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Biodiversity
Hotspot
Tropical Mountain | Rainforest



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PREFACE

In 2008, a booklet "The Mountain Rainforest: Scientific Discoveries in a Highly Diverse Ecosystem in Southern Ecuador" was published by a German Research Unit, informing the public about 10 years of biodiversity and ecosystem research in the Eastern range of the tropical Andes of Ecuador. The authors (K. Kiss & A. Bräuning) had compiled 14 contributions on diversity, dynamic processes and potential use of the primary forest and of its agricultural replacement systems. Another 8 years of research in the area have immensely widened the understanding of the ecosystem and its value for science in general and for the region in particular. The new book "Biodiversity Hotspot: Tropical Mountain Rainforest", starting with an introductory chapter on the research area as the second hottest biodiversity hotspot worldwide, presents in an apprehensible way the major results of 16 collaborative projects addressing questions of basic as well as applied research. Understanding ecosystem components and processes is the prerequisite for an assessment of its stability under climate and land use changes. With this book the authors acknowledge the long-standing support of the work by the German Research Foundation and by the foundation Naturaleza y Cultura Internacional in Loja and San Diego, as well as the fruitful collaboration with our Ecuadorian partners, the Universidad Tecnica Particular de Loja, the Universidad Nacional de Loja, the Universidad de Cuenca and the Universidad de Azuay, and the local weather service INAMHI.

We also appreciate very much the important contributions of our non-university research partners beyond NCI, ETAPA EP (Empresa Pública Municipal de Telecomunicaciones, Agua potable, Icantarillado y Saneamiento de Cuenca - Ecuador), Gobierno Municipal de Zamora and the regional water fund FORAGUA (Fondo Regional del Agua).

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INTRODUCTION

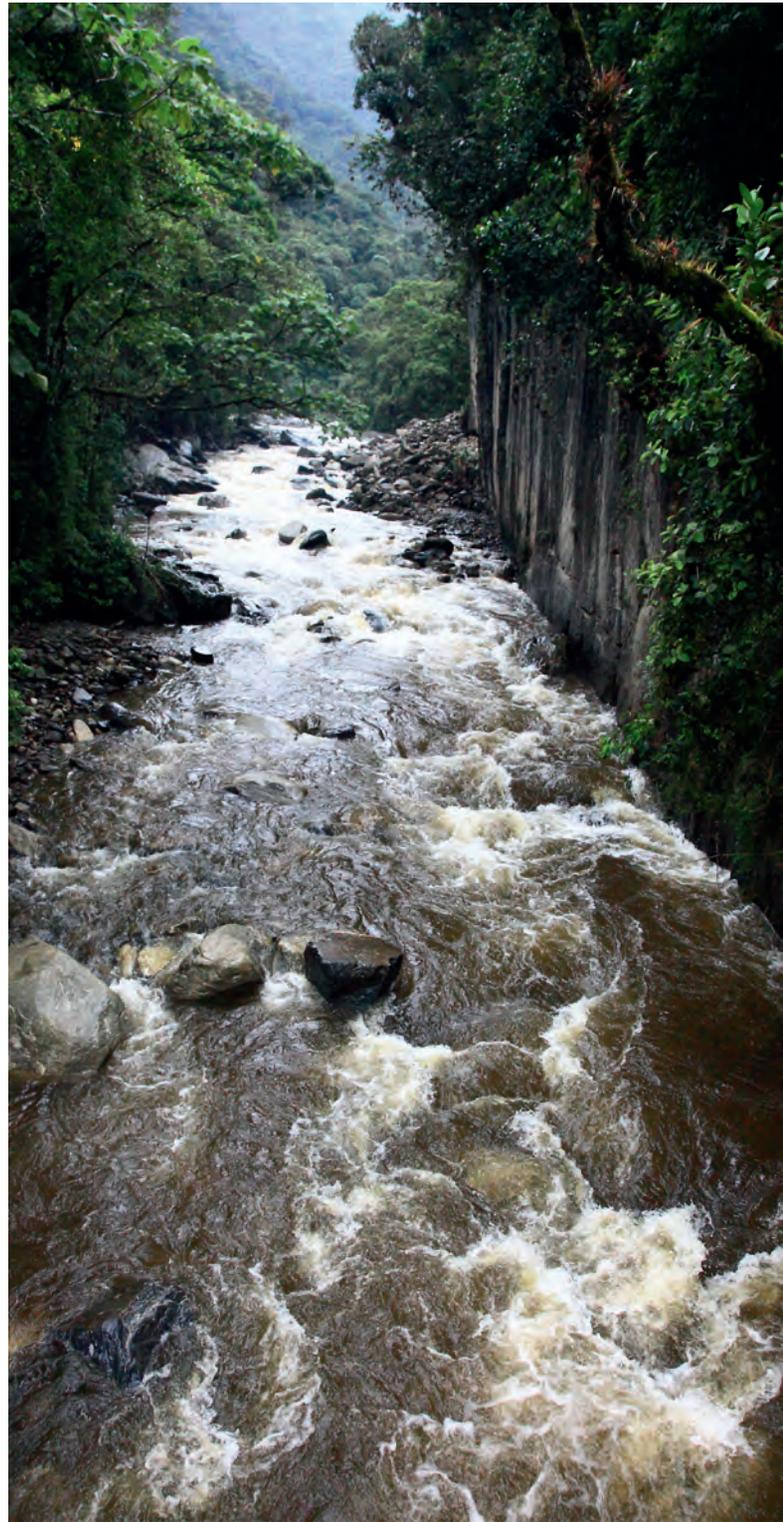
Germany's average precipitation is around 700 mm. Imagine the threefold amount to get an idea of the moisture in the research area, the San Francisco valley in South Ecuador. While seasons in the Northern Hemisphere are governed by the temperatures, in the tropics the amounts of precipitation determine the dry and the rainy season. In the research area, dry season means some less precipitation.



By Erwin Beck

The South of Ecuador harbors an outstanding richness of landscapes although the highest peaks rarely scratch the 4000 m contour. The area between 2° and 7 °S is known as the Amotape-Huancabamba-Depression (Fig.1) of the Andes, a geologically young transition zone from the northern to the central Andes both with peaks above 5000 and 6000 m. In the depression the tripartite structure of the Andes, consisting of the western and the eastern Cordillera separated by the inter-Andean upland, disintegrates in numerous smaller ranges and basins and a dense system of rivers and streams which drain partly to the Amazon, partly to the Pacific Ocean.

Due to the relatively low peak height of the mountains the Huancabamba depression has been interpreted as a transition zone from the tropical moist northern to the drier central Andes, as well as from the drier lowlands of the Pacific coast to the per-humid Amazon lowlands in the east. However, more recently, this part of the Andes has been considered rather an important biogeographical barrier (Weigend 2002), as concluded from an outstanding degree of endemism, especially of higher plants (for literature see Richter et al. 2009). Also climate conditions during the Pleistocene and the Holocene are more in favor of separating regions either by glaciation in the higher altitudes or by dryness especially in the large valleys, rather than providing corridors for migration (Jørgensen et al. 1995, Behling 2008). The multiplicity of landscapes originates from the fractionation of the Andes in small-scale massifs on the one hand and the extreme climate gradients on the other. As typical of the tropics the annual course of the temperatures is rather steady and depends mainly on the altitude, giving rise to the thermal zones: Tierra caliente, templada, fria and helada from the lowlands to the top of the mountains. Seasons are marked by the patterns of precipitation which, however vary strongly along horizontal and vertical gradients. In principle, the climate of the eastern part of Ecuador is dominated by the tropical trade-wind system with strong easterlies



(left) Sunflecks: Temporary and spatially confined high light intensity is a typical trait of the sub-canopy space in the forest, challenging the plants which are adapted to a low light intensity with a sudden transient hundred-fold increase of the irradiation. On a larger scale sunflecks can arise from gaps in the otherwise closed dense cloud layer, modelling the choppy terrain of the steep slopes (see also page 10). Bottom left: The road connecting the province capitals Loja and Zamora.

The Rio San Francisco is a tributary of the Rio Zamora which after crossing the eastern Andean foothills merges with the Rio Maranon, one of the major tributaries of the Rio Amazonas. The photograph shows the Rio San Francisco at low water; however after a heavy rain shower it becomes a torrent, as indicated by the flow mark on the rock face. A similar dynamics show also fountains and blind creeks which swell immediately after a heavy rain to rushing streams (compare pages 14 and 34).



The eastern ranges of the South Ecuadorian Andes prove as a rugged terrain with steep slopes and deeply incised valleys covered by the tropical mountain rain forest. The scar-like narrow natural landslides contribute considerably to the high

biodiversity of the region, representing areas on which the regeneration of the forest starts from the very beginning on the bare soil. Thus all developmental stages of the mountain rain forest are present in close vicinity.





Because the atmosphere of the mountain rain forest is almost saturated with water vapor, additional evapotranspiration from the forest results in the formation of dynamic wasps of mist

which appear and disappear from minute to minute. The forest silhouette and canopy show a tight mosaic of different tree crowns reflecting the high biodiversity of the area.





during the entire year while the western parts are subjected to a strong land-sea wind system and the South Pacific Anticyclone. In between the two tropics of Cancer and Capricorn, the inner-tropical convergence zone (ITCZ) where the NE and SE trade winds converge, passes two times a year over Ecuador resulting in two rainy and two dry seasons. However, this general scheme is modified by the N-S-stretching Andes where the air masses of the trade winds (as well as of the South Pacific Anticyclone) are forced upslope, resulting in cooling, moisture condensation, fog, clouds and strong rain. Therefore the Eastern Cordillera receives rain all year round, because both the NE- and the SE-easterlies carry humid air from the Atlantic over the Amazon up to the Andes. The contribution by Bendix et al. shows 12 humid months with a hump-shaped vertical gradient of annual precipitation. Rainfall maxima with 4000 – 5000 mm occur between 2500 and 3500 m elevation. Descending from the crests of the eastern Cordillera into the Inter-Andean Basin the air masses warm up and a dry foehn reduces the number of humid months to 8 at the capital of Loja and further to zero in a distance of 20 km at Catamayo with 340 mm annual rainfall. Over a horizontal distance of only 30 km the climate changes

A (neo)tropical mountain rain forest is a scientifically outstanding but logistically miserable working place for experimental research, combining steep terrain, 10 – 12 humid month and an unparalleled vegetation density from the ground layer up to the canopy. The research area in South Ecuador contributes a lot to the world's second hottest biodiversity hotspot.

Up to one fourth of the precipitation results from fog and mist which is combed out by the vegetation giving rise to an outstanding richness of the epiphytic flora (p. 17, 38 and 39).

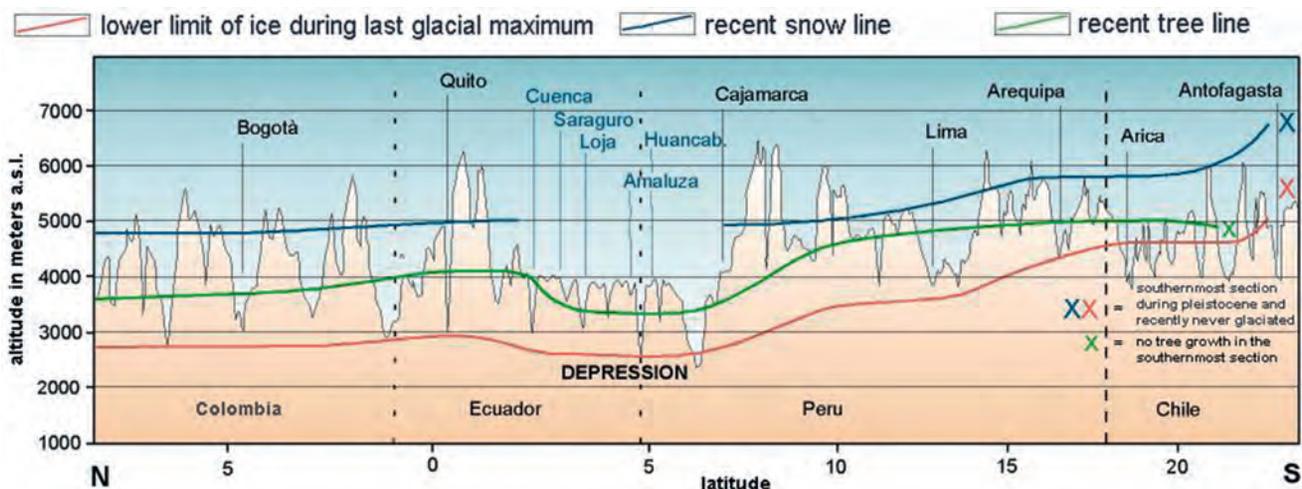


Figure 1: N-S-Profile of the tropical and subtropical Andes showing the Amotape-Huancabamba depression (M. Richter, Erlangen; by permission)



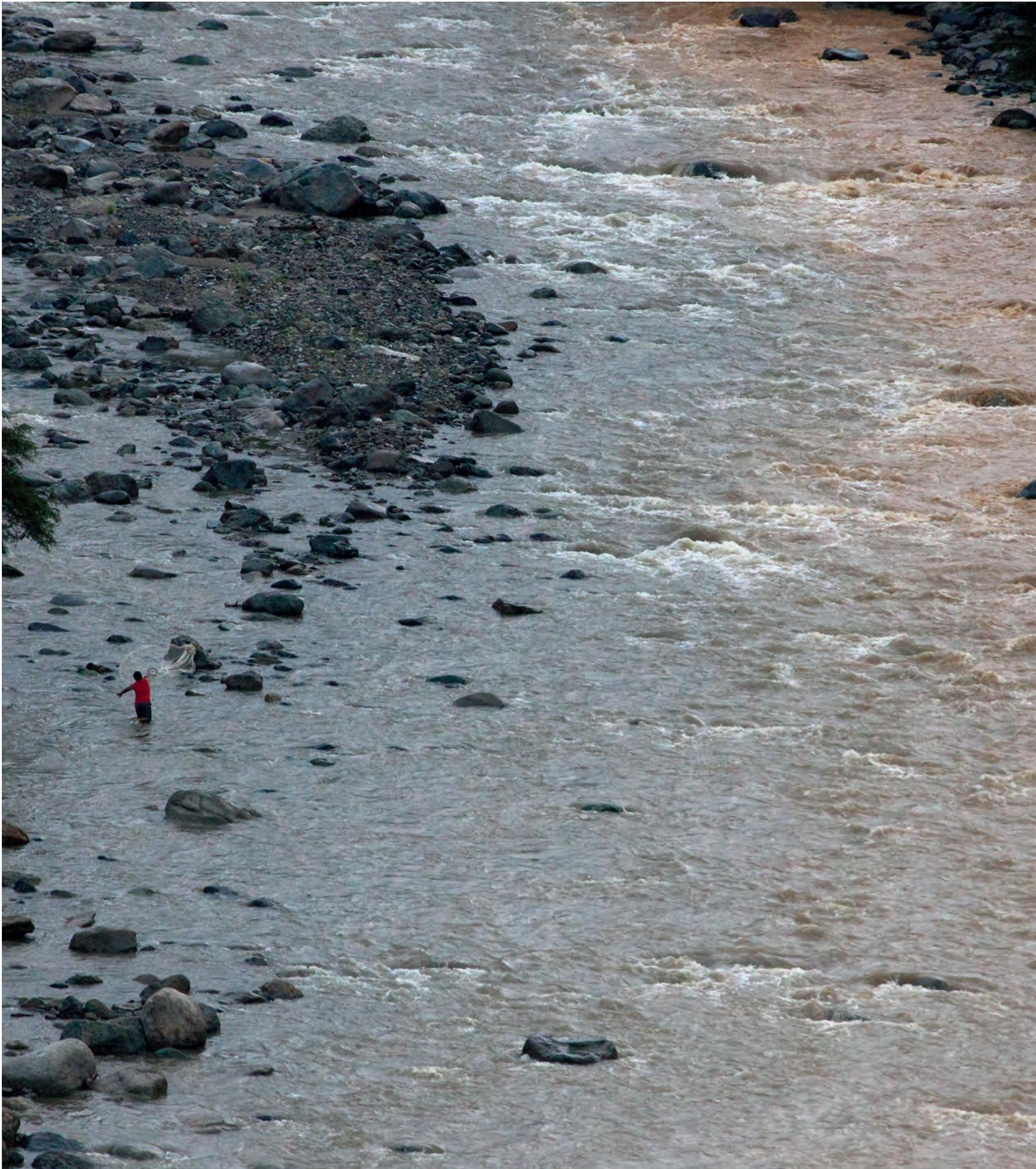


from 0 to 12 humid months a year (Fig. 1 in Bendix et al., p.51), giving rise to an enormous diversity of vegetation types from almost desert to evergreen mountain rain forest (p.11, 42, 43), elfin forest (p.17) and Páramo. Along the Pacific coast the high pressure associated with the South Pacific Anticyclone moving north and south together with the ITCZ, influences especially the southern part of the Huancabamba depression, suppressing the autumn equinox rainfall and thus only one rainy season between January and May remains. This is the area of the famous Tumbesian deciduous dry forests with its tall Ceiba trees with buttress roots and a green water-storing swollen stem, and the eye-catching Erythras and Bougainvilleas, which are densely covered with epiphytes like *Tillandsia usneoides* and other Bromeliads.

This "typical" climate is quasi- periodically modified by the ENSO phenomenon (El Niño – Southern Oscillation) which is generally subdivided in two phenomena with climate extremes. During El Niño the east and central tropical Pacific reveals positive sea surface temperatures (SST), leading to enhanced air temperatures in Ecuador and heavy rains particularly in the coastal plains, the Tumbesian dry forest and the slopes of the western Cordillera. Its antagonist, La Niña, is characterized by very cold SST anomalies which causes significantly reduces air temperatures and droughts in the aforementioned areas, but sometimes stronger rainfalls at the eastern slopes of the Andes in the mountain rain forest. The year 2015 was considered an El Niño year and in December President Correa declared the state of emergency for 17 out of the 24 Provinces of Ecuador. Usually the following year is characterized by an extraordinary strong South Pacific Anticyclone with drought in the western tropical South America and heavy rainfall in Indonesia.

The main rain event of the EN 2015 could be captured with the newly established weather radar network RadarNetSur (www.radarnetsur.gob.ec). The observations indicated rainfall totals of >400 mm in the southwestern part of the province of Loja (canton Zapotillo) close to the city of Celica (Figure 2, page 16). This spot was hit twice, on the 25 and 30 March by heavy rainfall.

After a heavy rainfall tributaries carry a lot of reddish material from the red tropical ferral soils into the receiving rivers giving rise to a colorful mix of waters over downstream stretches of hundreds of meters. Whether this helps the fisherman to improve his catch may be doubted.







(left top) Crowned by a tuft of up to 20 several meters huge leaves, tree ferns belong to the most spectacular “trees” in the tropical mountain forest. The slender stem is covered by the persistent bases of the dead leaves which are rather spiny. Although the stems appear to offer a good service as handrails for hikers in the steep slopes, the dense cover with spines allow only one try.

(left bottom) Four of the pinnules of about 20 of one of the up to 4 m long “giant” leaves of the tree fern. The genus Cyathea accounts for more than 300 species which are distributed over

the tropical and subtropical humid regions of the southern hemisphere. Their prime period was the carboniferous, when they constituted whole forests.

(up) Meeting a fairy in the elfin forest high up in the mountain is less likely than to come across an Andean bear. The bear’s proper home are the paramos from where it comes down into the forest. The frequent clouds and mist in the upper mountain forest lead to a dense cover of branches and leaves with so-called epiphytes: Mosses, ferns, bromeliads and even orchids.



(Grasses. Except several species of a scrambling bamboo of the extremely species-rich genus *Chusquea* (*Neurolepis*) the natural mountain forest of the Cordillera oriental (eastern range) does not harbor indigenous grasses. The pasture grasses, like *Setaria sphacelata* (left) are introduced by the farmers or are spreading from areas where the forest has been cleared long ago.

The spectacular *Cortaderia jubata* (right) grows up to 1.5–3 m tall, with graceful white inflorescence plumes. It spreads along the roads from the interandean basin. Other species of *Cortaderia* are known as Pampas Grass and used as ornamental plants.



(page 19) The family of the Fabaceae (Legumes) is not very rich in species in the Ecuadorian mountain rain forest, in contrast to the Tumbesian dry forest of which the conspicuous red-flowering *Erythrina*s are highly characteristic constituents. The photo shows one of the tree-like Legumes of the rain forest, *Dussia tessmannii*. The plant family of the Melastomataceae comprises herbs, shrubs and tall trees. All are conspicuous because of their flowers (*Tibouchina laxa*, bottom), or their ornamentally veined leaves (*Graffenrieda emarginata*, page 20, bottom) or because of both. The family is widely distributed in the Neotropics and 55 species have been recorded in the research area. *Tibouchina laxa* has been introduced recently as an expensive ornamental plant in European garden centers.





Introduction continued

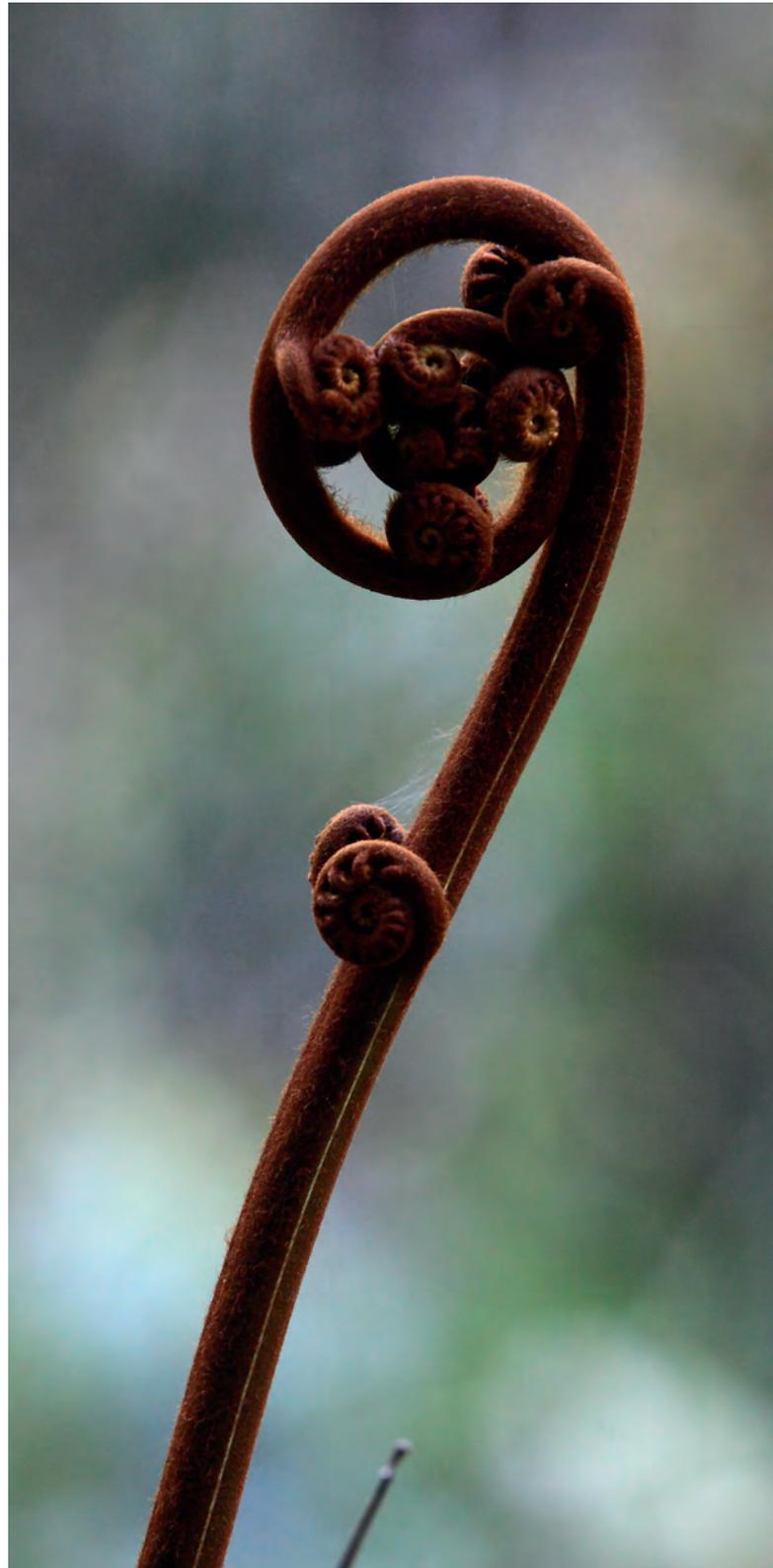
Such extremes are only occurring during EN situations in the dry forest area and are close to the annual totals normally registered here. The two events of March 2015 brought up to 333% of the normal monthly rainfall.

