preface

This book reports on a comprehensive study of a neotropical mountain rain forest, a type of an ecosystem that has received much less scientific attention than the rain forests of the tropical lowlands. Since the local pastoral population is crowded together in the limited accessible regions of the mountains, and because of the fragility of these ecosystems, tropical mountain forests are more endangered by human activities than most of the lowland rain forests. This holds in particular for the evergreen mountain rain forests of Ecuador, the smallest of the Andean countries which now, according to the 2006 FAO report, suffers the highest annual rate (1.7%) of deforestation in the whole of South America.

In spite of human impact the Ecuadorian Andes still represent one of the "hottest" biodiversity hotspots worldwide. There are many reasons for the outstanding biodiversity of that area, and those applying to the eastern range of the South-Ecuadorian Andes are discussed in this book: the steep altitudinal gradient over more than 1500 m, the upwind and lee effects, the extraordinary edaphic and microclimatic heterogeneity, the outstanding vegetation dynamics due to an enormous frequency of landslides, the limitation of nutrients and last but not least the eventful landscape history since the Pleistocene. This biodiversity is fostered and maintained by an incredible multitude of organismic interactions which significantly contribute to the stabilization of an otherwise fragile ecosystem.

A hotspot of biodiversity on the one hand and the highest deforestation rate on the other, this conflict is quite obvious in many valleys in the eastern Cordillera of southern Ecuador. One of these is the valley of the Rio San Francisco in the provinces of Loja and Zamora, where a widely undisturbed natural forest covers the orographically right slopes whereas on the left side the forest has been and still is – illegally – cleared by slash and burn for grazing livestock. The replacement of the natural ecosystem "tropical mountain rain forest" by a completely different anthropogenic system (pastures) within the same altitudinal range and geographic situation, separated by a horizontal distance of barely more than one kilometre provides one of the rare opportunities for a comprehensive comparison of two historically related ecosystems. Such a comparison not only helps to unravel functional interrelations of ecosystem compartments but is also extremely useful in examining the suspected loss of ecosystem services following human impact.

The autochthonous ecosystem “neotropical mountain rain forest” and its anthropogenic derivatives “tropical pastures” and “abandoned tropical pastures” have been studied in an interdisciplinary endeavour by temporarily up to 30 German/ Ecuadorian research groups. The research station “Estación Científica San Francisco” (ECSF), situated above the banks of the Rio San Francisco at 1850 m a.s.l. and close to the communicating road between the two provincial capitals Loja and Zamora, was and still is the centre of the ecological studies reported here. It is owned and operated by the foundation “Nature and Culture International” (Del Mar, California) through its Ecuadorian branch “Naturaleza y Cultura Internacional” (Loja). The project started in the late 1990s with an inventory of the biotic and abiotic compartments of the mountain rain forest. From the very beginning the investigations of soils, hydrology, climate, vegetation and fauna of the area were staged along an altitudinal gradient of almost 1500 m as the major guideline. In addition, all subprojects were carried out on the same core area of about 1000 ha, the so-called Reserva Biológica San Francisco (RBSF). In good time the results of the inventories could be used to address also processual relations between specific elements and compartments of the ecosystem, subsumed under the term “functionality”. Challenged by the non-sustainable practices of land use by the settlers, applied research projects were incorporated in the study programme. A gradient of land use intensity was identified which could also be considered as a gradient of human impact or disturbance: starting with a soft use of the natural forest and ending with home garden agriculture. However, due to the use of fire as an agricultural tool, the gained areas, mainly pastures, cannot be used sustainably as they are overgrown by persistent weeds like the bracken fern and amply propagating bushes. These form a new type of climax vegetation which forces abandonment of the areas but also prevents a natural recovery of the indigenous forest. This book therefore also reports on socially compatible measures of forest management and reforestation experiments with indigenous tree species at locations of different land use intensities, especially on already abandoned areas.

Ecuador is tied in a particular way to the name of Alexander von Humboldt whose fundamental description of the land, its people and especially its fauna and flora still merits our highest admiration. Even today, 205 years after Humboldt’s expedition to Ecuador, the majority of its biota may still await scientific description; nevertheless, a study of the tropical ecosystem, like that presented in this book, appears as a consequent further development of Humboldt’s idea of an ecological landscape portrait.