Although spectacular high topographic peaks like those of the Northern and the central Andes are missing in the Huancabamba depression, the high-elevation terrain as such is exciting with countless small lakes and remnants of moraines witnessing former glaciation of the to-days Páramos (Las Cajas, Lagunas de los Compadres), with gorge-like incised valleys with extremely steep slopes (page 35), naturally covered with evergreen forest in the humid, or with deciduous forest and shrubs in the dry areas. The driest part of South Ecuador is the deep Cañon of the Rio Jubones between Cuenca and Machala, where Cacti and sessile Bromelias characterize the sparse vegetation.

The areas of the German-Ecuadorian research group span an altitudinal range of 3600 m from the Páramo Las Cajas at 4000 m elevation down to Zamora at the northern edge of the Podocarpus National Park at 1000 m and Laipuna at 400 m a.s.l. However, this wide range consists of 3 individual altitudinal stretches, from Las Cajas to Cuenca (4000-2500m a.s.l.), from the Pico de Antennas to Zamora (3200-1000m a.s.l), both in the humid part of the Cordillera, and from 1500 to 400 m a.s.l. in the Tumbesian dry forest (Laipuna, close to the cities of Celica and Macará). The contents of this book focuses on the central research area, namely the valley and slopes of the Rio San Francisco, a tributary of the Rio Zamora. The valley is deeply incised in the Paleozoic bedrock of the so-called Chiguinda unit consisting of quartzites and black phyllites and gneissic granites in the eastern flank of the main range, the Cordillera Real

(left top) Members of the pepper family (Piper) are frequent components of the mountain rain forest of the research area. Less conspicuous members of that plant family are the herbaceous and succulent Peperomias which are often found as epiphytes on trees. About 1000 Peperomia species have been described, more than 350 alone from Ecuador. This species is probably new to science.

(left bottom) A fascinating leaf venation is typical of the tropical plant family Melastomataceae (gr. "Blackmouth family") irrespective of the size of the leaves. The big leaves of Graffenrieda emarginata show a heavy attack by a pathogenic fungus but also the resistance of the plant. Recognizing the attack the neighboring leaf cells commit suicide to detract the substrate for the fungus' further growth.



Natural artwork mimicking an esthetically carved crozier. Fern leaves, termed fronds, develop by gradual unwinding of the pinnae and pinnules, which may take more than a week for the big fronds of the tree ferns. Even the young and tender leaves of ferns are not browsed by herbivores due to a high content of deterrent chemical compounds.

towards Zamora. Due to a dense vegetation cover the uppermost parts do not show recent geomorphologic processes, but the deep valleys indicate the still ongoing process of the Andean uplift with a high relief energy. Side crests of the main range are interpreted as relics of formerly interrelated but meanwhile dissected terraces (Richter et al. 2013). Due to the high amounts of precipitation fluvial erosion and slope denudation by landslides are major geomorphological processes at mid-elevations. Almost 20 % of the valley slopes are steeper than 40°. Stability of the slopes is



*Pastures are wide-spread in the tropical Andes where the natural mountain rain forest has been or still is cleared. Cattle is very common, in contrast to sheep and goats which are rare. High numbers of cattle or long grazing periods on the same area results in terraces on the steeper slopes (overleaf, bottom) with a separation of the pasture grasses on the horizontal (*Setaria sphacelata*, *Axonopus compressus*) and the vertical (*Melinis minutiflora*) parts of the steps.*

Many pastures suffer from the invasion of weeds, mainly bracken fern and shrubs (overleaf, top, see also next pages) of the ruderal flora and the common mode of pasture rejuvenation by recurrent burning favors on the long run the growth of the weeds. Abandoning of useless pastures where the grass is more or less completely suppressed by the weeds is the consequence.

low and landslides are a common natural phenomenon (p. 10). Topography (slope steepness and curvature), bedrock and thickness of the soil, especially the occurrence of soil layers which swell upon water uptake, and the increasing weight of the growing vegetation destabilize the plant cover and an extra strong rain or the frequent earthquakes can finally trigger the landslide. Taking those factors into account, the probability of landslides can be modelled (Bendix et al. 2008) which is also very important for the connection road between the province capitals Loja and Zamora, providing the only access to the research station Estación Científica San Francisco. It is frequently blocked by tremendous landslides. Different from the gap dynamics in the mature mountain rain forest where an “incomplete succession” leads to the closure of the gap from a fallen tree, succession on the landslide has to start from the scratch on bare soil, where mosses, algae and lichens are the very pioneers.

The core research area, termed Reserva Biológica San Francisco of about 11 km², contributes significantly to the biodiversity hotspot of (south) Ecuador, which is considered the second hottest biodiversity hotspot worldwide (Richter et al. 2009). Orographic heterogeneity, resulting in a mosaic of differing landscape histories, in combination with a comparably favorable climate (Rodríguez et al. 2013), the interdigitation of northern and southern floral elements, alternating with temporary migration barriers (as mentioned above) as well as the ongoing small-scale or medium size turnover in the forest may be the major reasons for the species richness of the area.

Apart from favorable logistics such as reachability and the well-equipped Estación Científica San Francisco (p. 47) the area provides the benefit of an interesting pair of ecological contrasts, namely the original virgin evergreen mountain forest on the north-facing slopes of the Rio San Francisco valley and just across the narrow valley active and abandoned pastures as well as exotic afforestations replacing the natural forest. Ecological services of the natural and the anthropogenic ecosystem can be directly compared.

The area is sparsely populated by the indigenous Shuar on the eastern slopes of the South Ecuadorian Andes down to the Amazon, and by the Saraguros in the uplands of the eastern Cordillera. The Shuar are forest dwellers practicing a traditional system of shifting cultivation in a kind of rotation between agricultural land use and secondary forest. Cattle ranging is the





The common properties of the local farmers are narrow pieces of land which may extend from the valley floor up to the crest of the mountain. The horizontal extension is apparent from the distance of the fences on the foto. The lower part of the property is usually pasture, the upper forest.

While families of the Mestizos may live immediately on the pastures with small home gardens around their houses (e.g. below the right house) and a stable (in the middle), others visit their cattle on the pastures only sporadically and little houses serve as shelters and for safekeeping of tools and personal goods. Only a small patch of pasture is maintained for the donkey which is the common means of transportation.

traditional living of the Saraguros which extend their grazing areas more and more upwards even into the Parámo. Both ethnic groups cultivate species-rich home-gardens, the selection of crops being adapted to the elevation and climate of the settlement. As a third ethnic group, the Mestizo-Colonos have entered the valleys of the South Ecuadorian Andes since about 50 years, practicing a non-sustainable system of land use for cattle farming. They clear the forest by slash and burn and manually plant a fast growing African pasture grass (*Setaria sphacelata*, p. 18) into the new



area. Later on they use fire again to control the weeds and to stimulate growth of the grass. Use of fire favors growth of fire-resistant weeds, in particular of bracken fern and after a few years the areas are abandoned and new patches of the forests are cleared (Hartig and Beck 2003). Two of the German projects aim at a recovery of the abandoned area either by afforestation (p. 123) or by restoration of the pastures (p. 135). In the core research area, biodiversity and ecosystem studies have been and still are performed since 18 years and therefore the comparatively small area (not more than 30 km² including outposts) appears to be one of the best analyzed tropical ecosystems (Pitman et al. 2011) with some data series covering the entire time period.

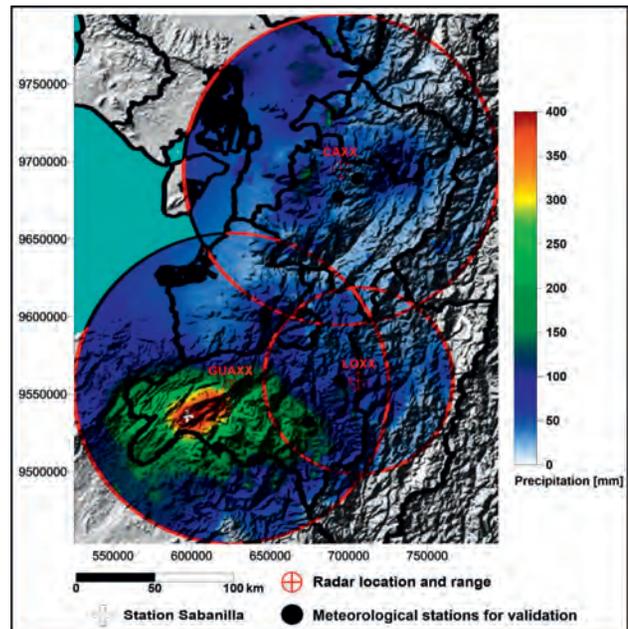


Figure 2: Rainfall totals for the EN period (March 25 – 31, 2015) as seen by RadarNet Sur. (From J. Bendix, Marburg)

References

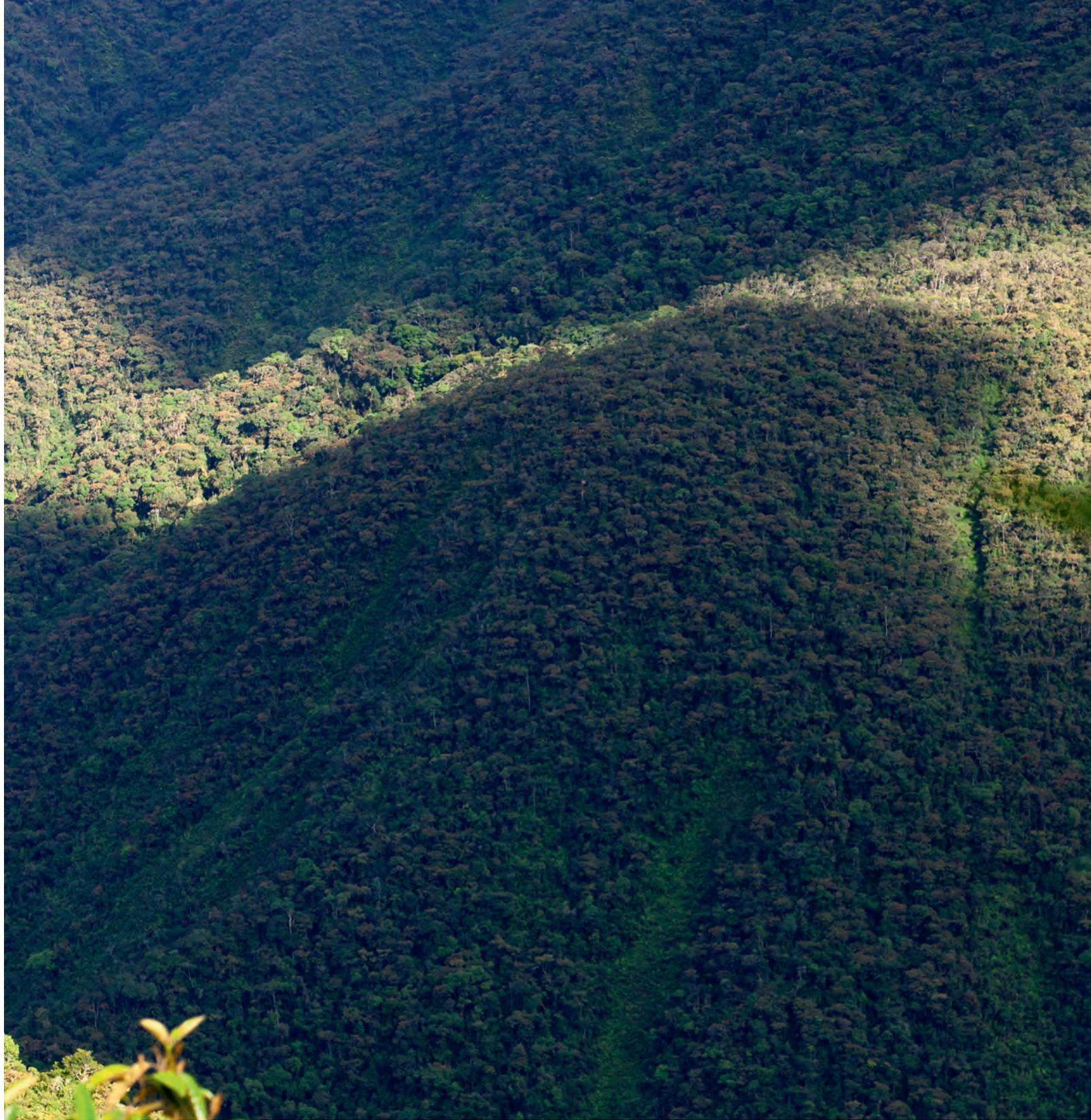
- Behling H (2008) Tropical mountain forest dynamics in Mata Atlantica and northern Andean biodiversity hotspots during the late Quaternary. In: Gradstein SR, Homeier J, Gansert D (eds) The tropical mountain forest – patterns and processes in a biodiversity hotspot. Biodiversity and Ecology Series 2: 25-33, Goettingen, Centre for Biodiversity and Ecology
- Bendix J, Dislich C, Huth A, Huwe B, Ließ M, Schröder B, Thies B, Vorpahl P, Wagemann J, Wilcke W (2013) Natural landslides which impact current regulating services: Environmental preconditions and modeling. In: Ecosystem Services, Biodiversity and Environmental Change in a tropical mountain ecosystem of South Ecuador (Bendix et al. eds) Ecol. Stud. 221: 153-170, Springer-Verlag Berlin Heidelberg
- Hartig K, Beck E (2003) The bracken fern (*Pteridium arachnoideum* (Kaulf.) Maxon) dilemma in the Andes of Southern Ecuador. ECOTROPICA 9: 3-13
- Jørgensen PM, Ulloa Ulloa C, Madsen JE, Valencia R (1995) A floristic analysis of the high Andes of Ecuador. In: Churchill SP, Balslev H, Forero E, Luteyn JL (eds) Biodiversity and Conservation of Neotropical Montane Forests. New York Botanical Garden, Bronx, pp 21-237
- Kiss K, Bräuning A (2008) The mountain rain forest. Scientific discoveries in a highly diverse ecosystem in south Ecuador. A project of the German Research Foundation. Nature and Culture International, Loja, 64 pp
- Pitman NCA, Widmer J, Jenkins CN, Stocks G, Seales L, Paniagua F, Bruna E (2011) Volume and geographical distribution of ecological research in the Andes and the Amazon, 1995-2008. Tropical Conservation Sci 4: 64-81
- Richter M, Beck E, Rollenbeck R, Bendix J (2013) The Study Area. In: Ecosystem Services, Biodiversity and Environmental Change in a tropical mountain ecosystem of South Ecuador (Bendix et al. eds) Ecol. Stud. 221: 3-17, Springer-Verlag Berlin Heidelberg
- Richter M, Diertl KH, Emck P, Peters T, Beck E (2009) Reasons for an outstanding plant diversity in the tropical Andes of southern Ecuador. Landsc Online 12: 1-35. Doi:10.3097/LO.200912
- Weigend, M. 2002. Observations on the Biogeography of the Amotape-Huancabamba Zone in Northern Peru. Botanical Review 68, 38-54. doi:10.1663/0006-101(2002)068 [0038:OOTBOT]2.0.CO;2

(right top) Not fog but smoke: Farmers set fire on their pastures to stimulate the growth of the grass and to combat the weeds. However, moist matter burns grudgingly and produces a lot of smoke when lit.

(right bottom) Large areas of primary or secondary mountain forest are still cleared by slash and burn, although this „technique“ has been officially banned. But who cares, if there is a fire at night. Since access is only on feet, control of a fire is very difficult. But there is rain on more than 200 days per year which helps to finish the fire.







In contrast to the forests in the temperate climate zone, e.g. of Europe, the age of which is more or less determined by the predominant tree species (e.g. beech 300 years), the age of the primary neotropical mountain forest is indefinite due to its richness in tree species with different life-times. Imagine a hectare of this forest with up to 260 or even more tree species. Of course, you would not find many individuals of the same species and of a comparable age. If a tree dies and falls over it leaves behind a gap in the vegetation (p. 28, center of the bottom photo) which immediately starts closing with herbs, shrubs lianas and

upcoming seedlings and saplings of pioneer trees. One or a few of these light demanding pioneers take over for some decades until juveniles of representatives of a "mature" forest replace them. Thus the final state of the primary forest is a small-scale mosaic entailing all phases of the forest dynamics which is scientifically termed "mosaic climax". Of course it is not possible to determine the age of such a forest. In the research area, this dynamic is boosted by the landslides, as the bare soil of the sliding area adds the very first steps of vegetation development to the changing plant diversity, i.e. algae, lichens, and mosses.

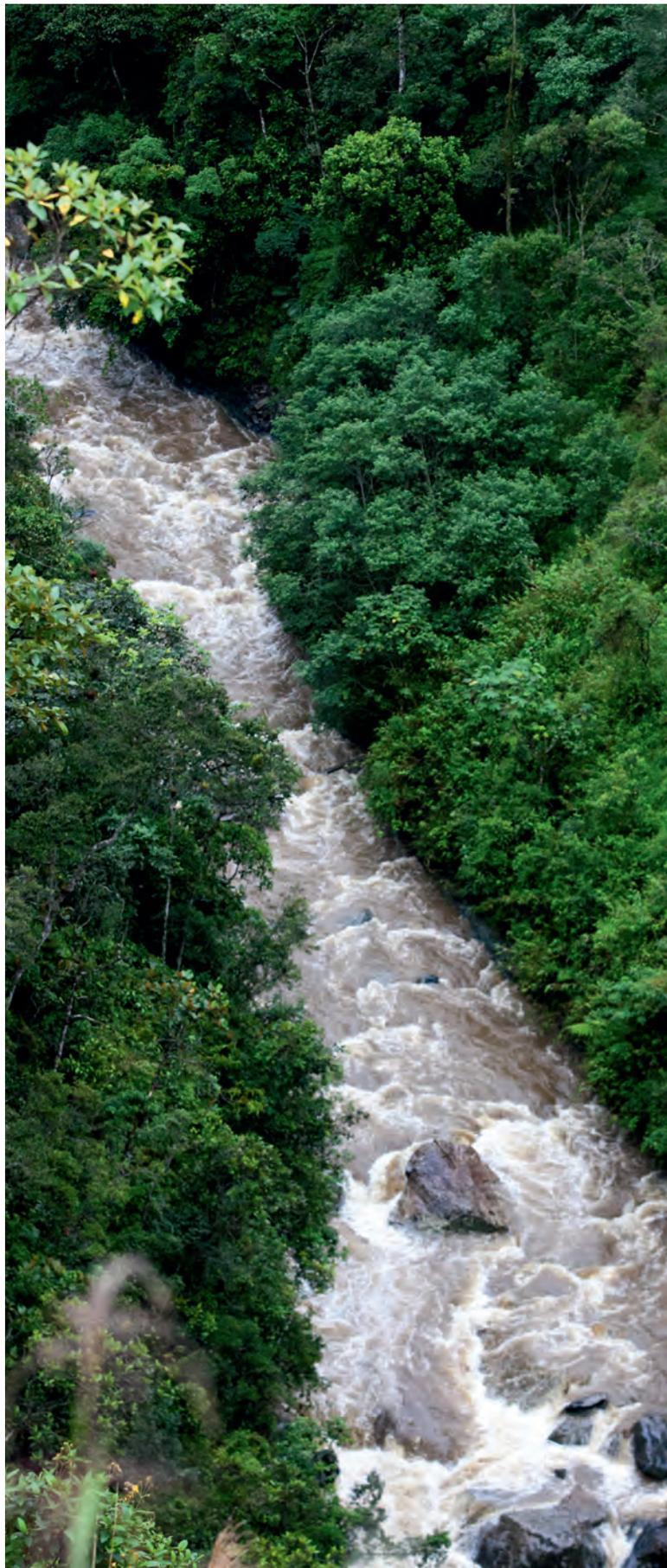


Chimney rocks and earth pillars, as well as crumbling roads are typical of areas in the South of the research area where heavy rain showers alternate with longer drought periods (e.g. between Loja and Vilcabamba). Small Bromeliads, mostly from the

genus Tillandsia which do not need to extract water from the substrate can get a hold on the rough surface. They absorb water from the rain or fog with a dense layer of scales on the leaf surfaces which opalise the entire plant.







(left) Apart from the very South, Ecuador is very rich in surface waters which discharge partly to the Pacific while the majority feeds the Amazon. However, the availability of this resource is threatened by the high rate of deforestation. Several meritorious initiatives care for preserving the functionality of the water catchments. The program FORAGUA collects money to finance the conservation, regeneration and watershed management of forested water catchment areas of 100.000 ha, serving 1 million people. The Socio Bosque Program was started in Sept 2008 by the Ministry of the Environment (MAE), offering economic incentives to owners of land with native forest to guarantee its protection; to date, conservation agreements have been signed for 630.000 hectares.

(below) Dams keep the lights on. Hydroelectricity is very important in Ecuador and several new dams are under construction, like DELSITANISAGUA at El Retorno in the valley of the Rio Zamora. With 2 turbines and an output of 115 MW it belongs to the bigger hydroelectricity projects of Ecuador in spite of a relatively small storage reservoir of 0.5 km length.

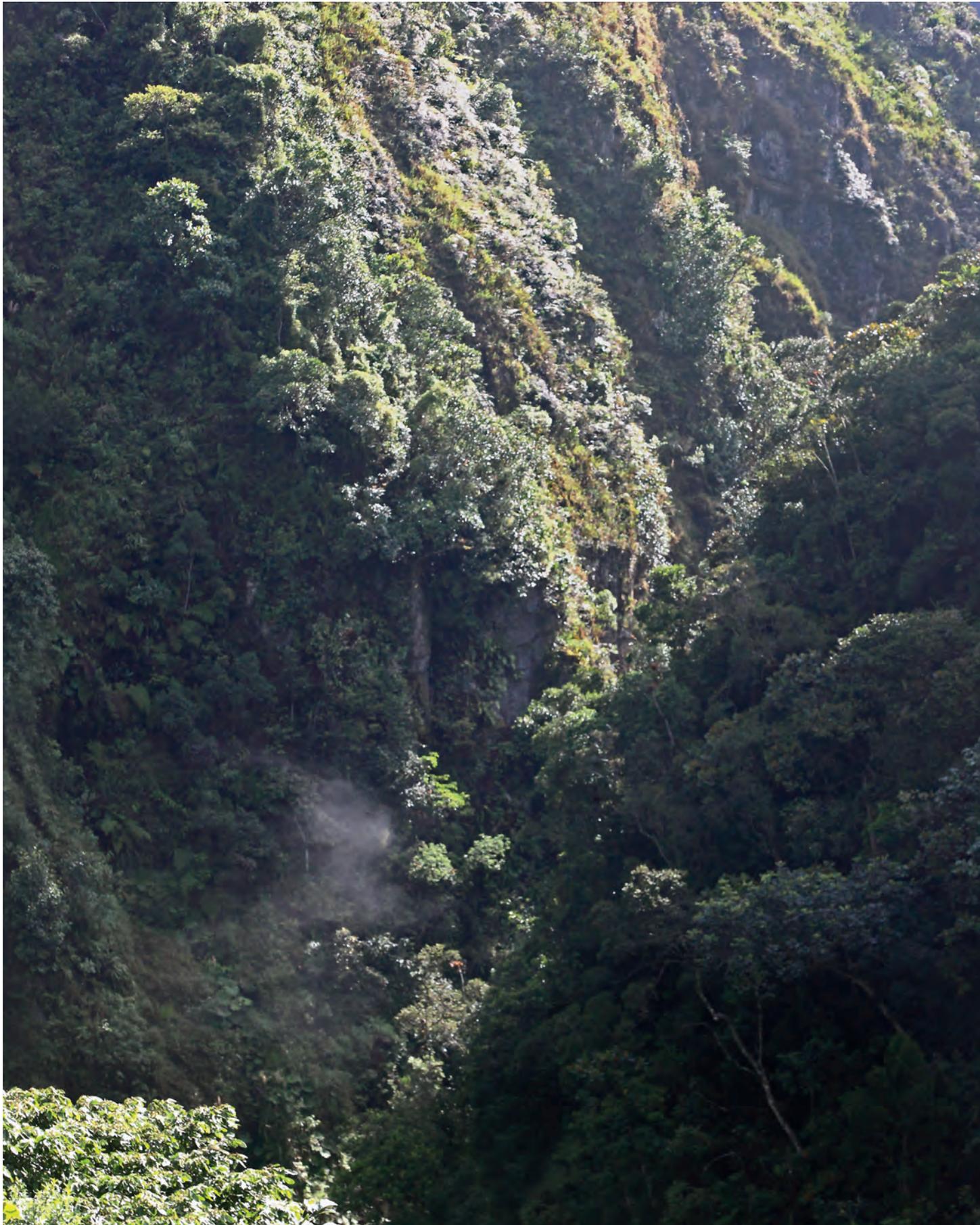




Waterfalls with changing channel flow are the El Dorado for algae, lichens and mosses. Due to the water-saturated soil the water flow reacts immediately to a rain shower but also may dry out on one of the rare days without rain.

(top) Capacity building is not restricted to knowledge transfer of pure science, but developing practical skills is also welcome. Confidence in the strength of a branch is required in tree climbing which can serve the investigation of the biological inventory of a crown as well as silviculture.

(page 35) Permanent moisture and a moderate temperature all year round allow a luxuriant plant life on each spot where a plant can capture a foothold. Thus even the steepest slopes and rocks, like here in the upper San Francisco valley, are covered with a green carpet of herbs, shrubs and trees.





(above) Gentians are generally known as pretty herbs with deep-blue flowers. However, members of the gentian family can be annual small herbs, shrubs, lianas or even large rain-forest trees; they occur on all continents except the Antarctic. The example shown here (*Macrocarpaea ovalis*) is a small tree of the tree-line ecotone.

(page 37 top) Above the tree line a shrub *Páramo* or *Yalca* covers the steep slopes and sharp crests of the mountains. An almost

permanent cloud from the easterlies veils the tops of the mountains and the stormy winds prevent growth of trees.

(page 37 bottom) *Purdiaea nutans* from the white-alder family (Clethraceae) is the only species of the genus *Purdiaea* in South America. It occurs sporadically in the Guyana Highlands and the northern Andes. The only *Purdiaea nutans*-forest known so far occurs in the Río San Francisco valley in about 2400 m, where it receives up to 5000 mm of rain per year (see Mandl et al. 2008).





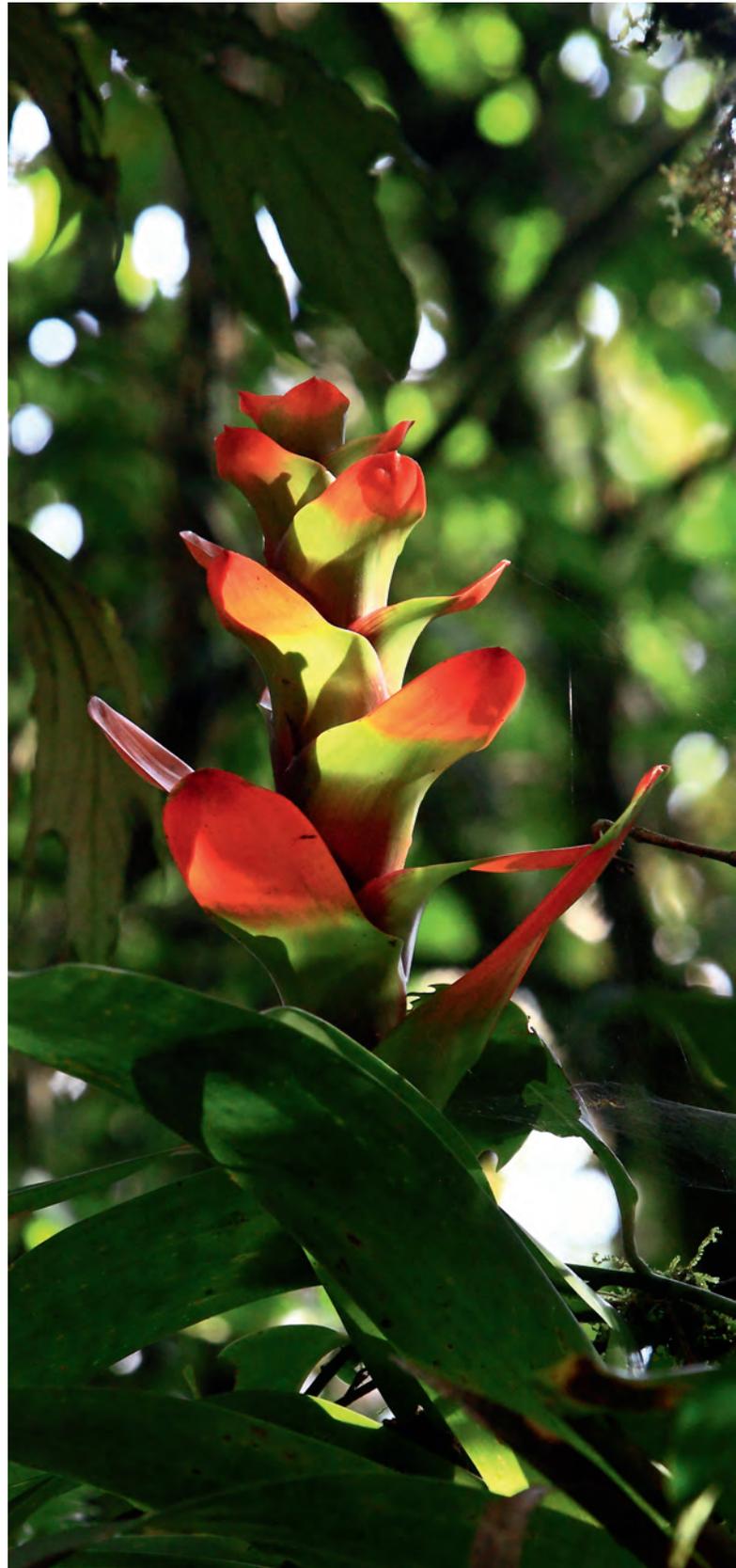
There are about 650 species of filmy ferns (Hymenophyllaceae) which grow in very damp places, often mistaken as liverworts. The fronds, apart from the central vein, are only a single cell thick, which makes it very susceptible to desiccation.



Hard ferns of the species-rich genus Blechnum are widespread on the southern hemisphere. Young leaves of this species produce red pigments as protection from high light intensities in sunflecks.



Because of their colorful bracts which support the rather inconspicuous flowers, the epiphytic bromeliads of the genus Guzmania are eye-catcher not only for human visitors but in



particular for humming birds which collect nectar from the cisterna-like bases of the bracts and thereby pollinate the flowers with their beak.



During the rainy season, the dry forest presents its foliage, resembling a broadleaf evergreen tropical forest. Most of the tree species flower before the rains start and therefore flowering trees can hardly be detected in the green canopy.

*A *Ceiba trichistandra* tree (Arbol de Ceibo) is a character species of the Tumbesian dry forest in the south of Ecuador. During the dry period it sheds its digitate leaves and the dense cover with epiphytes, mostly the lichen-like *Tillandsia usneoides* and *Tillandsia recurvate* and *Tillandsia latifolia* becomes apparent.*







*The evergreen mountain forest may sporadically gleams in different colors by reflection of sunbeams from dry or wet leaf surfaces, or from flowering of more frequent tree species like *Tabebuia chrysantha* (yellow), *Tibouchina laxa* (lilac), and *Piptocoma discolor* (white); flushing of new leaves (bright green or brownish) can also slightly change its color, but in general the forest maintains its green appearance all year round. In contrast, the Tumbesian dry forest has two completely different faces: Leafless, with only a few green spots from small evergreens in the dry and brown landscape, and completely bright green like an evergreen forest during the rainy season. Most of the tree species flower before the rains start and therefore flowering trees can hardly be detected in the green canopy.*

Next page:

(above) Until 2020 eighty percent of Ecuador's energy demand shall be supplied from renewable resources. While hydroelectricity is still the by far dominating source of energy, utilization of wind-power is in the upswing. First windfarms have been established in the South on the Guanaco close to Loja and on the Galapagos islands.

(below) Dramatic cloud scenes unfold when the moist easterly trade-winds and the dry westerlies from the Pacific are facing off in the Interandean basin. Moreover the strong tropical sun triggers the thermal rise of local air-masses which break through the cloud layers. Heavy downpours arise which are often accompanied by thunderstorms.







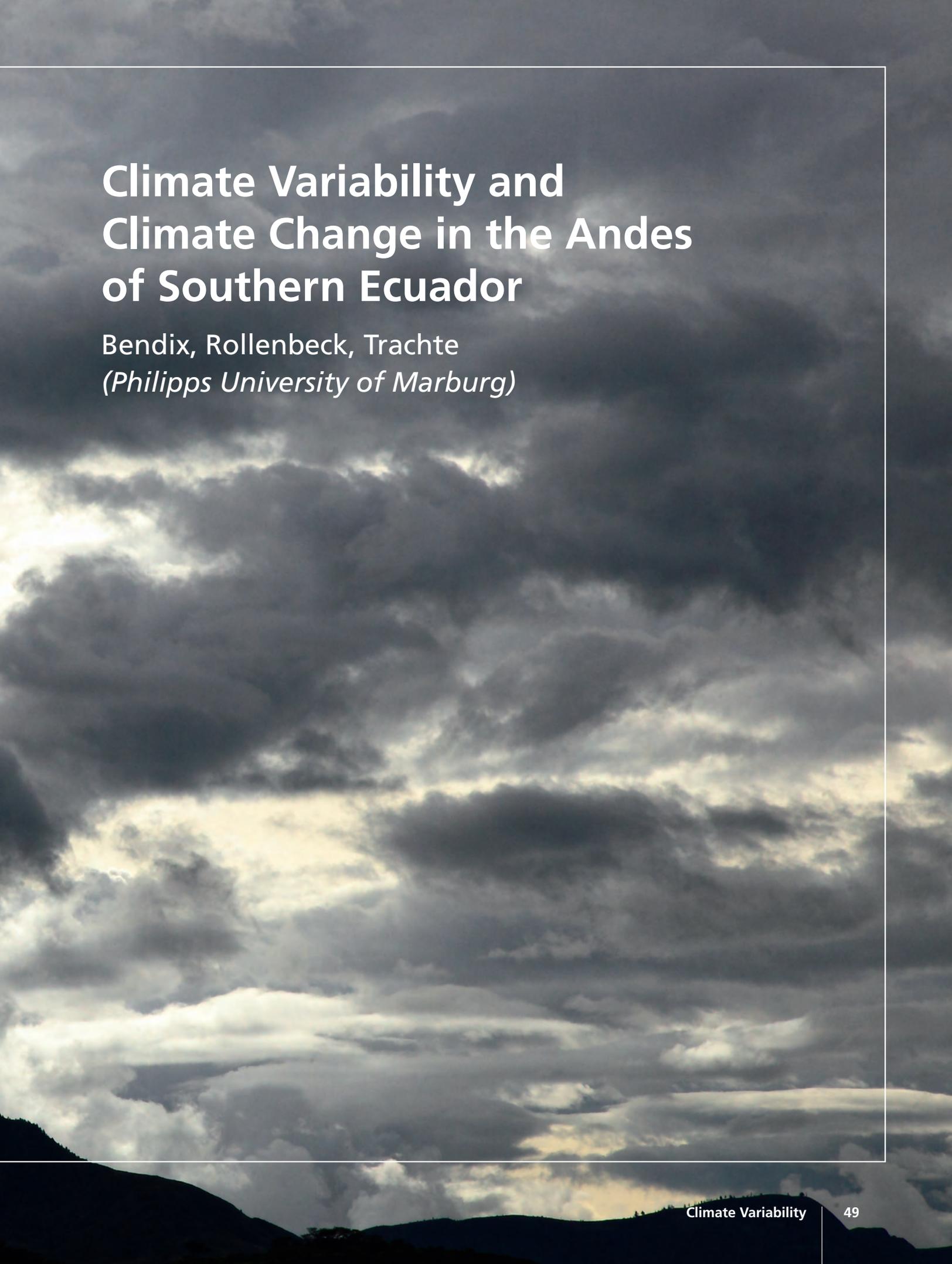
(top) Rapidly moving wafts of mist unveil changing fascinating sights of the variegated tropical mountain rain forest and the topographical fine structure of the terrain.

(right) The research station Estacion Científica San Francisco was inaugurated in October 1997 and later on expanded by a lab and a lecture wing. It is run by the foundation "Naturaleza y Cultura Internacional" located in Loja and San Diego (Calif.) and

can accommodate up to 32 researchers. Its position is central to the Province Capitals Loja and Zamora. The natural forest of the Reserva Biológica San Francisco on the southern slopes of the San Francisco valley can be easily reached with a hand-driven ropeway over the eponymous river while the various man-made ecosystems on the northern slopes are in walking distance. The Estacion can be reached by car via the state road that connects Loja with Zamora.







Climate Variability and Climate Change in the Andes of Southern Ecuador

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1. The basis

The Andean climate is generally characterized by high cloudiness and rainfall (Photo 1) which, however, might be altered in future by global climate change. To assess potential climate change impacts in the complex terrain of the south-Ecuadorian Andes, we first must understand the dominating processes which are related to weather and climate variability in space and time.

Seasonal variations of the global atmospheric circulation are leading every year to higher and lower rainfall in different months due to the influence of the global circulation (Fig. 1). Main elements affecting the Andes of S-Ecuador are (i) the predominant easterly airstream mainly impinging the eastern slopes of the Andes, (ii) the South Pacific Anticyclone (H; SPA) with major impacts on the weather at the western Andean slopes and (iii) the annual course of the sun which provides more solar irradiance two times a year (equinox) around March and September. The latter is responsible for the specific rainfall type in the inter-Andean basins (example Loja) where higher solar radiation during the equinox means more evaporation at ground, enhanced atmospheric moisture, stronger convection of warm air and consequently, with a short delay, more cloudiness and rainfall. The enhanced atmospheric instability during and shortly after equinox times goes along with the passage of the so called Inter-Tropical Convergence Zone (ITCZ). This pattern would generally hold for the western slopes, but in southern Ecuador, the well established SPA in austral spring (SON) leads to descending air movement and thus, to the suppression of rainfall where only one rainy season around March remains (type Laipuna). Because air is ascending over the mountains during ITCZ passage, it must descend in the same order over other regions to maintain the air mass balance of the atmosphere. This is the case at the eastern slopes, so that March and September rainfall is slightly suppressed, lea-

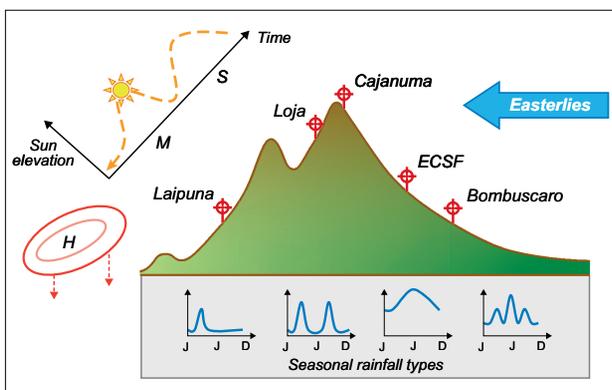


Figure 1: Major elements of the global atmospheric circulation and the extraterrestrial forcing influencing seasonal rainfall types along a transect from the Pacific coast to the eastern Andean slopes of S-Ecuador (Graphics: J. Bendix, simplified after Bendix & Lauer 1992)



Figure 2: The Andean mountain rainforest is frequently wrapped in clouds and rain (left). Due to the remoteness of the area, official long-term meteorological measurements are hardly available and a major challenge in the steep topography.

ding to peak rainfalls in JJA (seasonal type ECSF). However, the continuous easterly streamflow in the lower and mid troposphere produces strong forced uplift of air and comparably high rainfall totals during all months, partly overcoming the tendency of descending air mentioned before. Towards the foothills, a mixture of the highland and the eastern slope types occur. It should be stressed that an increase in rainfall mostly is accompanied by a drop of air temperature due to clouds shielding the incident solar radiation.

(Sub-) Decadal variations in temperature and rainfall are mainly introduced to S-Ecuador by the quasi-periodic ENSO (El Niño – Southern Oscillation) phenomenon (Bendix et al. 2011), which can modify the establishment of the normal rainy seasons as presented in figure 1 towards more extreme dry or wet conditions, mostly recurring in 3 to 11 year intervals. Unfortunately, the seasonal forecast of ENSO is not yet possible which consequently holds also for projections on the future development of this governing atmospheric pattern.

Topography-induced variations in local climate has to be considered as well. This is demonstrated by inspecting the rainfall map in figure 3. Generally, high rainfall is observed at the eastern slopes where moist Amazon air is impinging the mountains while precipitation is clearly decreased west of the main cordillera. However, the patchy structure of rainfall at the eastern Andean slopes shows that atmospheric water input to the ecosystem is exceptionally enhanced at the eastern slopes of mountain ridges promoting local forced updraft of the easterlies while the leeward valleys shielded by these ridges from the moist easterlies generally show reduced rainfall patterns e.g. due to descending air movement by lee waves. On a still smaller scale in the valleys, rainfall is thermally enhanced in the early afternoon by the upslope breeze system while at the same time is decreased over the valley axis due to the descending counter-

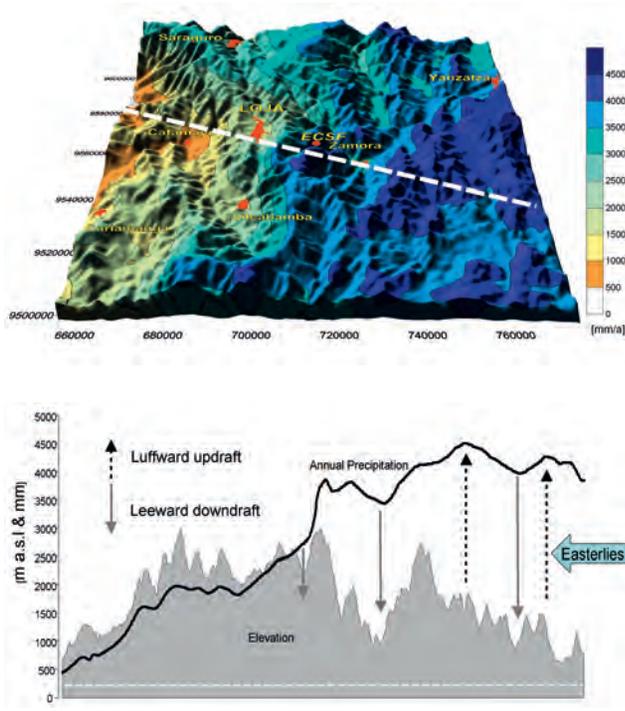


Figure 3a: Annual rainfall map derived from the rain radar at Cerro del Consuelo and profile line indicating the influence of topography and topographic sheltering effects in local rainfall (Graphics: R. Rollenbeck, adapted from data presented in Rollenbeck and Bendix 2011). The dashed white line marks the extracted profile (elevation and rainfall) from the top map which is displayed in the diagram at the bottom of figure 4.



Figure 3b: Flooding during El Niño in the coastal plains close to Guayaquil in March 2008. The main rainy season in March at the coast and the western slopes is extended and increased during El Niño events where monthly totals or precipitation in South-Ecuador partly reach more than 300% of the normal monthly rainfall.

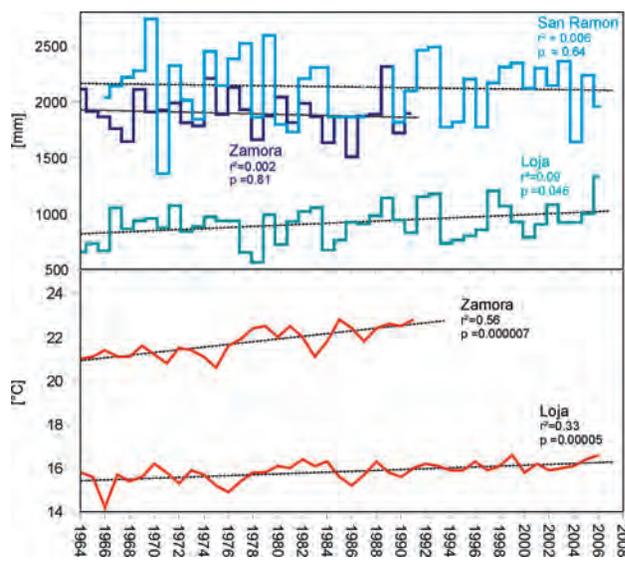


Figure 4: Time series of monthly means of 2 m air temperature (bottom) and rainfall (top) for the stations Loja – La Argelia and Zamora as well as Planta Electrica San Ramon (Graphics: J. Bendix after Peters et al. 2013)

current. And more complex, nocturnal cold air drainage flow from the eastern slopes protruding into the moist Amazon air leads to convection at the Amazon foothills, producing convective clouds which are transported by the easterlies back to the Andes, there leading to exceptional nocturnal rainfall.

2. Recent variability and trends

Observed trends in temperature and rainfall over the last decades show a significant warming for Loja (+0.6°C in total or 0.13°C per decade) and Zamora, concomitant with Global Warming, while no clear trend is observed for rainfall (Fig. 4). There is only a tendency for a slight decrease east of the main Cordillera (Zamora, San Ramon) facing a slight increase west of the main cordillera (Loja). However, clearly visible is the high year-to-year variability in precipitation significantly exceeding the weak trend, which is mostly related to complex ENSO dynamics. Tendency towards more extreme weather are predicted by the Intergovernmental Panel on Climate Change (IPCC). Figure 5 clearly shows that there is a change of rain rates over the last decades in Loja. Compared to 1964-1984, the frequency of days with very light rains (up to 2mm per day) and of stronger precipitation (> 12 mm per day) have clearly increased over the last decades, which means a tendency towards more extreme rainfall events. However, the frequency of heavy rainstorms (>30 mm per day) has not yet changed.