A book written by 104 authors requires a lot of endeavour and a sense of solidarity from the authors, the editors and last but not least the publisher. All of them are mutually grateful to one another, but special acknowledgement merits our assistant editor, Dr. Esther Schwarz-Weig, Mistelgau, for her fruitful suggestions and untiring efforts for the completion of the book. The authors would also like to thank the sponsor of the research, the German Research Foundation (Deutsche Forschungsgemeinschaft), the foundation Nature and Culture International for providing the facilities, in particular the famous station ECSF with the research area, and our counterparts from the Ecuadorian Universities, above all from the Universidad Técnica Particular de Loja

and the Universidad Nacional de Loja. In addition to the authors, numerous colleagues and other highly esteemed persons have contributed to the achievements reported in this book, but as the space of a preface is limited, they hopefully can forgive me for not mentioning them here by name.

Bayreuth, October 2007 Erwin Beck

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Chapter 1
The Ecosystem (Reserva Biológica San Francisco)

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1.1 The Research Area in Southern Ecuador

The investigated area, termed the “Reserva Biologíca San Francisco” (RBSF) is located in the Cordillera Real, an eastern range of the South Ecuadorian Andes (Fig. 1.1), which is the weather divide between the humid Amazon (“Oriente”) and the dry Inter-Andean region. In southern Ecuador the Andes are not as high as in the central and northern part of the country, but the topography of that area, called the Huancabamba depression, is more complicated. Here, a mountain junction culminates in the “Nudo de Loja”at 3800 m a.s.l., from which the Inter-Andean Sierras stretch towards SW, S and SE, all interrupted and dissected by valleys and basins. In spite of its dominance of the south Ecuadorian Andes the Cordillera Real only partly forms the watershed between the Pacific and the Atlantic Ocean. The map (Fig. 1.1) shows the looping course of the Rio Zamora, whose springs are south of Loja on the western slope of that mountain range. But north of Loja it turns eastwards and finally joins the Rio Marañon, a tributary of the Amazon. The valley of the Rio San Francisco, which is the main research area of the study presented here, belongs to the eastern escarpment of the Cordillera Real. Though still accompanied by pre-cordillera ranges, it is in principle exposed towards the Amazon basin.

The core area of the ecosystem study, the RBSF (3 ° 58' 30" S and 79 ° 4' 25" W, about 11.2 km^2), is located halfway between the province capitals Loja and Zamora in the deeply incised valley of the eponymous river (Fig. 1.2). It extends from 1800 m to 3160 m a.s.l. The logistic centre is the research station “Estacion Científica San Francisco” (ECSF), situated at the bottom of the valley at 1850 m a.s.l. and close to the communication road between Loja and Zamora. The RBSF comprises two manifestations of the ecosystem “tropical mountain rain forest”, mostly undisturbed natural forest covering the NNW-facing orographically right-hand slopes of the valley and its anthropogenic replacement ecosystems on the opposite side of the valley, where the forest has been cleared by slash and burn. Pastures which are still in use or have already been abandoned extend almost up to the crest of the mountains. One charm of the study is therefore the direct comparison of the two contrasting phenotypes of the same ecosystem. For a better understanding of the RBSF, a short introduction to nature and landuse in southern Ecuador is presented in the following.

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Ecological Studies 198.