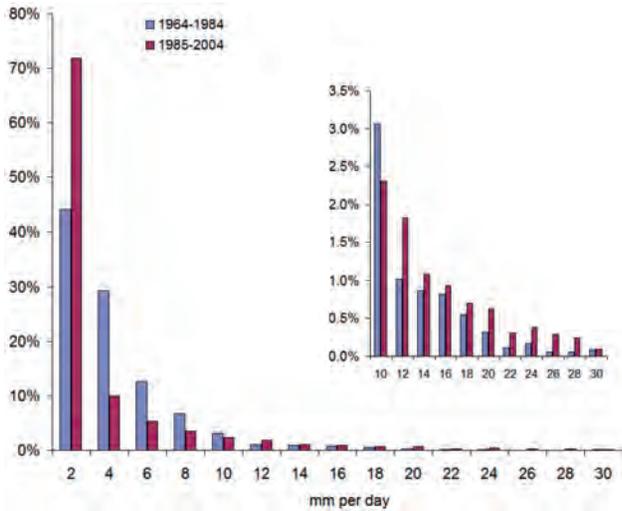
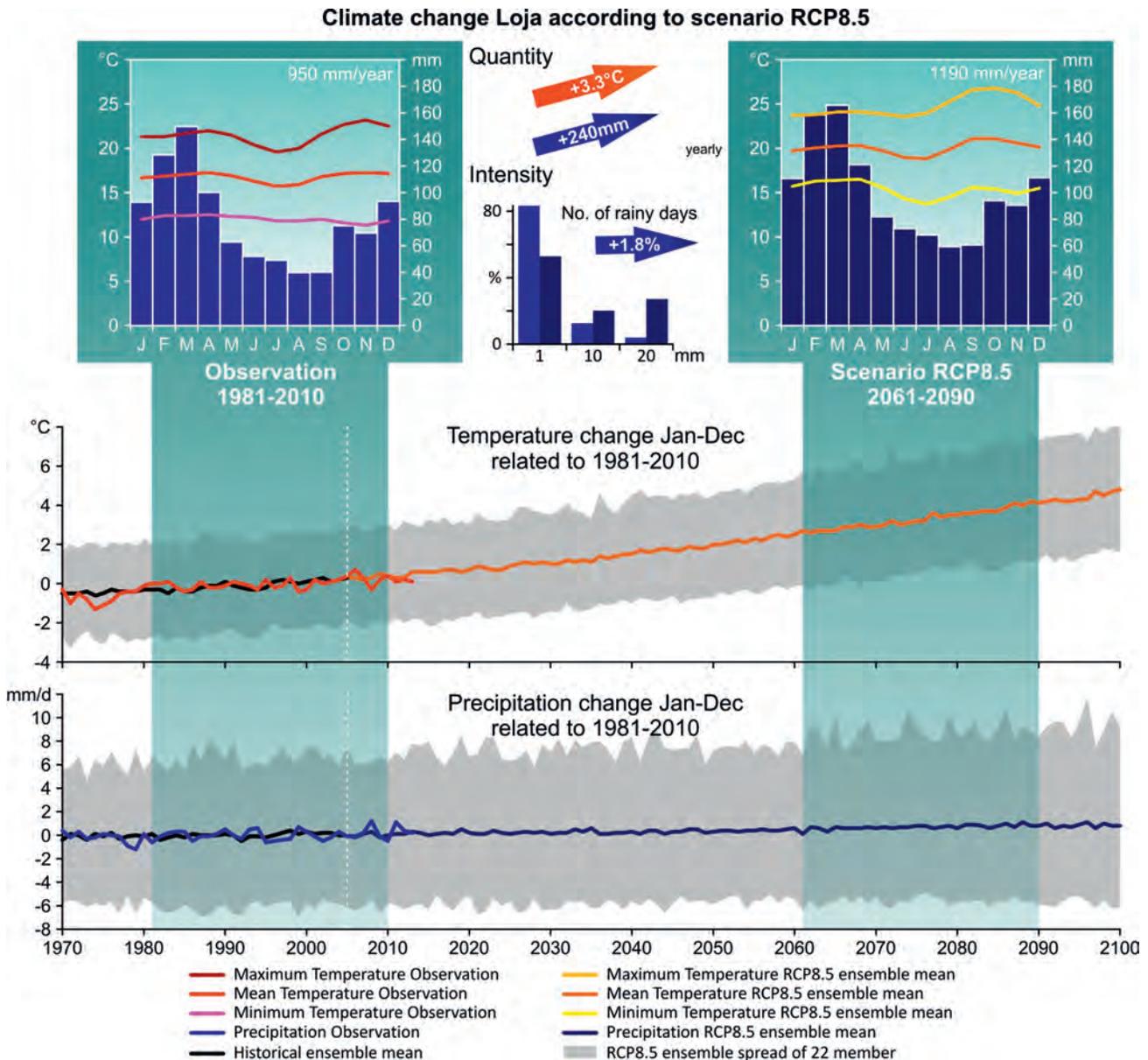


Figure 5 (left): Changes of relative frequency of daily rainfall at Loja (inset diagram enlarges the frequencies of stronger rainfall >10 mm / day) (Graphics: J. Bendix)

Figure 6 (bottom): Annual temperature and precipitation changes related to 1981-2010 reference period for the provincial capital Loja according to scenario RCP8.5. An ensemble of 22 different models* (grey shaded) was used to calculate the ensemble mean representing the annual variations (orange line for temperature and dark blue line for precipitation). The historical conditions, i.e. simulations based on observational data, are highlighted in black (1970 to 2005). The observational time series of the measurement station Loja are overlaid from 1970 to 2014 (red line temperature and blue line precipitation). Comparisons of observational temperature and precipitation conditions are presented by means of climate diagrams over a climate normal period of 30 years. (Graphics: K. Trachte)



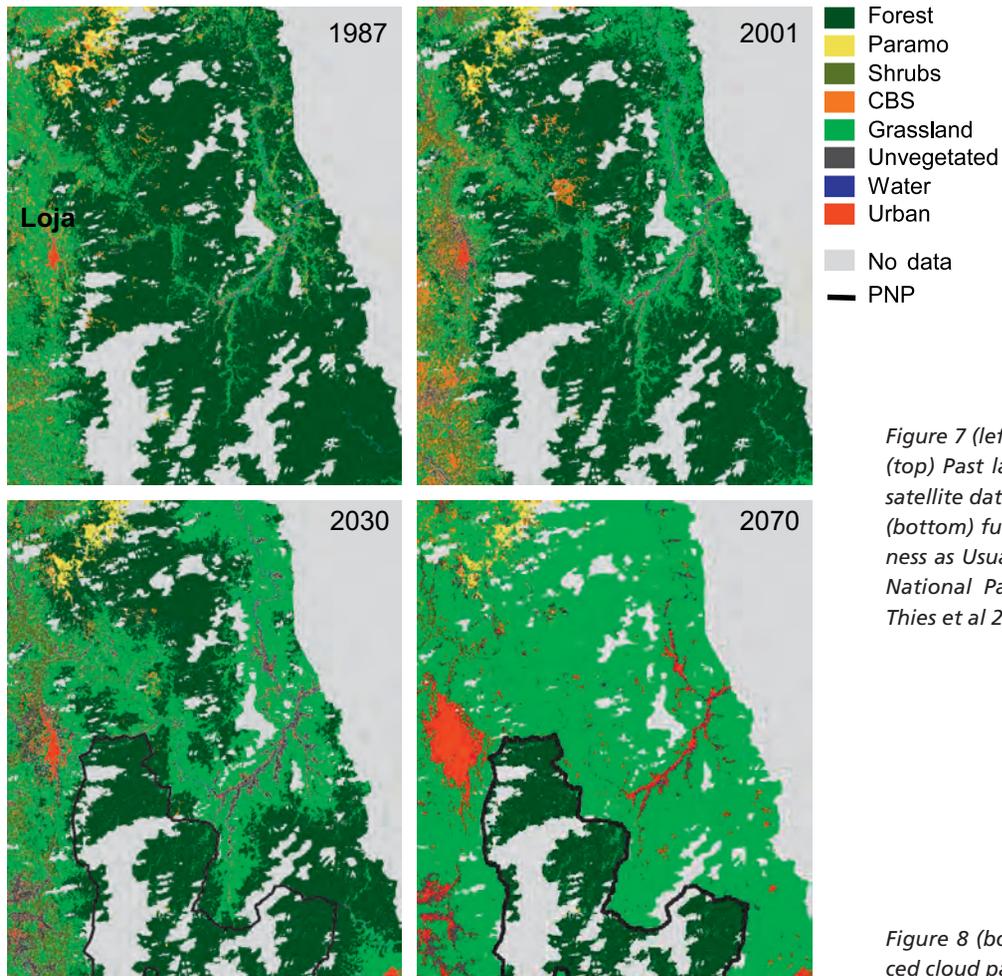


Figure 7 (left):
 (top) Past land use change derived from satellite data and
 (bottom) future change regarding a Business as Usual scenario. PNP = Podocarpus National Park (Graphics: Adapted from Thies et al 2014)

Figure 8 (bottom): Topographically induced cloud patterns in Loja



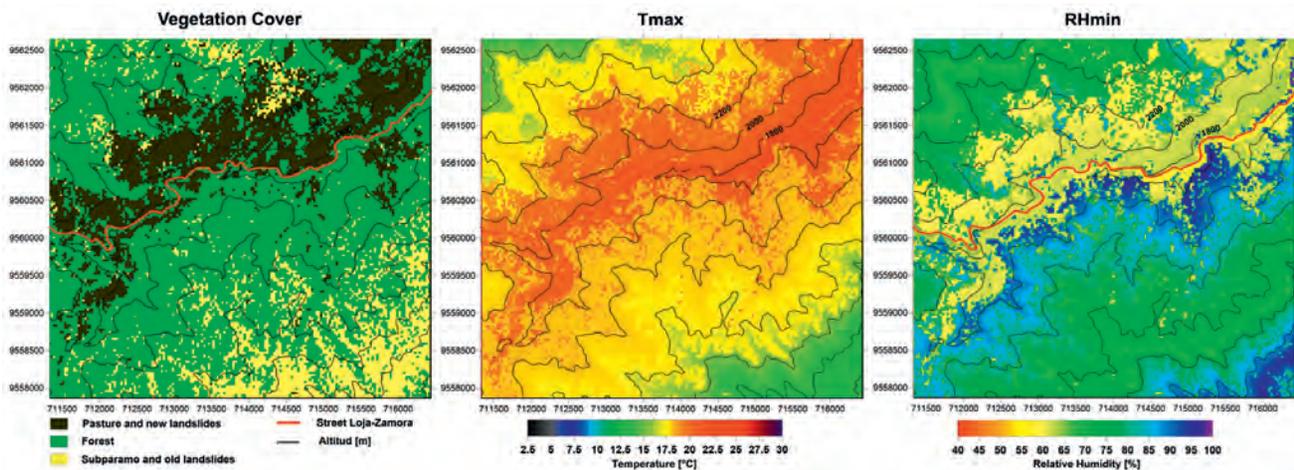


Figure 9: Average maximum temperature (TMax) and minimum relative humidity in the San Francisco Valley around the ECSF Park at 2 m above ground.

For the forest this means the situation inside the forest below the canopy (Graphics: Adapted from Fries et al. 2009, 2011)

3. The future

Future climate change can be assessed with climate modelling using model ensembles and emission scenarios (see Glossary Climate modelling). Figure 5 reveals the changes which can be expected for Loja applying the most likely emission scenario (RCP8.5). The comparison of 30 year means of rainfall and temperature of the \approx periods 2061-2090 in comparison to the recent climate conditions indicate a warming of 3.3°C till the end of the century. The rain intensities show that only an increase of 1.8% of the number of rainy days is expected. But a clear shift to more extreme rain events is revealed mostly leading to the overall increase in rain amount of 240 mm per year.

4. Interactions of Climate and Land Use Changes

Interactions land use and climate change: Land use change is a major issue in the Andes of Ecuador. Change detection by using satellite images shows an ongoing urban sprawl of the city of Loja and particularly a conversion of natural forest to grassland (Fig. 6 top). A business as usual scenario driven modelling of future land use change reveals that the complete forest might have disappeared until the year 2070 outside the protected area of the Podocarpus National Park (Fig.6, bottom). The forest loss has major impacts on the climate regulation function of the mountain forest ecosystem. By cutting the forest, the sheltering effect of the canopy is removed which is critical for climate-dependent organisms as e.g. epiphytes. Figure 7 clearly shows that temperature maxima and humidity minima are significantly exacerbated on the pasture in comparison to the forest.

References

- Bendix J, Lauer W (1992) Die Niederschlagsjahreszeiten in Ecuador und ihre klimadynamische Interpretation. *Erdkunde* 46: 118-134
- Bendix J, Trachte K, Palacios E, Rollenbeck R, Göttlicher D, Nauss T, Bendix A (2011) El Niño meets La Niña – anomalous rainfall patterns in the „traditional“ El Niño region of southern Ecuador. *Erdkunde* 65: 151-167
- Fries A, Rollenbeck R, Göttlicher D, Nauss T, Homeier J, Peters T, Bendix J (2009) Thermal structure of a megadiverse Andean mountain ecosystem in southern Ecuador, and its regionalization. *Erdkunde* 63: 321-335
- Fries A, Rollenbeck R, Nauss T, Peters T, Bendix J (2012) Near surface air humidity in a megadiverse Andean mountain ecosystem of southern Ecuador and its regionalization. *Agric Forest Meteorol* 152: 17-30
- Peters T, Drobnik T, Meyer H, Rankl M, Richter M, Rollenbeck R, Thies B, Bendix J (2013) Environmental changes affecting the Andes of Ecuador. *Ecol Stud* 221: 19-30
- Rollenbeck R, Bendix J (2011) Rainfall distribution in the Andes of southern Ecuador derived from blending weather radar data and meteorological field observations. *Atmosph Res* 99: 277-289
- Thies B, Meyer H, Nauss T, Bendix J (2014) Projecting land use and land cover changes in a tropical mountain forest of southern Ecuador. *J Land Use Sci* 9: 1-3



Glossary climate modelling:

Ensemble: Number of multiple realizations of possible future climate changes using different model systems. The aim is to assess and reduce the uncertainties in the climate change projections, which occurs due to the imperfection of each model.

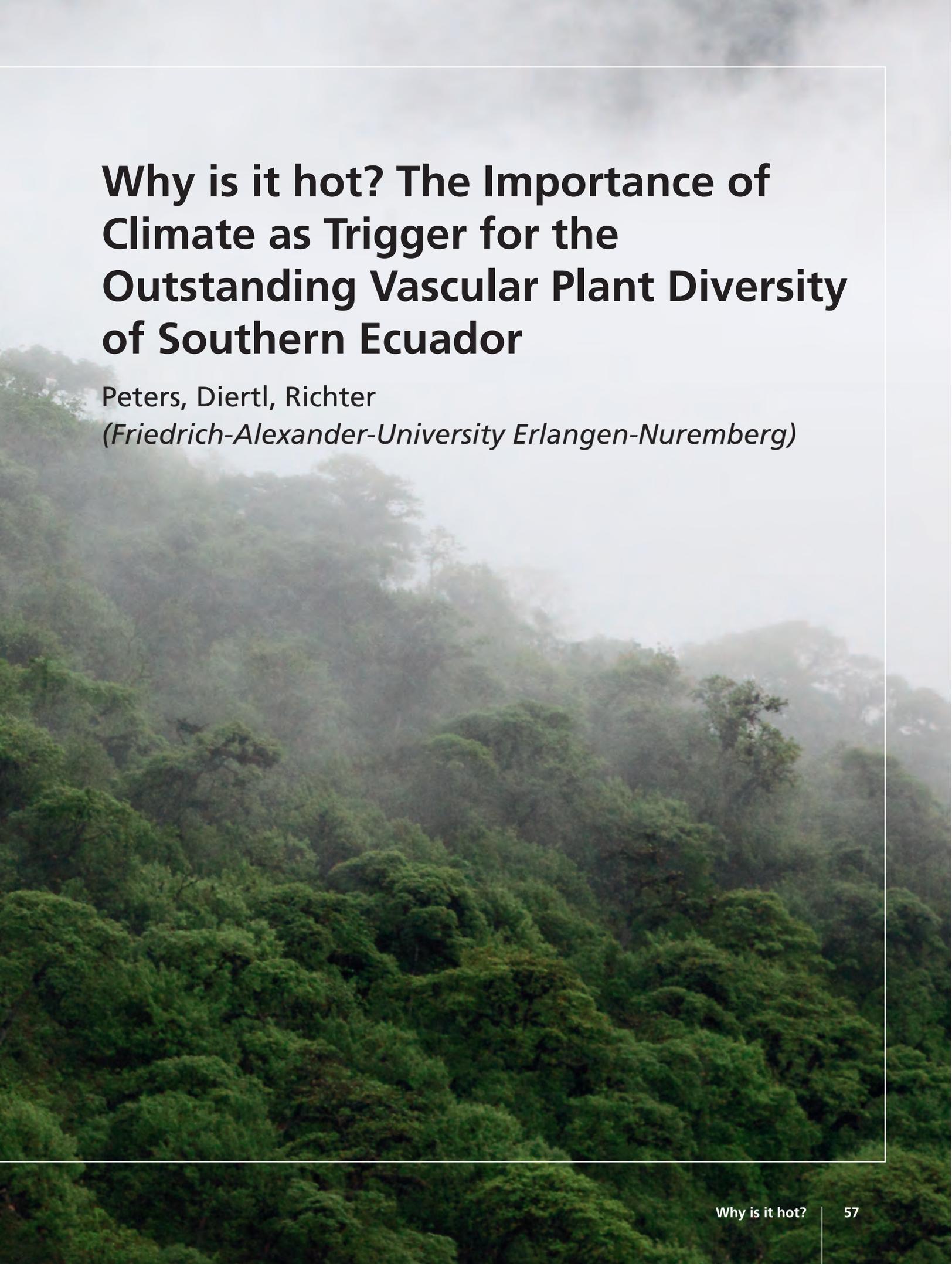
Climate scenario: Plausible and simple description of future climate that have been created to assess the potential future impact of anthropogenic climate change only.

RCP: Representative Concentration Pathways scenarios (RCP2.6, RCP4.5, RCP6.0, RCP8.5) of the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 5. The RCP8.5 scenario describes an increasing radiative forcing of 8.5 Watt/m² until the end of the current century. Primary energy consumption by mankind is considered three times higher than today. Carbon dioxide (CO₂) emissions are expected to increase from currently 10gt/year to almost 30gt/year at the end of the century. According to this scenario, a global warming of 4.4°C is expected.

Figure 10: The two faces of the valley of the Rio San Francisco in the Cordillera oriental of South Ecuador. The orographically right side is covered by the tropical mountain rain forest which is very dense in the ravines but more open on the crests where it is dominated by palms. A high number of natural landslides are typical of that vegetation type, especially on the steeper slopes. The area which culminates in the "Pico de Antennas" (3200 m, in the center) is part of the Podocarpus National Park where any kind of human action is prohibited.

*The opposite side of the valley, shows man-made replacement ecosystems of the natural forest which has been and still is cleared for pastoral agriculture and forestry. However the management of the artificial ecosystems is not sustainable. Active pastures show a bright green color but on the steeper slopes invasion by weeds, in particular by the bracken fern is visible (brownish color). The upper parts are completely overgrown by bracken and by weedy shrubs and have been abandoned as pastures. On the left part, the exotic *Pinus patula* has been used for reforestation which thrives well for about 20 years when it is harvested (see also contributions on pages 123 and 135).*





Why is it hot? The Importance of Climate as Trigger for the Outstanding Vascular Plant Diversity of Southern Ecuador

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Up to the present more than 1.7 million species of organisms have been described scientifically, while estimations of the total numbers of all plants, animals and microorganism are much higher varying between 5 and 30 million. With respect to vascular plants approx. 300,000 terrestrial species may exist globally (Barthlott et al. 2007). However, diversity of vascular plants is unequally distributed over the globe and there is a strong latitudinal decrease of species richness from the equator to the poles. In this context the Andes-Amazonia center must be highlighted as one of the five hottest hotspots of vascular plant diversity worldwide (Figure 1). All hotspots are located in tropical geodiverse habitats with a great variation of environmental conditions along steep gradients of topography and climate. This holds in particular for the Ecuadorian hotspot where a complex relief, steep altitudinal temperature gradients and xeric to hygric climate regimes have given rise to a multiplicity of vegetation types (Figure 2). Here, the Andes constitute an effective and discrete phytogeographic transition as well as a barrier zone between the Tumbes-Chocó-Magdalena hotspot in the west and the Amazonian lowlands in the east. All in all, the tropical Andes biodiversity hotspot harbors about a sixth of the planet's terrestrial plant life in less than one percent of the world's land area and approximately half of the estimated 20,000 Ecuadorian vascular plant species are found between 900 and 3000 m a.s.l. This could be exemplified

by our own syntaxonomical studies of the primary mountain forest ecosystem of the Reserva Biológica San Francisco (RBSF). Here, the primary mountain rainforest was investigated in altitudinal steps of 100 m vertical distance between 1950 m and 3150 m a.s.l., each step consisting of four horizontal transects (of 2 × 50 m). Epiphytes, hemi-epiphytes, lichens and mosses were not sampled, but within the 48 transects (e.g. a total area of only 4800 m²!) more than 1000 terrestrial vascular plant species (incl. 152 morpho-species) of 111 different plant families were identified. Families of highest species diversity are Asteraceae (71 species) and Melastomataceae (66 species) which are widely distributed at each altitudinal level. Species of the Araceae, Lauraceae, Rubiaceae and Piperaceae are mostly restricted to areas below 2600 m a.s.l. while those of the Symplocaceae, Ericaceae and Aquifoliaceae prefer higher altitudes. Among plant life-forms trees, shrubs and herbs are represented by similar species numbers at the bottom of the gradient (Figure 3). At higher altitudes tree species numbers decrease and shrubs and herbs prevail. A local minimum of shrub and herb species was found at approximately 2750 m a.s.l. where the local upper treeline ecotone is located. As calculated by the Jackknife 2 estimator approximately 50 % of the absolute species numbers of the area may have been encountered by the applied mode of investigation. Using a scale dependent approach, Richter et al. (2009) compiled the reasons for this high plant diversity

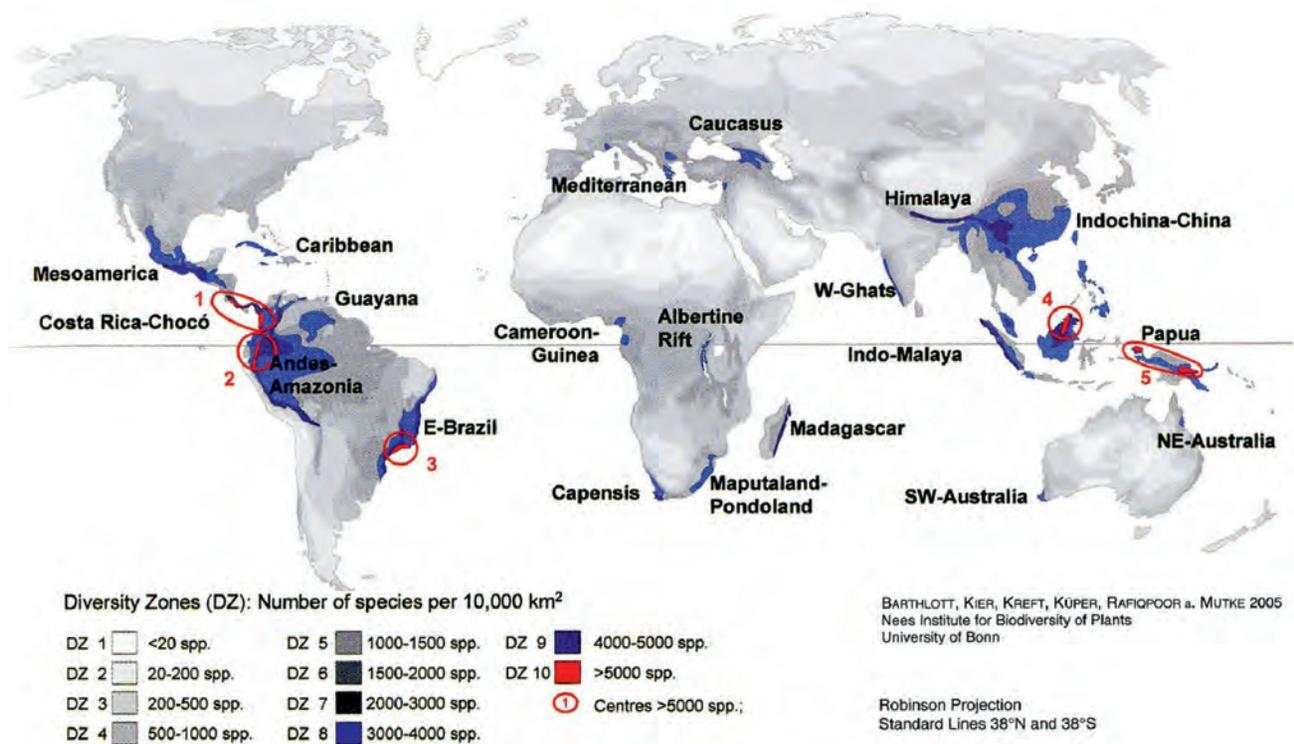


Figure 1. Global map of vascular plant species richness. The research area (RBSF) is situated within one of the five world's megadiversity hotspots (#2). The Costa Rica-Chocó area, south-eastern Brazil, northern Borneo and the New Guinea mountain range represent the other hotspots. Source: Barthlott et al. (2007)

(Figure 4). On a global scale, high species numbers are explained by the so-called "Rapoport's Rule", encompassing the effective evolutionary time in the tropics since mid-Tertiary and the exceptionally high precipitation. The latter causes nutrient leaching and triggers competition of plants for the few soil nutrients. As a result, fast growing competitors cannot take advantage of their competitive strength and thus are not able to outcompete others, allowing many species to co-exist in a non-equilibrium state. On the regional scale, the northern Andes form an important interface between the Tumbes-Chocó-Magdalena hotspot in the west and the Amazonian lowlands in the east. Here, the uplift of the

mountain chain during Pliocene triggered an extensive evolutionary radiation of the dominating Gondwana elements. Furthermore, the closure of sea gates between Northern and Southern America facilitated the subcontinental species exchange via the gateway of the Central American land bridge. On the local scale, heterogeneous and harsh climatic conditions strongly give rise to a highly diverse pattern of vascular plant species. For most time of the year the eastern Cordillera Real is exposed to strong easterly winds which are carrying large amounts of moisture from the Atlantic Ocean over the Amazon lowlands towards the Andes of Ecuador. While those easterlies are leading to steady and very high rain-

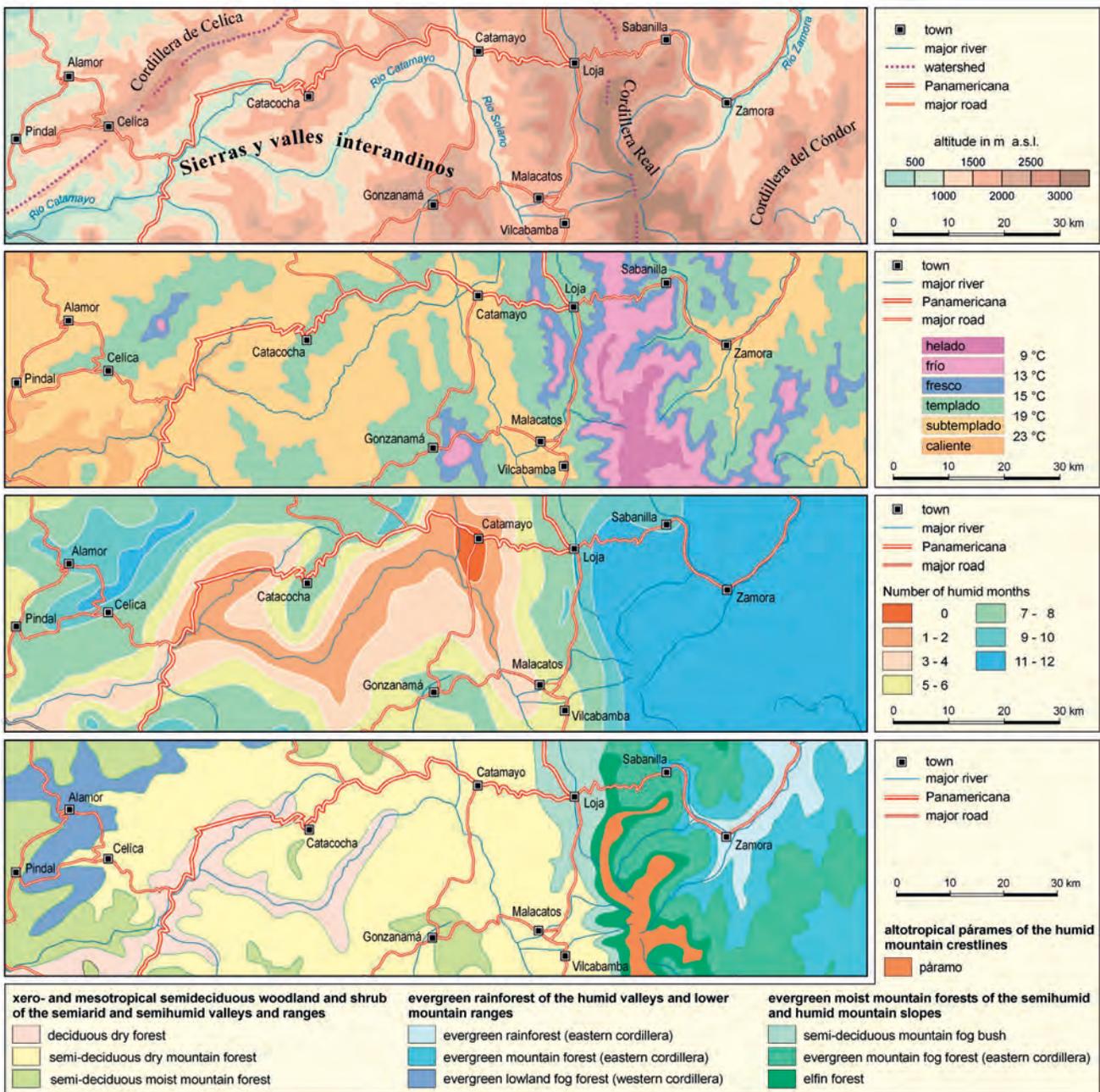


Figure 2. Topography, climate and vegetation types of Southern Ecuador. Richter et al. (2009)

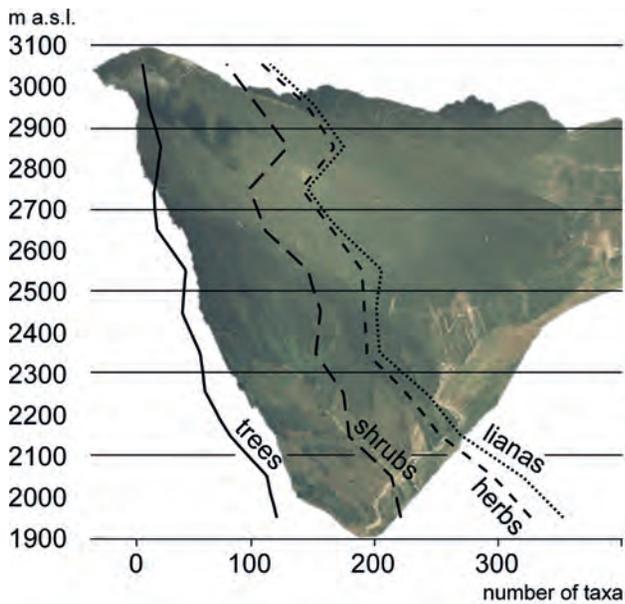


Figure 3. Cumulative taxa numbers per altitude and plant life-form within the RBSF area. The primary mountain rainforest ecosystem was investigated in regular altitudinal steps of 100 m vertical distance with four transects (a 2x50m) at each altitude.

fall amounts (>6000 mm/a) on upper parts of the eastern escarpment of the mountain chain, foehn effects and increasing influences of westerly winds cause a different precipitation regime of only one rainy season and a long lasting dry season on the western escarpment (Figure 5). In spite of extremely high precipitation amounts in the Cordillera Real, the same localities on top of the mountains are exposed temporarily to extremely high global irradiance values (up to 1,832 W/m², Emck & Richter 2008). Since exclusively radiative effects of clouds have been singled out as source of the "super-irradiations", UV radiation with its mutagenic potential might reach record levels as well. In the Cordillera Real, representatives of some plant families stick out by conspicuous reddish or purple colors of their young vegetative organs resulting from an accumulation of anthocyanins in the epidermis or carotenoids in the developing chloroplasts for protection of the young cells from photo damage. Among plant families whose members are strongly affected by UV radiation Clusiaceae, and Ericaceae as well as Blechnaceae and Huperziaceae are extraordinarily rich in species, suggesting high rates of speciation at the higher altitudes in this region. Thus longitudinal as well as altitudinal climate gradients contribute to the high plant diversity of the area. Best examples could be given from the narrow altitudinal belts of the eastern elfin forests and the

following shrub páramos (or "yalca", see also Figure 3 and 6). Here, stress factors such as quasi-permanent trade winds, high amounts of annual precipitation and extraordinary intensities of solar irradiation are favouring an outstanding complexity of plant communities concomitant with a likewise high phytodiversity.

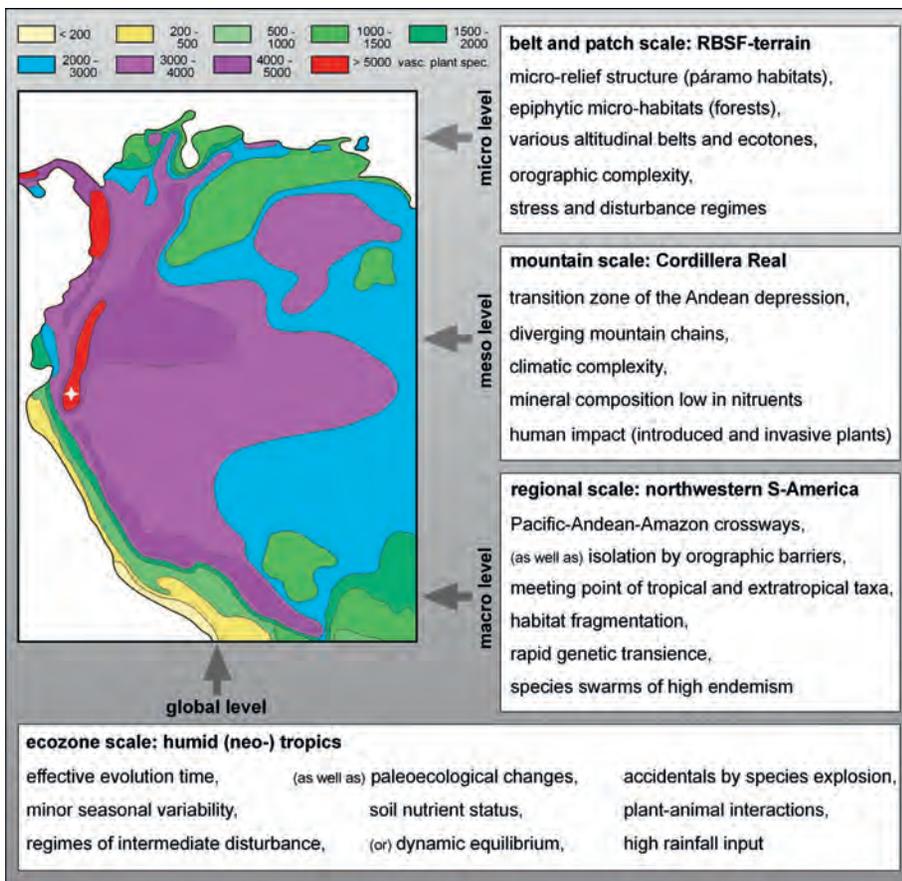


Figure 4. Scale dependent factors contributing to plant diversity in the study area in southern Ecuador. The four levels from global to microscale are expressed by boxes (Richter et al. 2009). The plant diversity map on the left is based on a section of the world map by Barthlott et al. (2007)

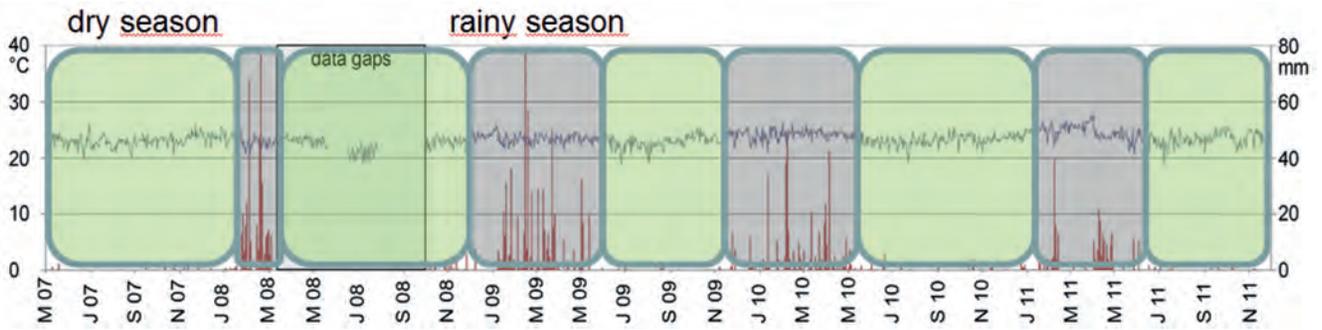


Figure 5. Temperature and precipitation regimes at the seasonally dry forest area „Laipuna“ on the south-western escarpment of the Ecuadorian Andes

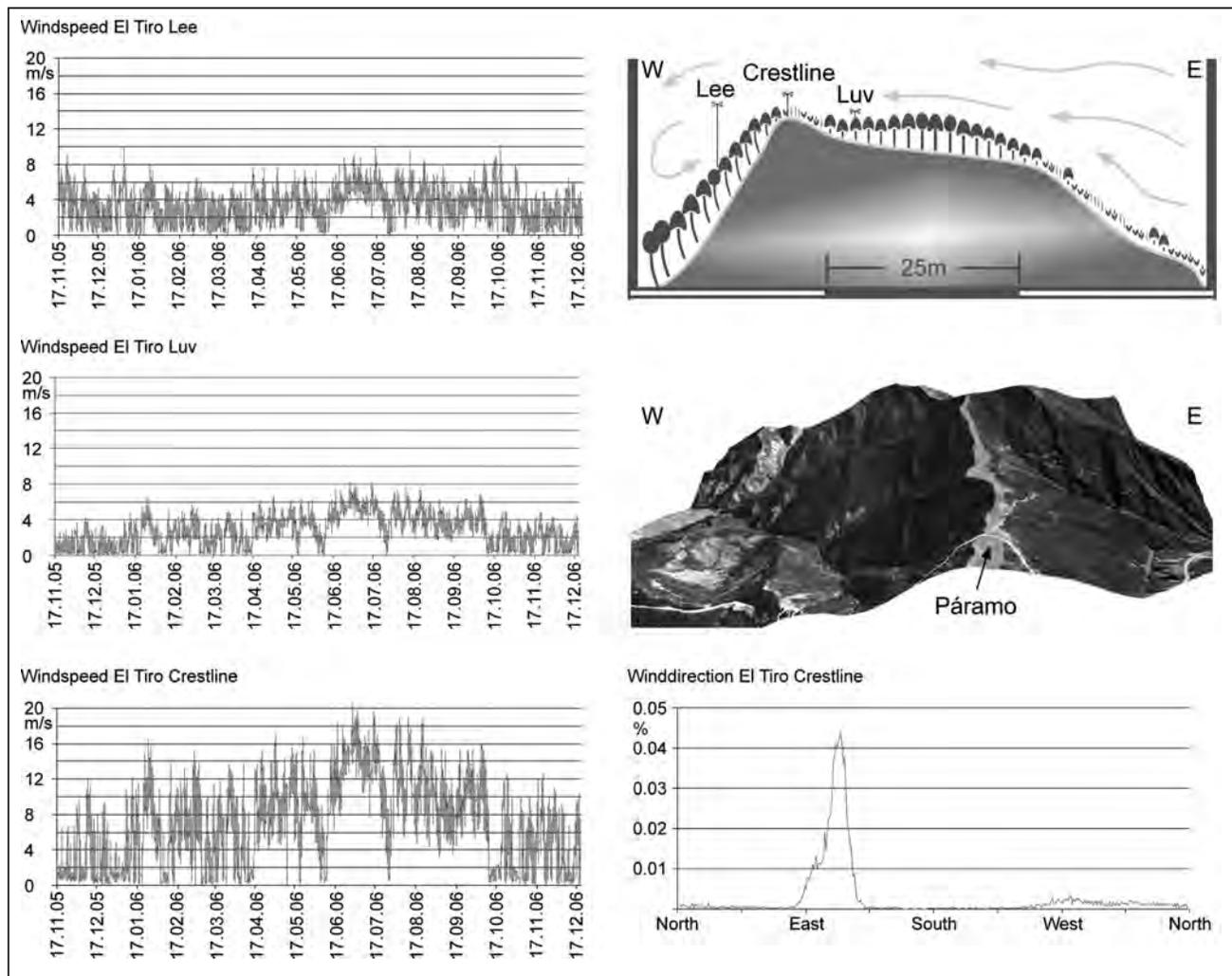


Figure 6. Wind regime and forest structure at the upper timberline ecotone close to the pass El Tiro (2800m a.s.l.)

References

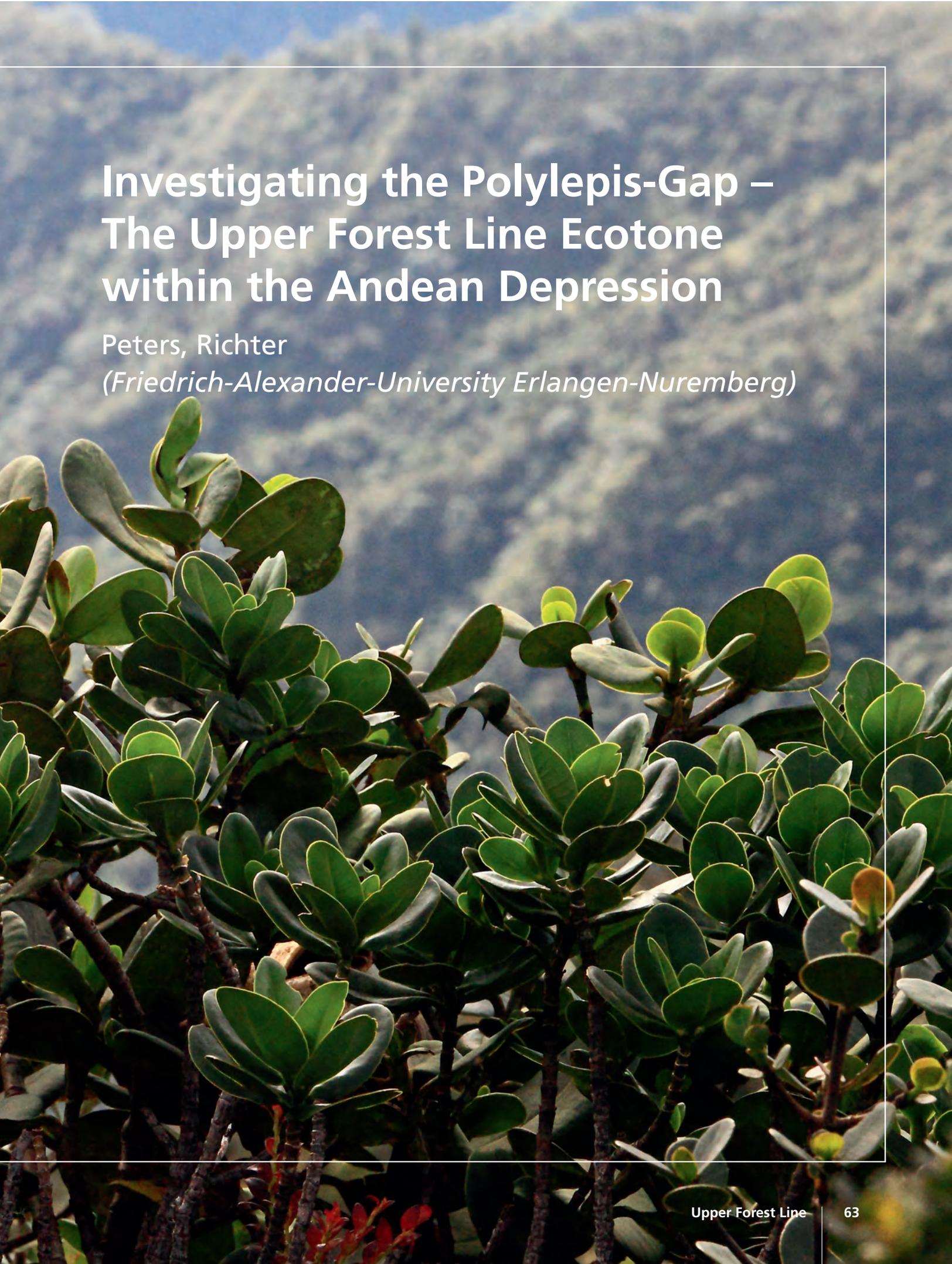
Barthlott W, Hostert A, Kier G, Küper W, Kreft H, Mutke J, Rafiqpoor D, Sommer JH (2007) Geographic patterns of vascular plant diversity at continental to global scales. *Erdkunde* 61: 305-315

Richter M, Diertl KH, Emck P, Peters T, Beck E (2009) Reasons for an outstanding plant diversity in the tropical Andes of Southern Ecuador. *Landscape Online* 12: 1-35

Emck P, Richter M (2008) An Upper Threshold of Enhanced Global Shortwave Irradiance in the Troposphere Derived from Field Measurements in Tropical Mountains. *J. Appl. Meteor. Climatol.* 47, 2828–2845

Peters, T., Diertl, K.H., Gawlik, J., Rankl, M., Richter, M.: Vascular plant diversity in natural and anthropogenic ecosystems in the Andes of Southern Ecuador. In: *Mountain Research and Development*





Investigating the Polylepis-Gap – The Upper Forest Line Ecotone within the Andean Depression

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Systematic investigations of the upper forest line (UFL) mainly concentrate on mid- and high-latitudes of the Northern hemisphere whereas studies of tropical UFLs are still fragmentary. In the north-south stretching tropical Andes, the factors that determine its altitudinal position are not well understood and little information is available about tree diversity and species distribution at the UFL. *Polylepis* sometimes associated with *Gynoxis* is the most important indicator tree genus of the higher situated UFLs of the Andean Cordilleras. This is best demonstrated by comparing two UFL sites in Northern Ecuador (Páramo de Papallacta) and Central Peru (Cordillera Blanca). At Papallacta, the UFL is situated between 3.700 m and 4.700 m a.s.l. *Polylepis pauta*, *P. incana*, *Gynoxis buxifolia*, *G. acostea* and *Escallonia myrtilloides* are the prevailing tree species (Lauer et al., 2003). South of the Andean Depression, the UFL of the Cordillera Blanca is located at almost the same altitude between 3.800 m to 4.550 m a.s.l. Here, *Polylepis weberbaueri*, *P. sericea*, *Gynoxis caracensis* and *Buddleja usush* are dominant (Figure 7). Between those higher situated UFLs a less well known lower timberline is situated inside the Andean Depression (Figure 1) between 3°S and 7°S. Here, monotypic forest patches dominated by *Polylepis* were only found at El Cajas, Fierro Urco, Huancabamba,

Barro Negro, and Llanganuco, all located at the margins of the Andean Depression. In contrast, the lower situated UFL inside the Andean Depression is characterized by a species-rich forest, which lacks the elsewhere dominant UFL genus *Polylepis*. On a global scale several studies show that temperature is the most important natural factor for limiting tree growth at the UFL. On a local scale, further climate elements (e.g. wind, precipitation, soil moisture) and environmental factors such as the relief, various types of slope induced processes and the occurrence of fires affect the position of the natural UFL as well. Within the Andean Depression temperature cannot be considered a cause for the above mentioned lowering of the local timberline ecotone. The analysis of climate data shows that soil as well as air temperatures at the center of the study area are clearly above 5.5° C, i.e. the postulated global threshold value for tree growth within the tropics (Körner 2007). This conclusion is also corroborated by the altitudinal distribution ranges of the investigated tree species. Many tree species have previously been recorded at higher elevations elsewhere in Ecuador and Peru (Figure 2), indicating that their upper altitudinal distribution limit within the Andean Depression is not driven by low temperature. Instead, quasi-permanent strong trade winds, high amounts of