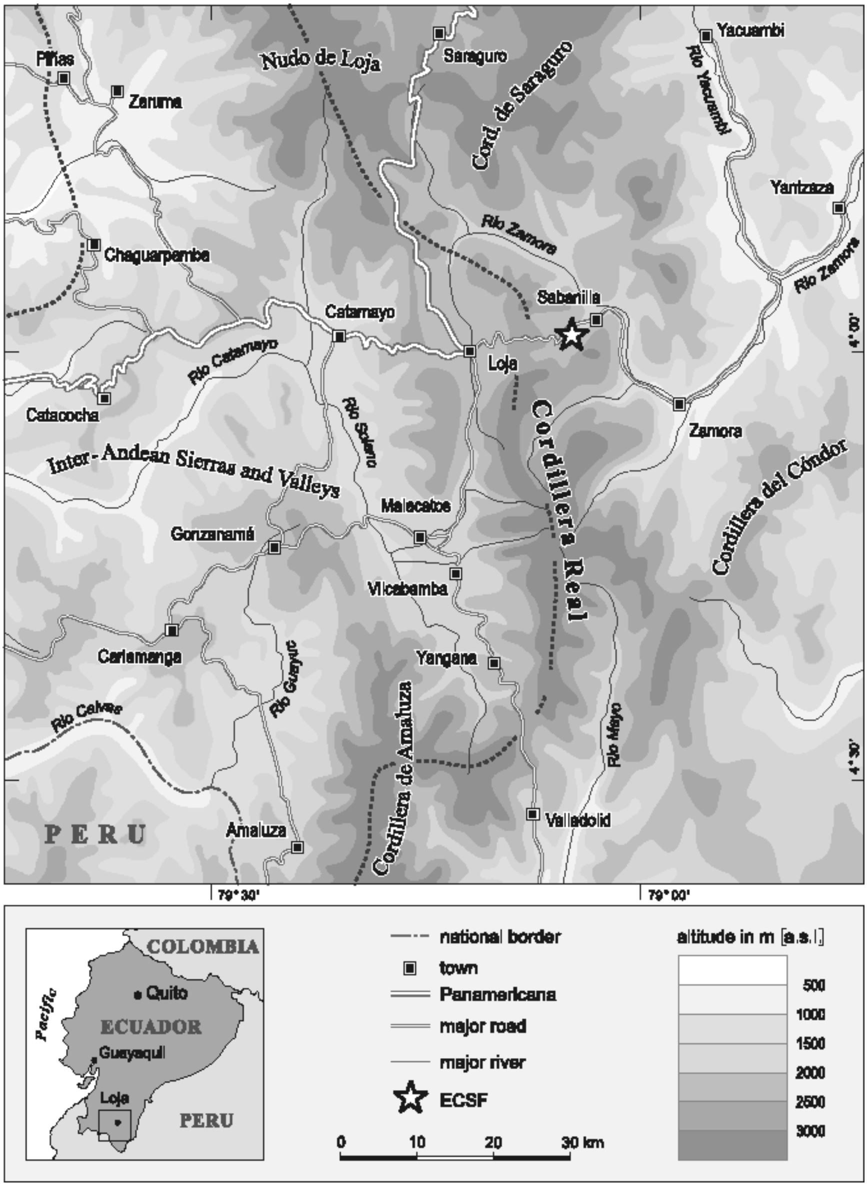

Fig. 1.1 Topographic map of southern Ecuador and location of the Research Station "Estacion Científica San Francisco" (ECSF)

Fig. 1.2 Research area and location of the permanent plots of the study at the Reserva Biologíca San Francisco (RBSF)

1.2 Geology

Ecuador comprises three geomorphological and geological regions: the coastal plain (la Costa) in the west, the Amazon lowlands (el Oriente) including the Sub-Andean foothill zone (e.g. Cordillera del Condor) in the east and the Andes (la Sierra) in the center. The coastal plain consists of tertiary (Eocene) and quaternary sediments (Baldock 1982) whereas the Oriente is composed of a peri-cratonic foreland and a back-arc sedimentary basin, in which marine paleozoic, mesozoic and cenozoic sediments were deposited on the margins of the stable Guyana shield. The Sub-Andean zone is structurally linked to the Andes and comprises folded and slightly metamorphic mesozoic sediments like black slates, calcareous phyllites and quartzites, covered by tertiary sediments of conglomerates, shales and sandstones. Three plutonites mould parts of the western Sub-Andean zone along the major fault, which forms the tectonic margin of the Cordillera Real. One of them is the Zamora batholith, into which a part of the research area extends, consisting of leuco-granidiorites and hornblende granodiorites.

The northern and central Andean regions (la Sierra) comprise the Cordillera Occidental (Western Cordillera), the Inter-Andean basin and the Cordillera Real (Eastern Cordillera). In the West, cretaceous and eocene andesitic volcanics are overlaid by younger marine sediments and volcaniclastics. Neogene to quaternary volcanic deposits form some of the major strato-volcanoes. The Inter-Andean basin is filled with quaternary sediments and pyroclastic deposits. The eastern Cordillera consists mainly of paleozoic metamorphic rocks probably formed during a Caledonian orogenic event (Baldock, 1982).