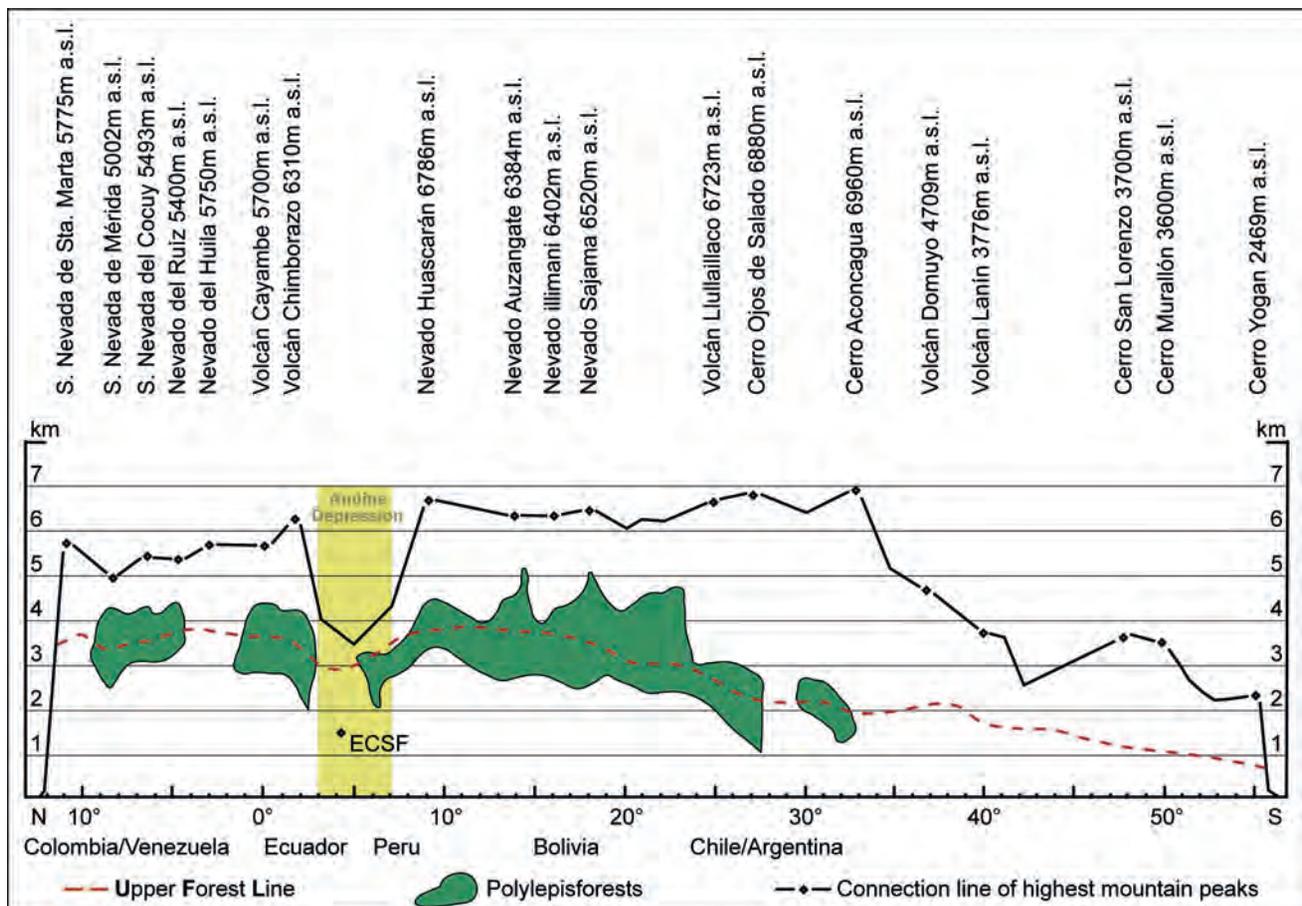


Figure 1. The altitudinal distribution of the genus *Polylepis* along the Andes (see also Figure 7). (changed after Baumann)

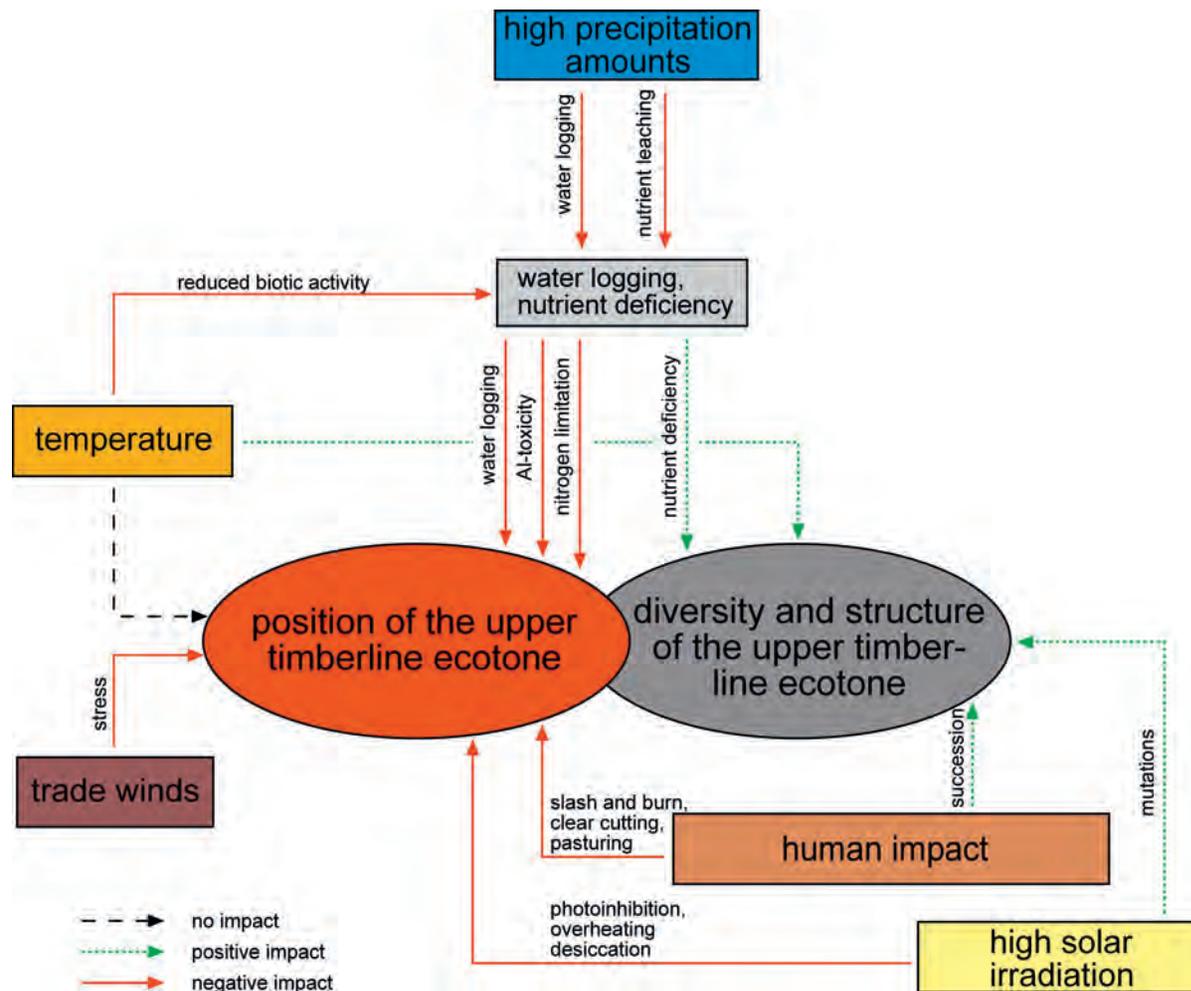


Figure 2. Impacts of selected ecological factors on the position, structure and diversity of the upper timberline ecotone of the Andean Depression

annual precipitation and extraordinary intensities of solar irradiation could be responsible for the depression of the local timberline ecotone (Figure 3). High global irradiation triggers radiation stress for tree seedlings outside closed forest stands and thus hinders tree regeneration above the upper timberline (Bader et al. 2007) while simultaneously strong easterlies additionally constrain the establishment of forests in the higher ridge areas that carry a subpáramo vegetation (Figure 4). In addition, high precipitation amounts are leading to long-lasting drenching and nutrient leaching on flat ridges of the study sites, whereas forests create their own water regime by a thick top soil layer of organic material on the adjacent steeper slopes of the Andean valleys. Last but not least human slash and burn practices lower the local timberline ecotone at some sites.

With respect to climate change, the western inter-Andean basin of Loja and the eastern Andean escarpment around Zamora reveal a significant warming trend. The ecological importance of such a thermal shift is obvious and the increase of temperature might result in an

upwards shift of ecothermal belts and species ranges in the study area (Figure 5). Changes in precipitation are expected to be very heterogeneous across the Andes and areas west of the Cordillera Real might be affected by a slight increase of rainfall and vice versa. This situation let us conclude that weakened mid- and upper tropospheric easterlies and strengthened westerlies would cause longer and more frequent drought events (Figure 6). However, it should be kept in mind that a high variability of annual precipitation and the limited length of the data series do not yet permit a distinct trend analysis.

With regard to the position of the upper forest line ecotone the analysis of recent forest stands suggests that rising temperature alone is unlikely to cause a pronounced uplift of the region's tree lines. Nevertheless, an increase of temperature would presumably allow tree species of lower regions to extend their habitats into higher altitudes thus enhancing tree diversity there. Under this assumption intensified competition could result in the suppression of recent timberline species

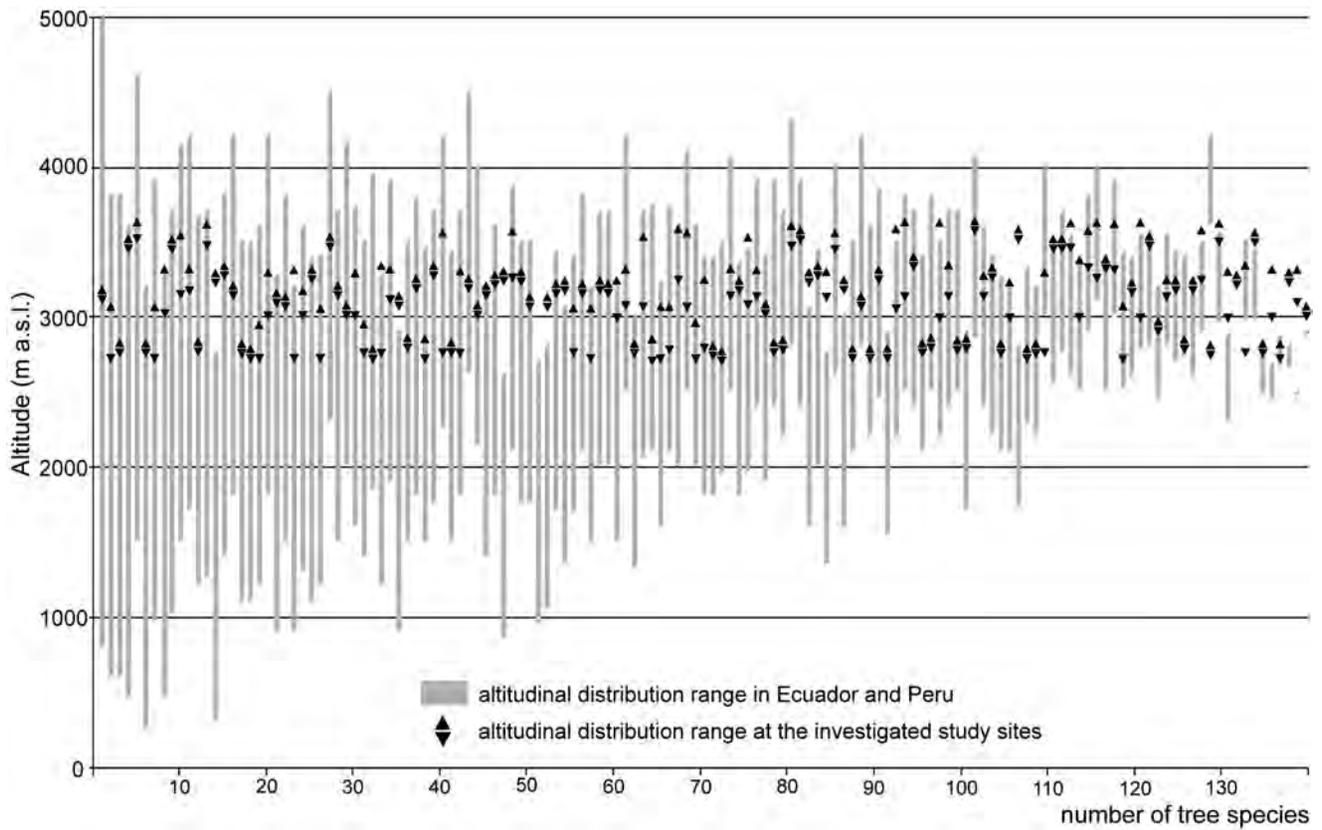


Figure 3: Tree species occurrence at upper forest line sites in southeastern Ecuador and northern Peru (ranges shown by black triangles) relative to their distribution ranges in Ecuador and Peru acc. to the Tropicos database of the Missouri Botanical Garden (grey bars)

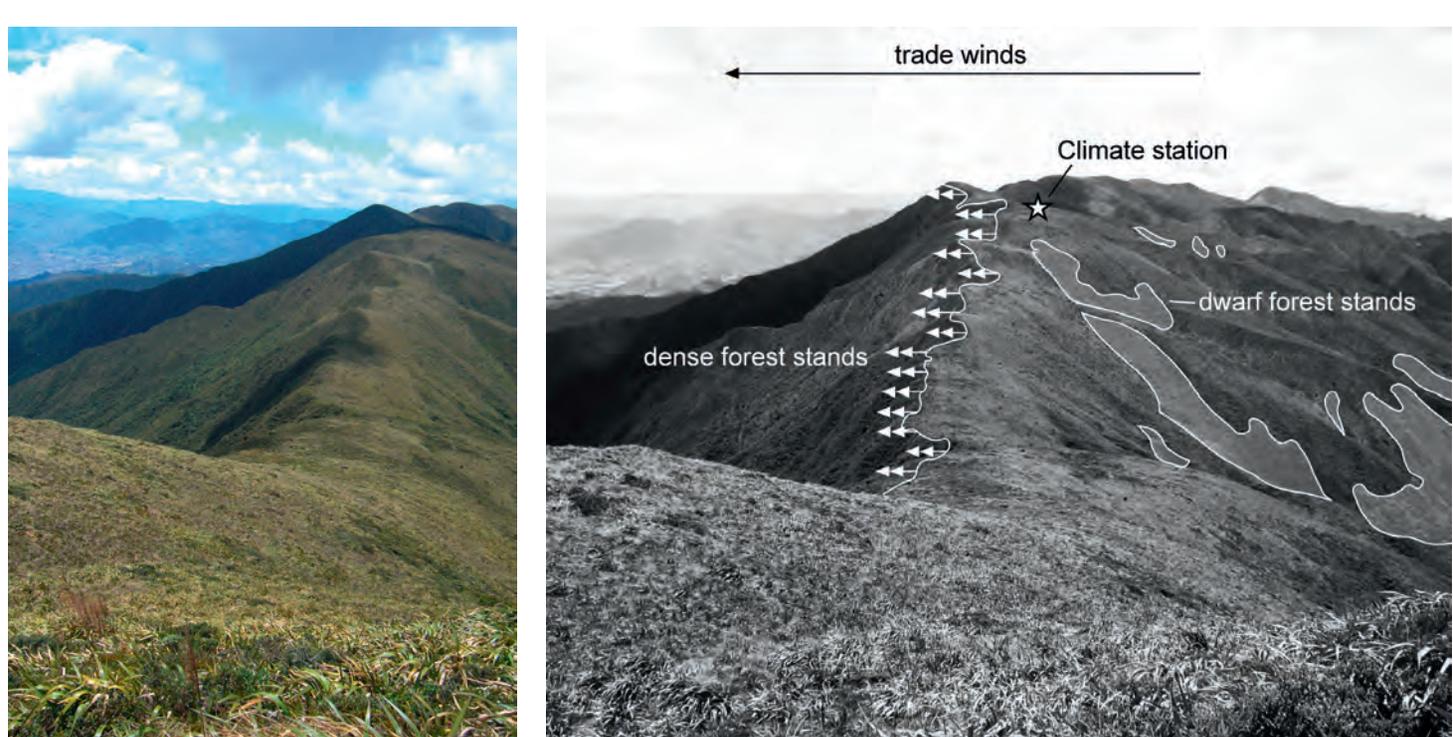


Figure 4 Upper forest line ecotone at Cajanuma. Especially the eastern flanks are covered by páramo vegetation whereas the wind protected western flanks and flat eastern hollows are covered by dense stands of low forests. Photos: Peters 2010

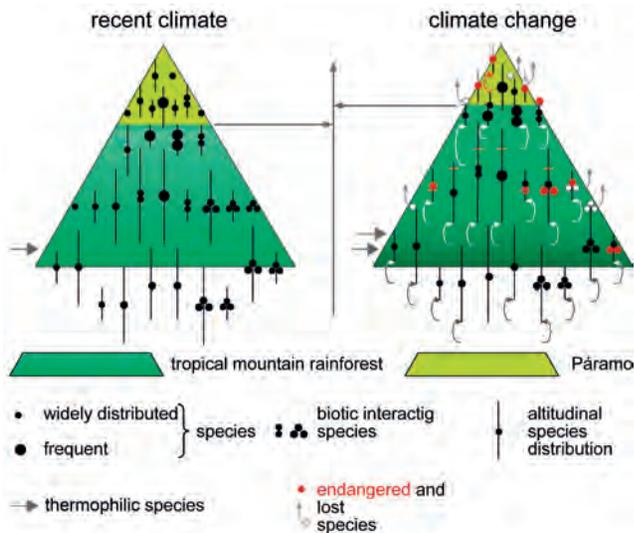


Figure 5. Possible upward shift of plants within the Andes caused by temperature increase

some of which might completely disappear in the worst case. More impact on the recent position of the upper forest line and its species composition might result from shifts in regional circulation and precipitation patterns. An increasing frequency of drought events resulting from occasional western air flows (“veranillo del niño”) could indeed affect plant diversity patterns, in particular of the very sensitive timberline and subpáramo ecotones. Abundant treeline species with a high demand of moisture such as *Axinaea macrophylla*, *Hedyosmum racemosum* and *H. scabrum*, or *Weinmannia rollottii* may not be able to survive under dryer conditions and may be replaced by more drought tolerant species from lower elevations. Drought, in addition to its direct eco-physiological effects, promotes additionally the incidence of wildfires which can change species composition dramatically due to the implementation of different plant successional stages. However, the extent to which climate change will affect the position and species composition of the upper forest line ecotone is difficult to assess due to the ecological complexity of this area.

References

Bader MY, van Geloof I, Rietkerk M (2007) High solar radiation hinders tree regeneration above the alpine treeline in northern Ecuador. *Plant Ecol* 191: 33-45
 Baumann F (1988) Geographische Verbreitung und Ökologie südamerikanischer Hochgebirgspflanzen. Beitrag zur Rekonstruktion der quartären Vegetationsgeschichte der Anden. – Physische Geographie Vol. 28. Geographisches Institut der Universität Zürich: 206 pp
 Bendix, J.; Behling, H; Peters, T.; Richter, M.; Beck E. (2010): Functional biodiversity and climate change along an altitudinal gradient in a tropical mountain rainforest. In: Tcharntke, T.; Leuschner, C.; Veldkamp,

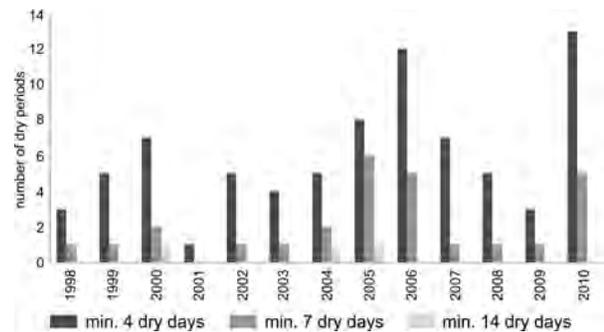


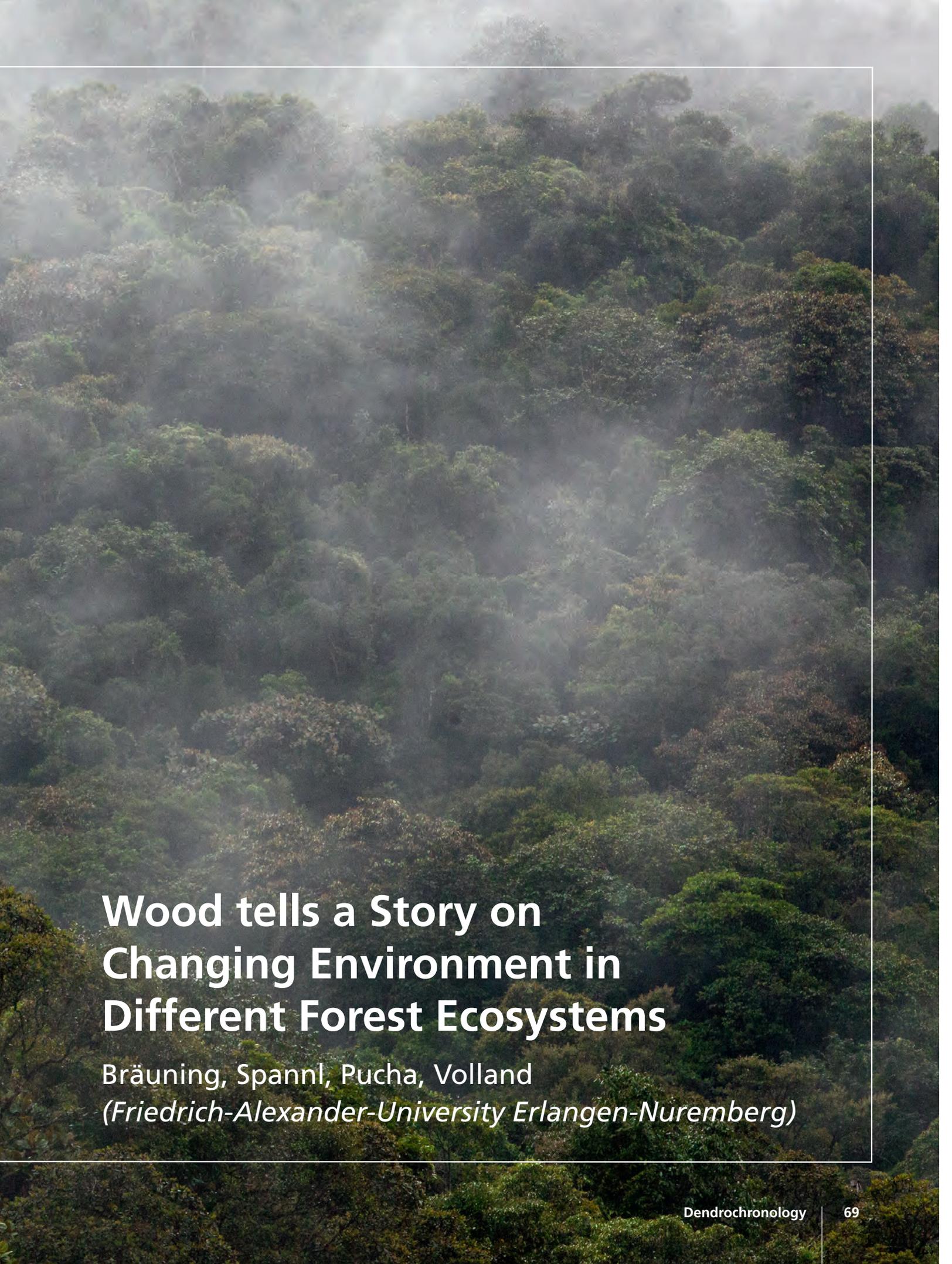
Figure 6. Number of periods at the ECSF meteorological station during which no rain fell, and which were continuously dry for at least 4, 7, or 14 days



Figure 7. Leaf shoots and red coloured bark of *Polylepis*. Photos: Peters 2006

E.; Faust, H.; Guhardja, E.; Bidin, A. (Eds): Tropical rainforests and agroforests under global change. Environmental Science and Engineering / Environmental Science, Springer, Berlin, 239-268 Körner C (2007) Climatic treelines: Conventions, global patterns, causes. *Erdkunde* 61: 316-324
 Lauer W, Rafiqpoor MD, Bendix J (2003) Vergleichende Geoökologie der Hochgebirge der Nördlichen (Mexiko) und Südlichen (Bolivien) Randtropen sowie der inneren Tropen (Ecuador). *Abh Math-Naturwiss Kl* 1: 154 pp
 Peters, T.; Bräuning, A.; Münchow, J.; Richter, M. (2014): An ecological paradox: high species diversity and low position of the upper forest line in the Andean Depression. In: *Ecology and Evolution* 4(11), 2134-2145, DOI:10.1002/ece3.1078



A photograph of a dense, misty forest landscape. The trees are lush green, and a thick layer of white mist or fog hangs in the air, partially obscuring the forest canopy. The scene is captured from an elevated perspective, looking down into the forest. A thin white border surrounds the entire image.

Wood tells a Story on Changing Environment in Different Forest Ecosystems

Bräuning, Spann, Pucha, Volland
(Friedrich-Alexander-University Erlangen-Nuremberg)

The wood of trees is an archive informing us about historical changes of the environment during the lifetime of a tree. Wood is a very heterogeneous and complex tissue. Its primary functions are to stabilize the tree against mechanical stress and to raise the leaves of the tree crown towards the sun for the harvest of light. On the other hand, the wood of a tree stem must guarantee the supply of the transpiring leaves with water from the soil and with nutrients. In broadleaved trees, the functions of water transport and mechanical strength are accomplished by different cell types, namely the vessels and the fibers, which are both characterized by thick cell walls that are lignified. A third cell type, the parenchyma, forms a network of living cells between vessels and fibres and can store sugars and water. The size, distribution and arrangement of vessels are species specific characteristics and have a big influence on the capacity of water transport through the stem. However, the climatic conditions – dry or humid – have an influence on vessel formation and therefore size and arrangement of vessel can vary from year to year.

Cutting tools for wood, so-called microtomes, produce thin sections of ca. 1/50 of a mm in thickness, which allow detailed quantitative measurements of cell sizes and cell wall thicknesses by using image-analyses computer software or with micro-computer tomographs used in medical science (Van den Bulcke et al., 2014). For example, *Alchornea lojaensis* Secco (Euphorbiaceae) is an evergreen broadleaved tree species which is endemic in the research area Reserva Biológica San Francisco. Despite the constant per-humid conditions of the Podocarpus National Park mountain rainforest, *Alchornea lojaensis* exhibits seasonal growth rhythms, which are visible in distinct growth boundaries (Figure 1a) – proving the existence of annually formed tree rings also in this

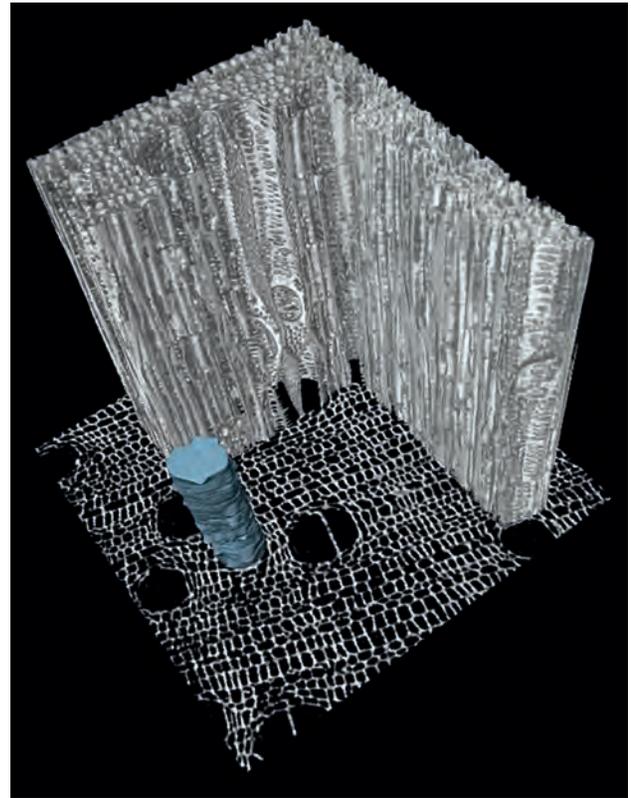


Figure 2. 3D volume rendering of a small branch piece of *Alchornea lojaensis*. Simple perforation plates are clearly visible. A solitary vessel segmentation is illustrated in light blue. Figure by S. Spann.

tropical forest. About 30% of the vessels are solitary, the rest occur in radial multiple radially oriented groups (Figure 1b). Vessel walls show alternate positioned pits allowing the movement of water within the stem by so-called perforation plates between neighbouring cells (Figure 2).

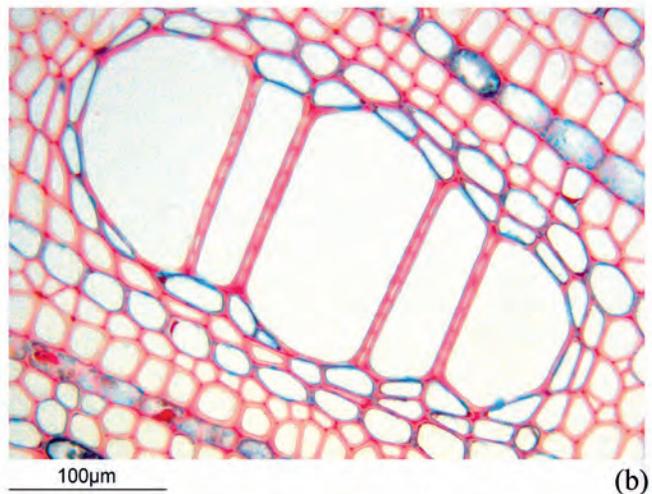
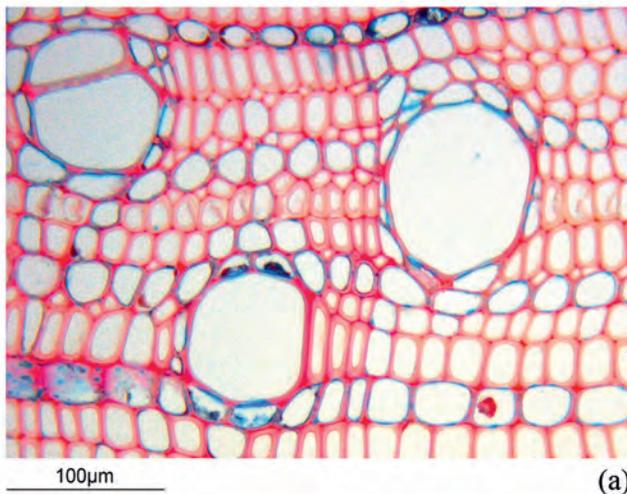


Figure 1. Transvers section of a branch piece of *Alchornea lojaensis* with (a) distinctly thickened and flattened libriform fibres marking the growth boundary and (b) solitary and radial multiple vessels. Woody elements with lignified cell walls are colored in red, living parenchymatic tissues are colored in blue. Photographs: S.Spann.

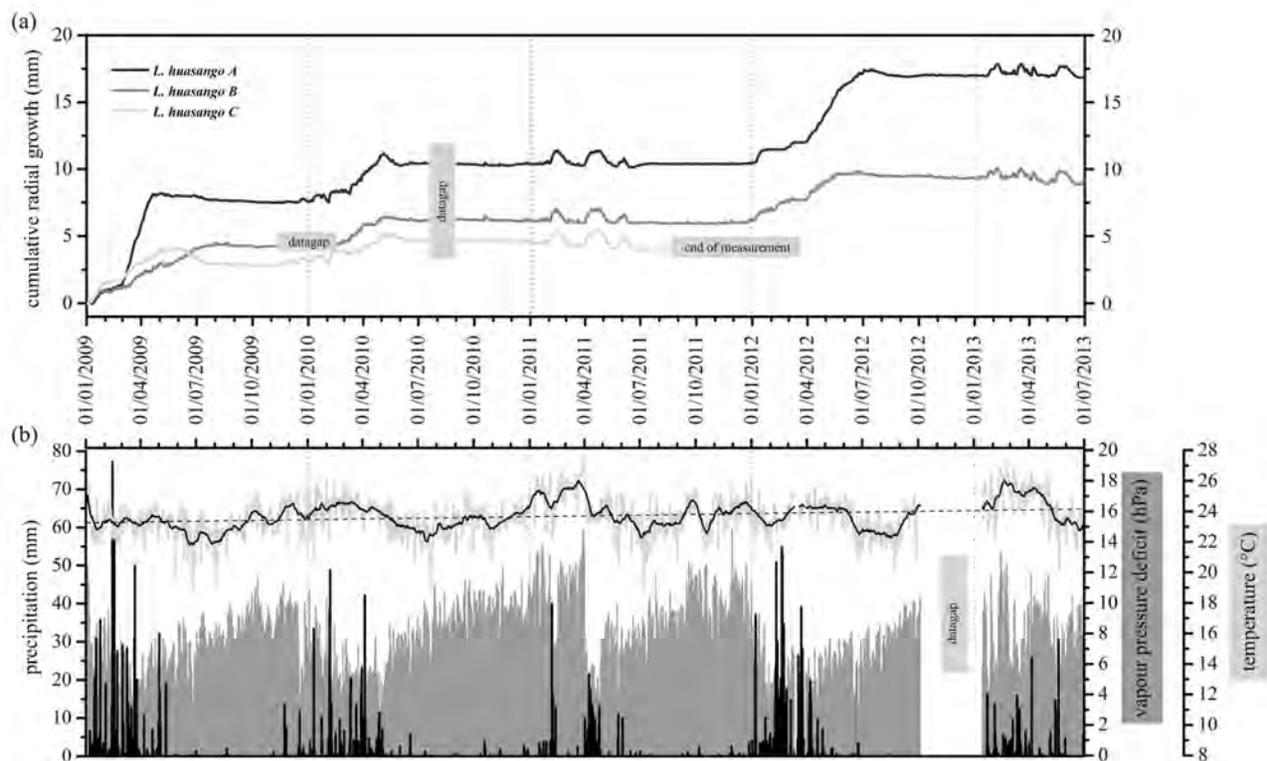


Figure 3. (a) Cumulative radial growth of three *Loxopterygium huasango* trees and its connection with (b) daily sums of precipitation (black bars), daily maximum vapour pressure deficit (grey bars), mean daily temperature (light grey line) and twenty-smoothed spline of temperature (black line) from January 2009 to July 2013. Dark grey dashed line represents the temperature trend. Figure by S. Spann.

In the mountain rainforest, most evergreen tree species show more or less continuous growth over the year, with some interruption during short dry periods or during flowering season. However, due to the complex topography of southern Ecuador, the climatic conditions vary strongly within short distance. In the rain shadow of the Andes towards the southwestern border of Ecuador, the rainy season only lasts from January to April, while almost 8 months during the year are dry. While annual precipitation in the mountain rainforest exceeds 2000 mm rainfall per year, rainfall in the Reserva Laipuna strongly varies between different years and can fluctuate between around 800 mm to 300 mm per year (Spann et al., 2016). The humid air masses that bring ample rainfall from the tropical Atlantic Ocean to the Amazon lowland and the eastern declivity of the Andes rarely reach this area. Instead, westerly winds bring moisture from the tropical Pacific Ocean during the wet season. As a result, the area is covered by a different forest ecosystem called 'bosque seco' or Tumbesian dry forest. Trees growing in this type of forest have developed different strategies to adapt to the low water availability during the dry season. Such adaptations include the formation of water-storing succulent roots or stems

and a modification of leaf phenology by shedding all leaves in the dry season to reduce water loss by transpiration.

As a consequence of losing their leaves, trees cannot maintain photosynthesis and hence interrupt their growth activity. The growth of trees can be registered with so-called dendrometers which are electronic sensors that register very small variations of the diameter or circumference of a tree at a high temporal resolution of ca. 30 minutes. With such instruments, the increment of a tree by water uptake or growth and the shrinkage of a stem due to water loss can be precisely quantified, dated, and related to changing environmental conditions. The stepwise stem increment caused by the seasonal rhythm of dry and wet seasons can be seen in long-term dendrometer measurements. Figure 3 shows five years of stem diameter variations of *Gualtaco* trees (*Loxopterygium huasango*) growing in the dry forest. It can clearly be seen that tree growth during the more humid years 2009 and 2012 was quite high, whereas the trees did almost not form any wood in the very dry La Niña year 2011. In such years, almost no carbon is gained by the dry forest, and the carbon balance of the ecosystem may even turn negative.

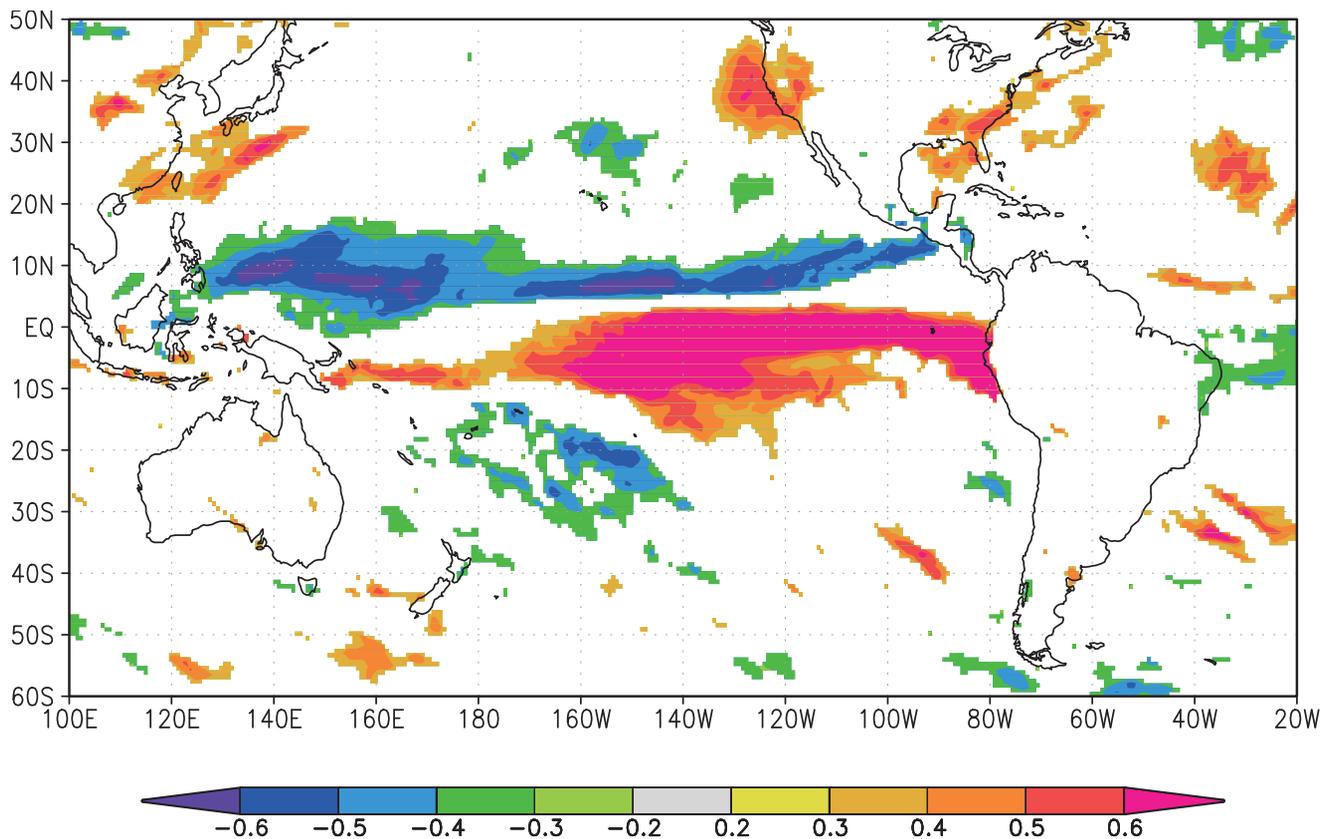


Figure 4. Spatial correlations between the ring width index chronologies (RWI) of *Bursera graveolens* in the dry forest of southwest Ecuador (grey triangle in the map) and gridded data of monthly mean precipitation during the wet season (January to May). The map was created using the Netherlands Meteorological Institute (KNMI) Climate Explorer (<http://climexp.knmi.nl>) and the Climatic Research Unit (CRU) TS 3.22 dataset with a grid of $0.5^\circ \times 0.5^\circ$ (Mitchell and Jones, 2005) from 60°S to 70°N latitude and from 0°W to 120°E longitude. The analysed period is 1979–2009; regions with significant correlations are highlighted by colours. Figure by Darwin Pucha.

Due to the clear alternation of dry and wet seasons, several tree species of the dry forest ecosystem form distinct growth ring boundaries, allowing the measurement of annual ring width and the establishment of precisely dated tree-ring chronologies. The economically and culturally important species Palo santo (*Bursera graveolens*) that forms fragrant resin is such an example (Figure 5). A 120-year long tree-ring chronology of Palo santo highly correlates with the amount of rainfall during the wet season, allowing better tree growth under more humid conditions. A map of spatial correlations between tree growth rates in the dry forest with gridded climate data of precipitation over land and ocean regions shows that tree growth in the dry forest of southwestern Ecuador is strongly controlled by the sea surface temperatures over the tropical Pacific Ocean (Figure 4; Pucha Cofrep et al., 2015). Thus, precipitation variations controlled by the El Niño-Southern Oscillation pattern have a strong influence on forest productivity and health of tree species in the dry forests of southern

Ecuador. Currently, a monitoring system to detect climatic changes by using different tree species and wood parameters, including radial growth, wood anatomy, and stable isotope variations in the wood is under construction within the project TRENCH – a Tree-Ring Environmental Network for Climate Change Monitoring for Southern Ecuador.

References

- Darwin Pucha Cofrep, Peters, T., Bräuning, A. (2015): Wet season precipitation during the past 120 years reconstructed from tree rings of a tropical dry forest in Southern Ecuador. *Global and Planetary Change*. 133: 65–78.
- Mitchell, T.D., Jones, P.D. (2005): An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatology* 25 (6): 693–712.

Spannl, S., Volland, F., Pucha, D., Peters, T., Bräuning, A. (2016): Climate variability, tree increment patterns and ENSO-related carbon sequestration reduction of the tropical dry forest species *Loxopterygium huasango* of Southern Ecuador. *Trees, Structure and Function*. DOI: 10.1007/s00468-016-1362-0.

Spannl S, Homeier J and Bräuning A (2016). Nutrient-induced modifications of wood anatomical traits of *Alchornea lojaensis* (Euphorbiaceae). *Frontiers in Earth Science* 4:50. DOI: 10.3389/feart.2016.00050.

Van den Bulcke, J., Wernersson, E.L.G., Dierick, M., Van Loo, D., Masschaele B, Brabant L, Boone MN, Van Hoo-rebeke L, Haneca K, Brun A, Hendriks CLL, Van Acker J. (2014): 3D tree-ring analysis using helical X-ray tomography. *Dendrochronologia* 32(1): 39-46.

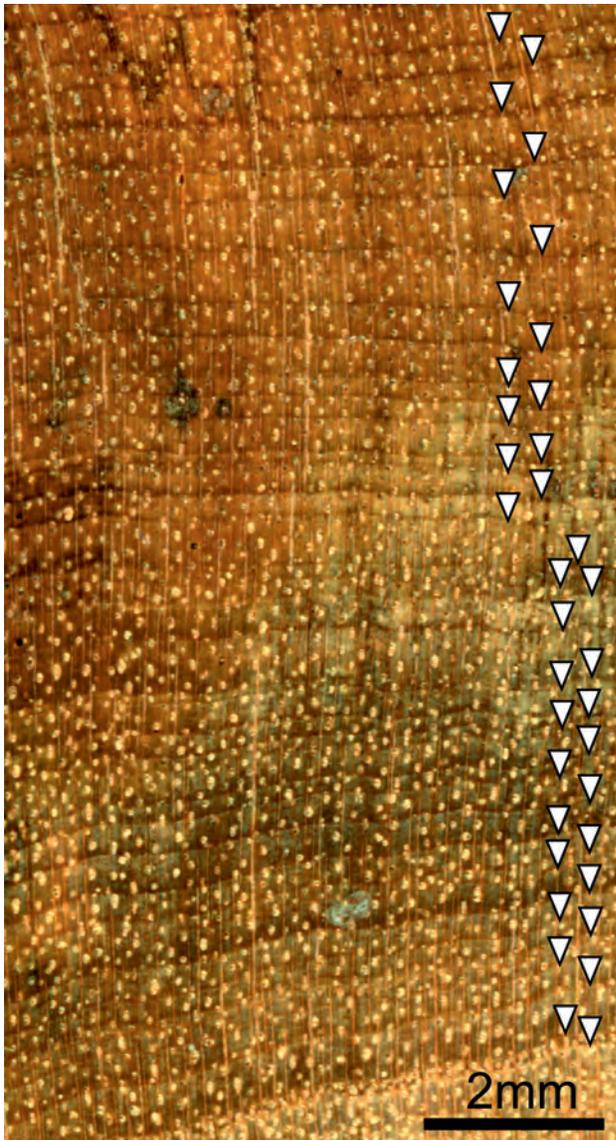


Figure 5. Growth ring boundaries (white triangles) in Palo santo (*Bursera graveolens*) from the dry forest.



Figure 6. A young *Ceiba schistandra* tree with green bark and many prickles, equipped with an electronic dendrometer.





Development of Spatial Soil Patterns under Montane Cloud Forest Vegetation

Ließ (*Helmholtz Centre for Environmental Research – UFZ*)

Pedogenesis

Primarily understood as the medium for plant growth, the pedosphere (from greek pedon "soil" and sfaira "sphere") is the outer zone of the terrestrial lithosphere, which is transformed by weathering under the influence of climatic agents, changes in temperature and organisms. Accordingly, it is formed at the interface of the lithosphere, atmosphere, hydrosphere and biosphere (Figure 1). Lithospheric minerals are decomposed and new minerals are formed resulting in a mixture of primary and secondary minerals. Organic material is added mainly as dead plant biomass. Material can accumulate, can be transformed, translocated or removed so that a number of layers, so-called soil horizons are formed. Processes forming and altering the soil (Buol, 2012) are:

1. Heating and cooling of the soil in the daily and annual temperature cycles.
2. Wetting and drying of the soil by precipitation and evaporation, but also through water uptake by plants from the soil.
3. Nutrient cycling, starting with nutrient uptake from the soil, temporal storage in the vegetation and finally concentration at or near the soil's surface upon decomposition of dead plant biomass. Animals feeding on the vegetation and depositing the remains elsewhere, humans applying fertilizers and removing crops and their residuals, also affect nutrient cycling.

4. Weathering processes alter primary minerals that are unstable under the current environmental conditions and form secondary soil minerals.

5. Removal and deposition of soil material by erosion processes, induced by wind and/or water remove soil material from one soil and deposit it on another; likewise agricultural activities by humans e.g. levelling of a land surface alter the soils.

6. Similarly soluble compounds can be translocated or washed out by soil water

7. Redox processes: Frequent saturation with water (water logging) leads to the development of hydromorphic properties, indicated by orange oxidation colours (iron oxides) being intermixed with grey reduction colours.

Soil development results in a double differentiation: in the soils' vertical sequence of layers, so called soil horizons and their spatial variation.