According to Litherland et al. (1994) lithologies present in the region include a thick sequence of Paleozoic semipelites (Chiguinda unit), pelitic schists and paragneisses (Agoyan unit), amphibolites (Monte Olivo) and ortho- and paragneisses (Tres Lagunas granites, a Sabanilla unit) overlaid by mesozic metavolcanics, quartzites, slates, pelitic schists and marbles. The research area is located in the Chiguinda unit with contacts to the Zamora batholith (Fig. 1.3). The dominating metasiltstones, sandstones and quartzites of this unit are interspersed with layers of phyllite and clay schist which in concordance with the mountain range strike N–S. This complex (comprising 30 km) consists mainly of products of low-grade metamorphism which border the highly metamorphous and (again 30 km wide) Sabanilla unit in the East of the RBSF (M. Chiaradia, personal communication).

1.3 Geomorphology

The famous Ecuadorian mountains, such as the volcanoes Chimborazo, Cotopaxi or Antisana, with altitudes up to and above 6000 m a.s.l. are concentrated in north and central Ecuador. In contrast, volcanoes are absent in the Huancabamba depression, and the crest of the Ecuadorian Cordillera Real does not exceed 2800–3400 m a.s.l. Except for the breach of the Rio Zamora (about 2000 m a.s.l.) the lowest region of

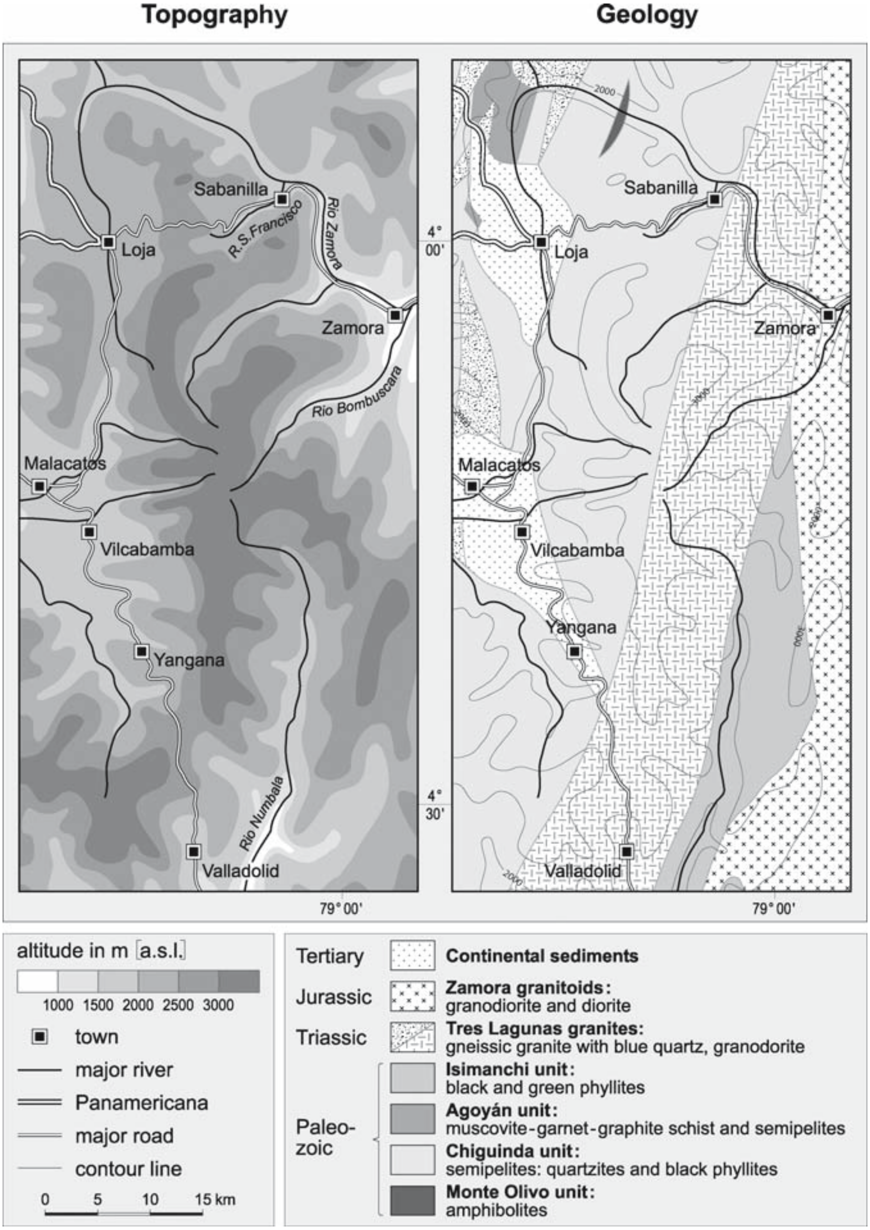

Fig. 1.3 Topography and geology of the Cordillera Real (after Litherland et al. 1994)

the Cordillera Real is the "El Tiro" pass (2750 m a.s.l.) east of Loja. Nevertheless, even here features of Pleistocene glaciation are obvious, such as head walls behind cirques containing tarns (e.g. "Lagunas de los Compadres"), smoothened bedrock with truncated spurs, and lateral and terminal moraines forming a typical nunatak landscape. The uppermost part of the Cordillera Real, although subjected to extremely wet conditions exhibits almost no indications of recent geomorphologic processes, due to the shelter by the dense páramo vegetation. The geomorphologic structure of the study area itself is quite complex. While quartzite dikes form narrow ridges declining from S to N and from SSE to NNW, respectively, the deeply incised V-shaped valleys indicate the occurrence of schist and phyllites (Sauer 1971). Due to the rugged terrain, the slopes face in all directions, with highest percentages stated for N (28%), NW (18%), SW (15%) and NE (12%). GIS-based analyses of inclination distribution prove a share of only 2% of slopes with angles less than 10 °, while the majority (57%) has angles between 25 ° and 40 °, and those steeper than 40 ° still cover 19% of the area. The steepness of the forest-covered slopes combined with the perhumid climate of the research area promotes an extraordinary frequency of landslides, partially associated with mudflow activities (Hagedorn 2002). Especially where the slopes have been scratched by human activities, e.g. by road construction, processes of fast mass movement such as rock-, earth- and landslides are dramatically enforced.

East and west of the rugged Cordillera Real the valleys are less steep and interspersed by wide basins filled with alluvial deposits. In the humid pre-cordillera east of the study area erosion and denudation processes are similar to those of the core region. In the semi-humid to semi-arid western zone torrential downpours result in gullies and debris transport, with the danger of riverbed changes by overflow and sedimentation of the adjoining floodplain. The sediments derive from sheet erosion from the slopes which has been accelerated by cultivation for hundreds of years.

1.4 Soils

The soils vary considerably between the warm and humid eastern side, the cold perhumid crest area and the warm semi-humid to a semi-arid area in the rain-shaded West of the Cordillera Real (Valarezo 1996).

Soils around the drier basins in the West often exhibit an enrichment of clay and are saturated with exchangeable cations: albic luvisols and eutric cambisols frequently occur up to 2200 m a.s.l. With increasing precipitation between 2000 m and 3200 m a.s.l. dystric cambisols, dystric planosols and gleysol gain importance (Schrumpf et al. 2001). Histosols and umbric regosols are widespread above 3000 m characterized by a high content of plant fibers, especially in the Páramo belt. Soil reaction ranges from pH 5.5 in the valleys to pH 3.0 in the Páramo.

On the humid eastern side of the Cordillera Real humic alfisols, humic acrisols and dystric leptosols are frequent between 1000 m and 2000 m a.s.l among the clay soils. Between 1500 m and 2800 m terric histosols prevail as water saturation lasts for several months (i.e. May to August at RBSF). Landslide areas within that region are characterized by umbric regosols and dystric cambisols. The latter are typical for the mountain forests between 1800 m and 2800 m a.s.l., but higher up dystric regosols are more abundant. Due to the high rainwater input most of the soils above

1800 m a.s.l show podzolic features like bleaching of the A horizon. Many of the soil profiles show reddish or black placic subsurface horizons indicating redoximorphic processes.

The stone contents of the A horizons vary considerably between more than 80% on fresh landslides and less than 10% in undisturbed mature forests with mighty organic layers. The turnover times of the organic material under closed forest canopies range between less than 8 years in the lower Zamora area and up to more than 15 years at higher altitudes. The generally low ECEC values decrease with elevation. However, the proportion of exchangeable cations increases as the kaolinite:illite ratio decreases with altitude. Plant-available N decreases with altitude concomitantly with increasing C/N values, low nutrient content of the litter, unfavourable thermal conditions and temporary water logging. Reaction of the mineral is strongly acidic (pH 4.5) and even decreases (pH 3) with altitude from the mountain forest to the Páramo. The soils, due to the diversity of the parent material and the altitudinally varying climatic and hydrologic factors display a high degree of small-scale heterogeneity (Wilcke et al. 2002) which is mirrored by the vegetation.

1.5 Climate

The climate of Ecuador is dominated by the tropical trade wind regime which is well established in the mid- and higher troposphere, with strong easterlies all over the year. The surface wind field is locally and regionally modified by the complex topography of the Andes and the thermal land-sea contrast at the Pacific coast. As outlined in Chapter 8, the south-eastern part of the country encompassing the RBSF area is also mainly influenced by easterlies, but westerlies occasionally occur especially in austral summer.

The major factors governing air temperature in Ecuador are topography, terrain altitude and ocean temperatures off the coast. The altitudinal gradient starts with the "tierra caliente" (hot land = annual average between 25 °C and 19 °C) below 1100 m, followed by the "tierra templada" (temperate land) between 1100–2200 m (19-13 °C), the "tierra fria" (cold land, 13-6 °C) up to 3800 m, the "tierra helada" (frost land, 6-0 °C) up to 4800 m and finally the "tierra nevada" at altitudes >4800 m a.s.l. The RBSF belongs to the tierra templada but extends into the tierra fria in which the thermal regime of the eastern escarpment differs significantly from the area west of the Cordillera oriental causing an asymmetric distribution of the "Tierras" (Richter 2003, see Fig. 1.4).

Spatial patterns of cloud frequency in Ecuador are illustrated in Fig. 1.5 and reveal two nearly contour-parallel bands of maximum cloud frequency (up to 85%) along the western and eastern Andean escarpments. The region of high cloudiness of the western band abruptly ends in the south Ecuadorian Huancabamba depression where the western Cordillera of the Andes attenuates and the inner Andean basin broadens. In that region the south Pacific anticyclone, in combination with divergent coast-parallel winds from the South, suppresses convection (Lettau 1976). On the

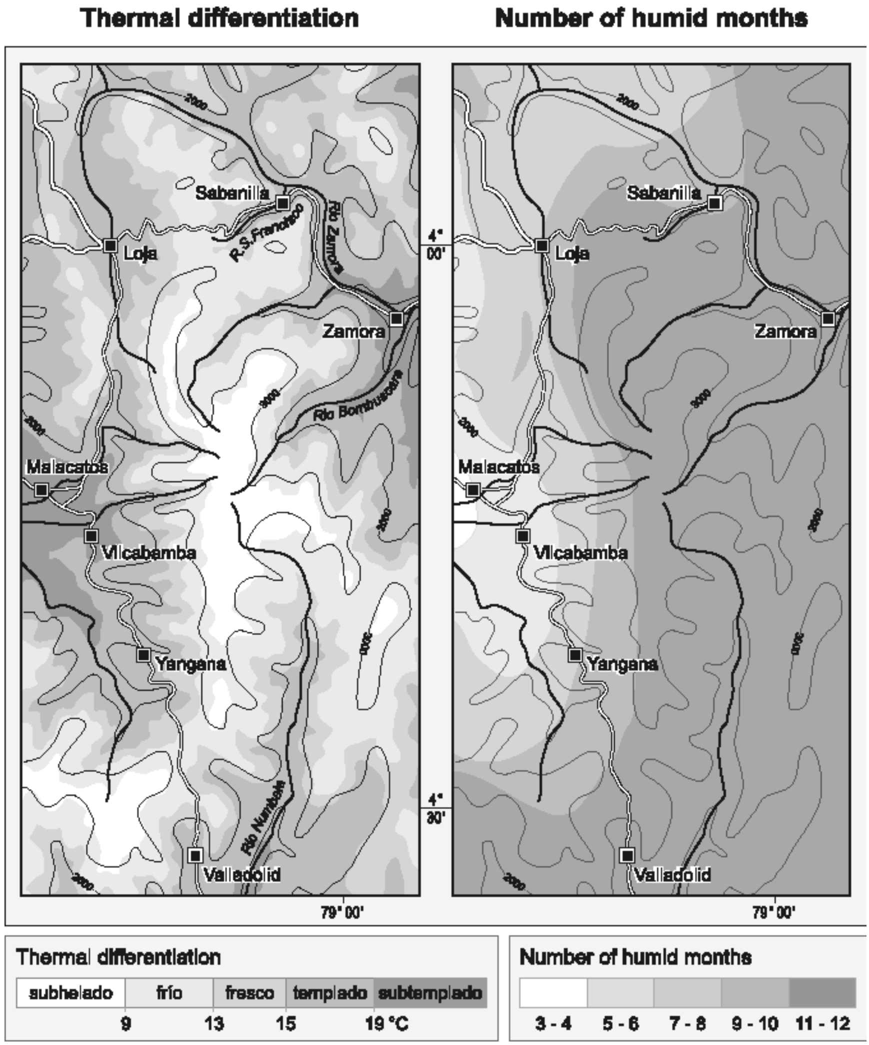

Fig. 1.4 Mean annual temperature and number of humid months for southern Ecuador based on epiphyte distribution as indicator for hygric conditions (Richter 2003), soil temperature and data from 29 meteorological stations

eastern slopes, cloudiness increases approaching the foot-hills of the Cordillera Real, with a maximum above >1800 m a.s.l. This zone is wider and more clearly established in the southern provinces of Ecuador and thus, in the RBSF area.

A detailed analysis of the spatio-temporal distribution of rainfall in Ecuador is presented in Bendix and Lauer (1992). It could be shown that rainfall formation is especially heavy at the eastern Andean slopes where the easterlies are lifted by forced convection, leading to intense condensation. Conspicuously, the zone of intense

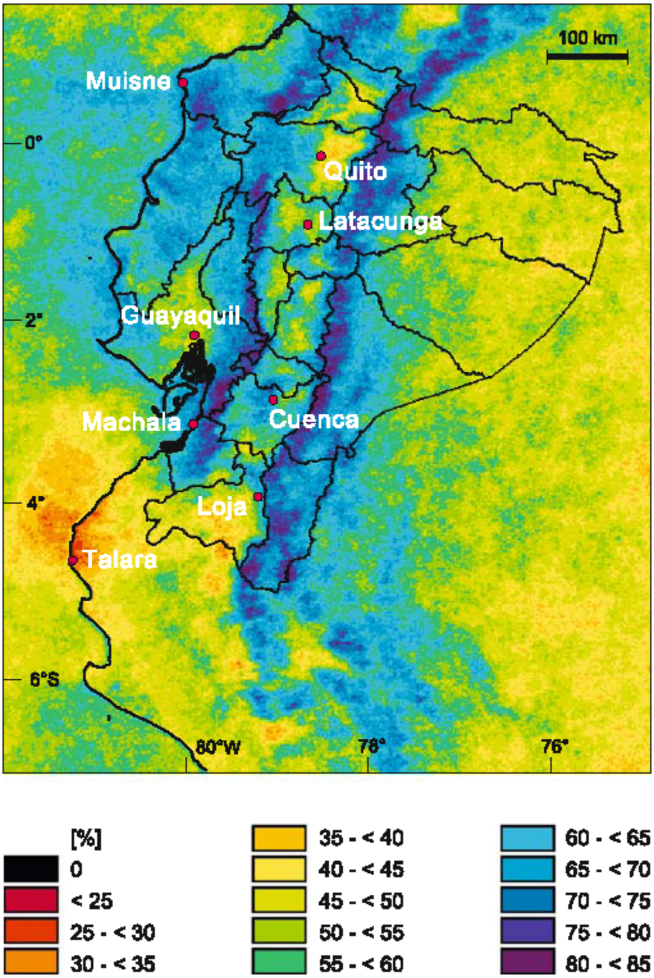

Fig. 1.5 Relative cloud frequency for Ecuador (2002–2003) and adjacent areas derived from NOAA-AVHRR data (from Bendix et al. 2004)

precipitation coincides quite well with the line of high cloudiness (Fig. 1.5) and is well known as the Andes-occurring System (AOS; refer e.g. to Bendix et al. 2006b). In contrast to the eastern slopes, the inter-Andean basins receive generally less than 1000 mm rain per year, but show a distinctive patchy structure of precipitation fields. Particularly dry "islands" are orographically isolated basins sometimes with annual precipitation below 500 mm as e.g. the Catamayo Valley in southern Ecuador.

The small-scale structure of rainfall (and cloudiness) can lead to marked climatic gradients over a short distance, which holds especially true for southern Ecuador in the vicinity of the RBSF area: The horizontal distance between the driest and the wettest point is less than 30 km (383 mm year^{-1} vs >6000 mm year^{-1}, from Catamayo to the Cordillera Real). As a consequence, the "coldest" and "hottest"