Digital soil mapping

Traditionally, surveyors used the morphology of the landscape and particular site conditions to acknowledge the spatial soil pattern below ground. This interpretive approach goes back to V. Dokuchaev who is commonly regarded as the father of soil science. He was convinced that spatial variation in soils is related to parent material, organisms, climatic and topographic factors and the

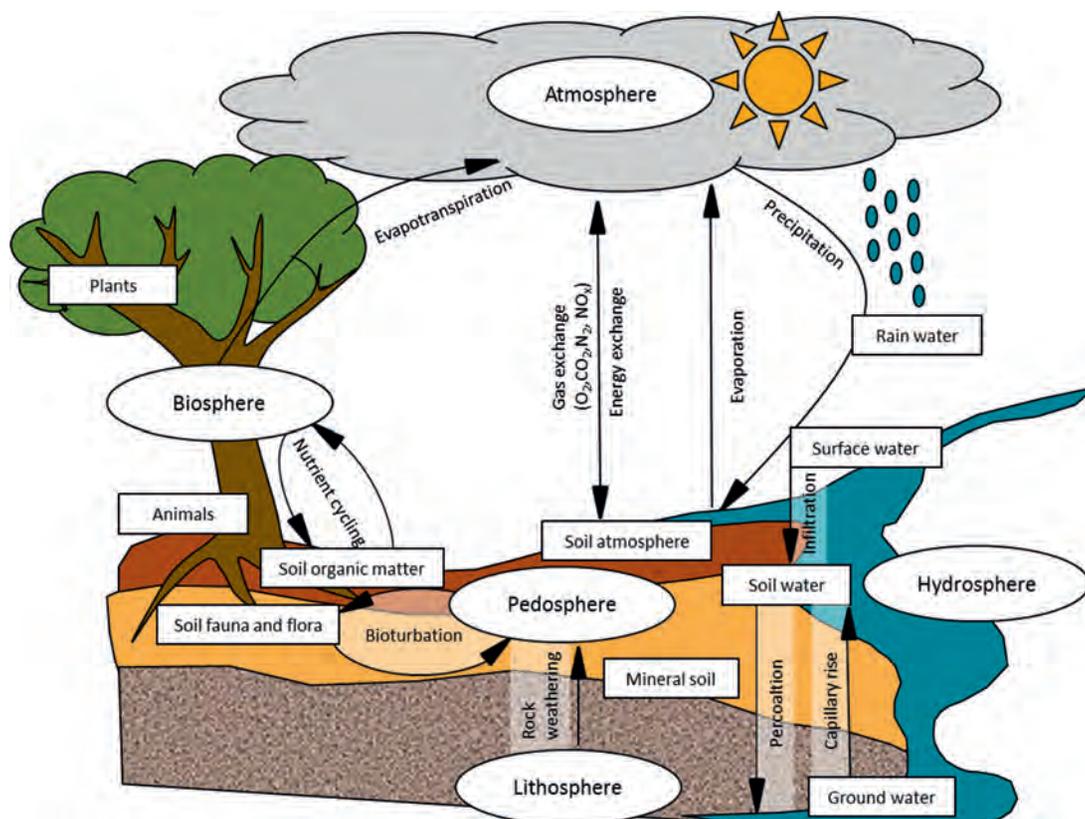


Figure 1: The pedosphere is formed at the interface of the lithosphere, atmosphere, hydrosphere and biosphere.

time for soil formation, “pedogenesis” to take effect. A new soil mapping approach, better known as “digital soil mapping” uses these factors of soil formation as predictors in soil-landscape models. These models are based on the information gained from soil profiles at selected point locations, the distance between these points, and the continuously available area-wide predictors (topographic parameters gained from digital elevation models, vegetation indices obtained from satellite images, etc.). The so obtained continuous soil maps include an estimate of uncertainty. This is important because each map and model is a simplified, not a perfect representation of the reality. In order to display the site specific uncertainty within the spatial context of the map, position specific density functions are very useful as will be shown in the next paragraph (Ließ et al., 2014).

The spatial soil pattern of the cloud forest area

The tropical mountain area surrounding the San Francisco research station (ECSF) is covered by montane rain forest. The soils of the area are influenced by slope processes such as shallow slope parallel subsurface flow and landslides (Bauer, 2010). Water saturation at the soil surface leads to the development of hydromorphic soil properties and favours the accumulation of organic material

due to low decomposition rates. Landslides disturb the spatial soil pattern as they lead to a translocation of soil material. Their influence is difficult to capture in soil-landscape models, since many former landslide scars are once again covered by dense forest vegetation. On the other hand, it is particularly these rainfall-triggered soil slides which are a major research interest within this area. Landslides are even assumed to significantly contribute to the high diversity of this biodiversity hotspot. Accordingly, they may have also caused the high pedodiversity (spatial variation of soil properties within an area) of this landscape.

Soils with hydromorphic properties and thick organic layers are dominating the area (Ließ et al., 2014). Figure 3 shows the median and interquartile range of the above mentioned position specific density functions. In some parts of the area the soil properties were predicted with higher interquartile ranges indicated by red colors in Figures 3b and 3d. This might indicate that the corresponding soil-landscape model matches certain parts of the landscape better than others. However, another possible explanation is that the pedodiversity might be higher leading to these higher interquartile ranges. Organic layer thickness is highest on mid slope positions (40 to 55 cm, Figure 3a). The exposed mountain ridges and the

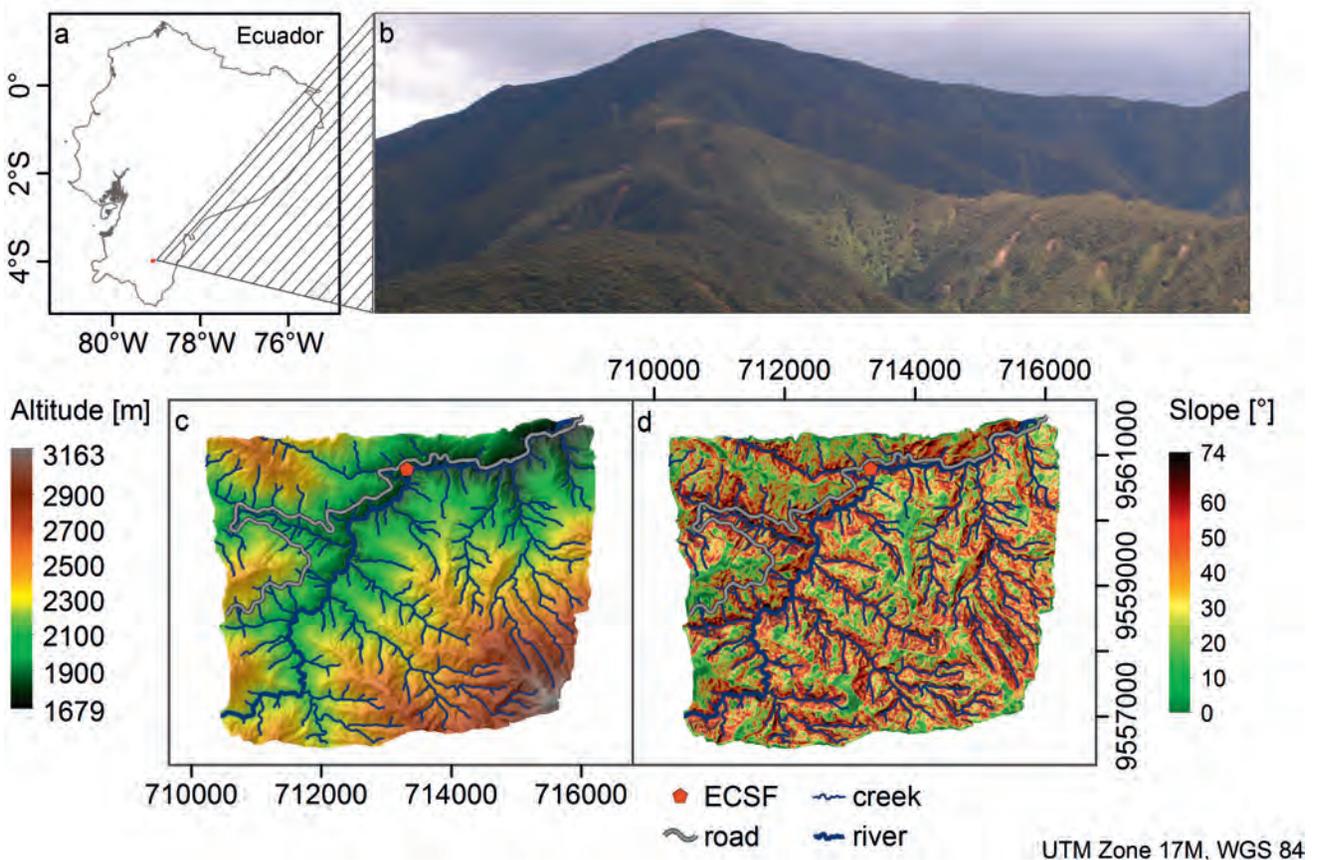


Figure 2: Investigation area in the surrounding of the San Francisco Research Station (ECSF). a) Position of the area within Ecuador, b) photograph of the landscape, c) altitudinal map and d) slope map.

parts close to the creeks and river exhibit the smallest organic layers with a median thickness of 22 cm. Along the mountain ridges, a less dense vegetation produces lesser litter and the higher direct solar radiation and wind exposure might favor decomposition rates. Along the river network, seasonal higher water discharge probably hinders the accumulation of thick organic layers. There is no apparent increase of organic layer thickness with altitude as was hypothesized due to the increase in rainfall and decrease in temperature and the expected lower decomposition rates. Furthermore, the spatial pattern of organic layer thickness does not coincide with the spatial water logging pattern (Figure 3c). Median probability of hydromorphic soil properties is highest between 2100 and 2500 m a.s.l. It is particularly high in the soils of the flat platform-like areas above 2100 m a.s.l. (compare Figures 2c, d and 3c). The lower probability above 2500 m a.s.l. can be attributed to a higher soil hydraulic conductivity due to a sandier soil texture (compare Figures 2c and 3c) and, therefore, less chance for the development of hydromorphic soil properties (Ließ et al., 2012). The lower probability below 2100 m a.s.l. should result from the higher inclination (compare Figures 2c, d and 3c) leading to a higher discharge of surface and subsurface flow and the higher soil bulk density (Figure 5a). Topo-

graphic parameters describing soil water accumulation and discharge were useful predictors in the corresponding soil-landscape model to predict the spatial occurrence of hydromorphic soil properties.

Soil texture development is closely linked to the parent rock material. Accordingly, the particularly high sand contents in the South-Eastern summit area (Figure 4a) are due to a high occurrence frequency of sandy bedrock material. However, in an area which is influenced by landslides and therefore mass transport of soil material, many soil profiles did not develop from the underlying rock material (Ließ et al., 2012). And finally, soil texture is also influenced by less powerful slope processes. Figure 4 shows, that the spatial soil texture pattern follows the topographic water flow pattern. Concave gully structures provide pathways for surface and shallow subsurface flow after rain events. The water flushes the tiny clay particles downhill, while leaving the larger sand grains behind (Figure 4a). Clay deposition areas form downslope in areas of low inclination where the flow velocity decreases (Figure 4c). Apart from the above mentioned soils with hydromorphic properties, there are also Cambisols, Umbrisols and Regosols within the area (Ließ et al., 2009). The bulk density in these soils is lower compared to soils with hydromorphic properties (Ließ et al., 2011; Bauer, 2010).

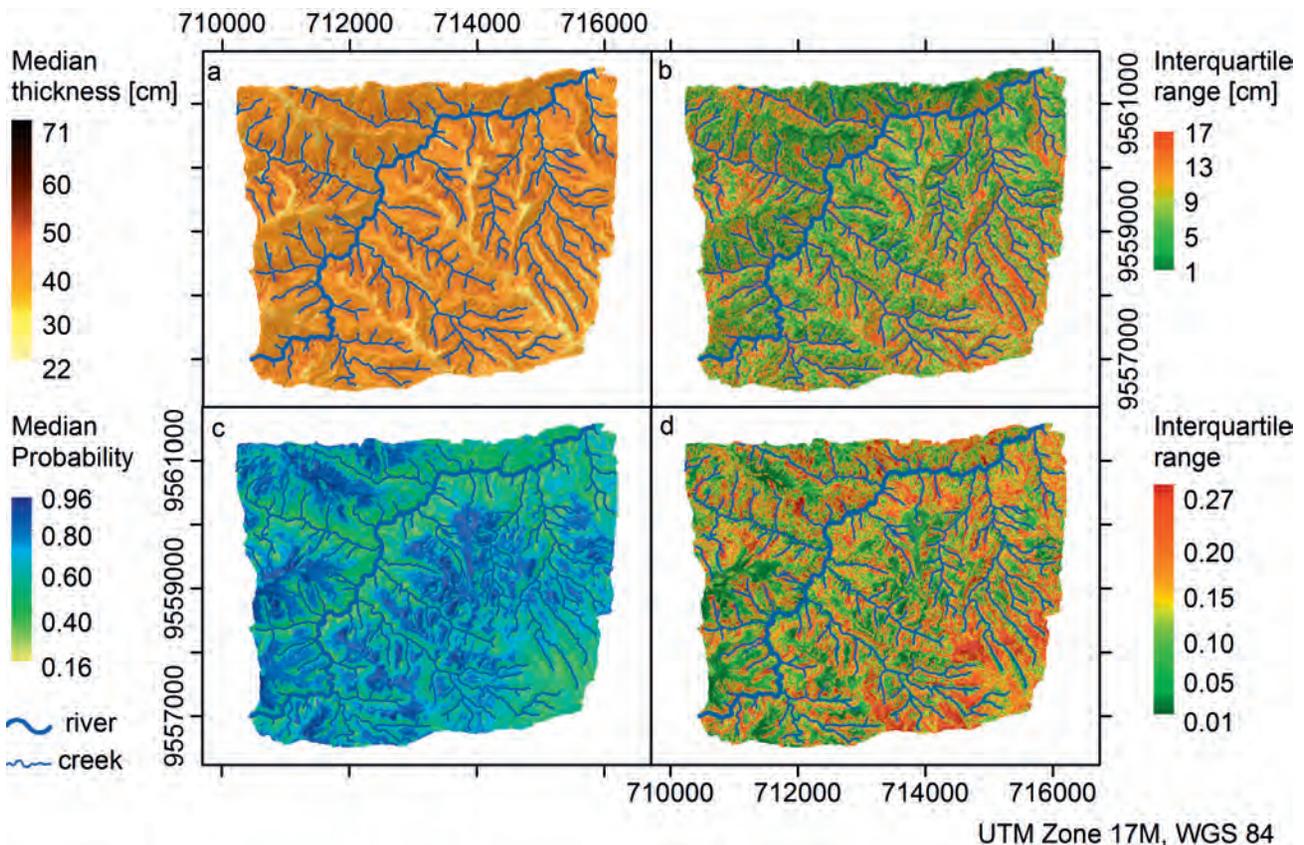


Figure 3: Spatial soil pattern. Organic layer thickness (a) with interquartile range (b) and occurrence probability of hydromorphic soil properties (c) with interquartile range (d) (adapted from Ließ et al., 2014).

In fact, it is the low porosity of the soil that goes along with a high bulk density and a clayey or silty soil texture which often leads to soil water logging. It happens when the amount of incoming water from rainfall, surface and subsurface flow exceeds the amount of water leaving the particular soil compartment. Soils of a low bulk density are particularly found on the steep slopes in the lower part of the area where many of the sampled soil profiles were influenced by former landslides (compare Figures 2c, d and 5a). Accordingly, it was hypothesized that probably any soil of the area which does not show hydromorphic properties and is not originating from sandy bedrock material might have been influenced by landslides in the past resulting in the observed lower bulk density (Ließ et al., 2011).

To summarize, fine-textured soils with high soil bulk densities may lead to water logging and the development of hydromorphic properties. In contrast to this, lower bulk densities and coarser soil textures support a higher water percolation. Water logging limits organic layer decomposition, but is not the only cause of the formation of thick organic layers in this montane rain forest area. It is the complex interaction of the various soil forming factors which leads to the development of the spatial soil pattern of a particular soil landscape.

References

- Bauer, F.C., 2010. Water Flow Paths of an Undisturbed and Landslide Affected Mature Montane Rainforest in South Ecuador. PhD thesis, Bayreuth.
- Buol, S.W., 2012. Pedogenic processes and pathways of horizon differentiation, in: Certini, G., Scalenghe, R., Ugolini, F.C. (Eds.), *Soils. Basic concepts and future challenges*, 1. paperback ed. ed. Cambridge University Press, Cambridge.
- Ließ, M., Glaser, B., Huwe, B., 2009. Digital soil mapping in southern Ecuador. *Erdkunde* 63 (4), 309–319.
- Ließ, M., Glaser, B., Huwe, B., 2011. Functional soil-landscape modelling to estimate slope stability in a steep Andean mountain forest region. *Geomorphology* 132 (3-4), 287–299.
- Ließ, M., Glaser, B., Huwe, B., 2012. Uncertainty in the spatial prediction of soil texture. *Geoderma* 170, 70–79.
- Ließ, M., Hitziger, M., Huwe, B., 2014. The Sloping Mire Soil-Landscape of Southern Ecuador: Influence of Predictor Resolution and Model Tuning on Random Forest Predictions. *Applied and Environmental Soil Science* 2014 (3), 1–10.

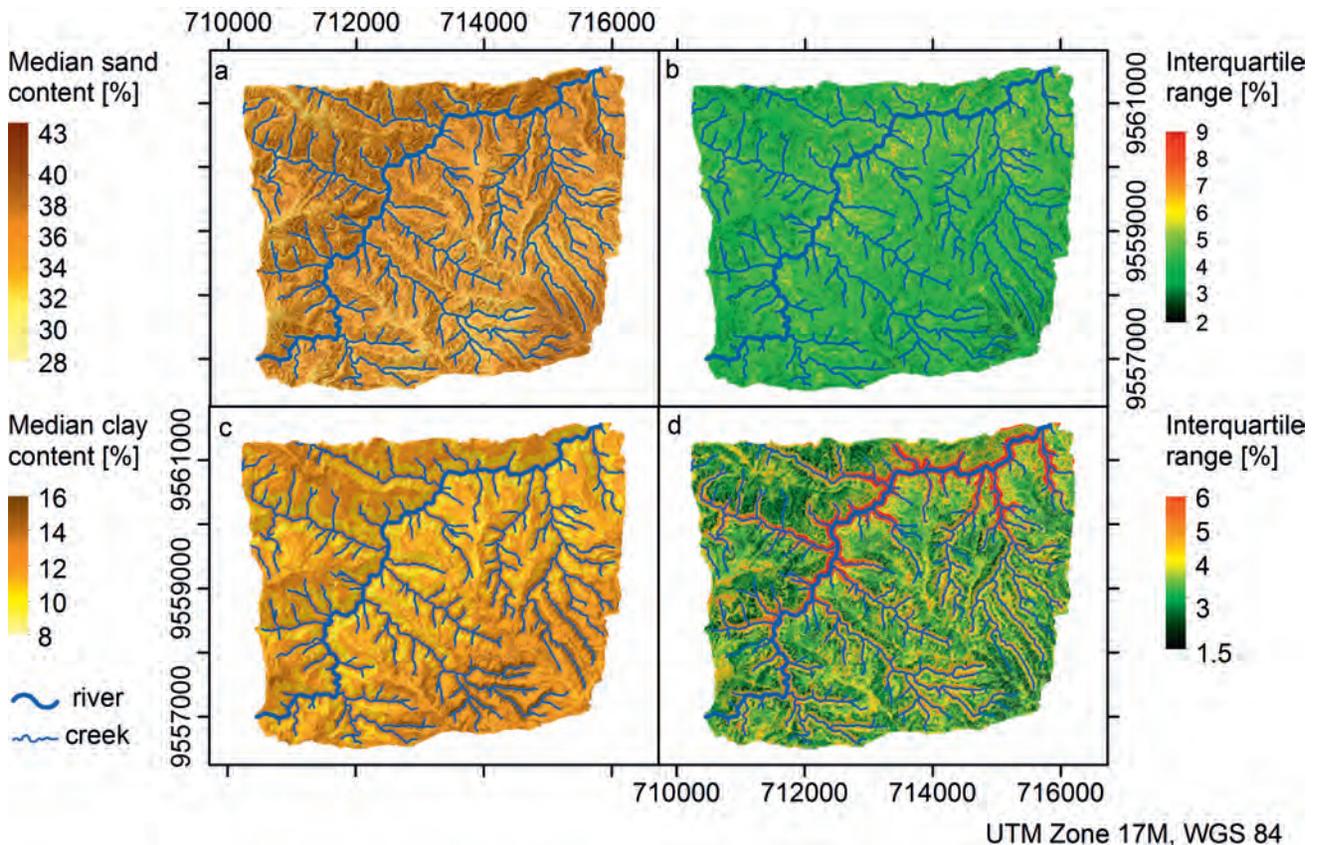
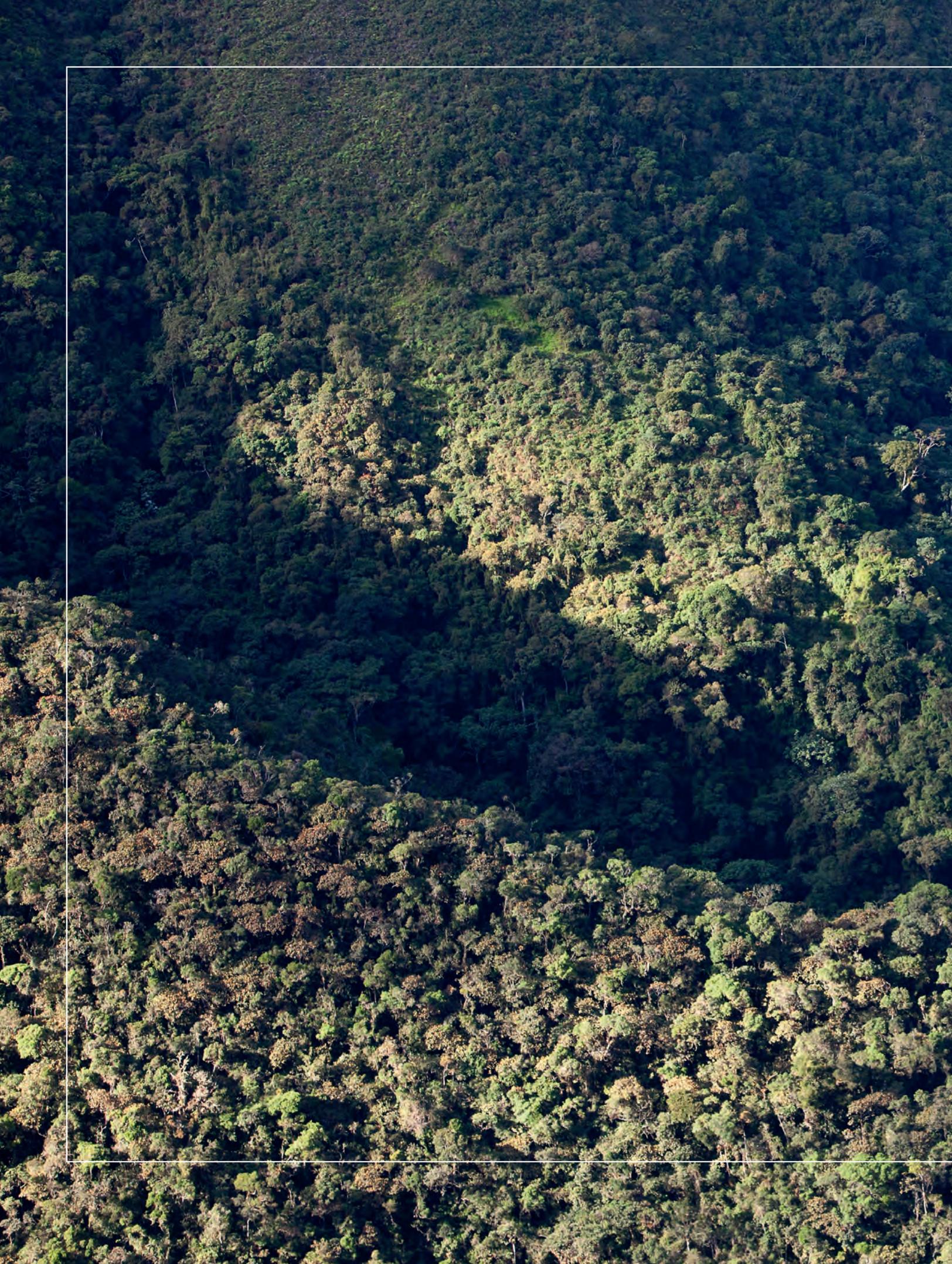


Figure 4: Soil texture. Median sand content (a) with interquartile range (b). Median clay content (c) with interquartile range (d). Prediction according to the model published in Ließ et al. (2012).





Rising Nitrogen Inputs to the Tropical Mountain Rain Forests

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Nitrogen (N) is the plant nutrient that is most needed of all mineral nutrients. Frequently, the availability of N determines plant growth. At our study site – the tropical mountain forest on the eastern cordillera of the Andes in southern Ecuador – the fertilizer addition experiment (NUMEX) has shown that N together with phosphorus (P, the second most essential nutrient) limits the productivity of the forest.

N-fertilization from atmospheric deposition

Usually, N enters the terrestrial ecosystems from the atmosphere, which consists to ca. 80% of the inert N_2 gas. Without interference of humans, the main path of N entry to the ecosystem is the microbial N_2 fixation, which can be realized by free-living, plant-associated, or symbiotic microorganisms. Symbiotic microorganisms, e.g., the Rhizobia, live in plant roots mainly of the Fabaceae (legumes including e.g., soybean, peanuts, beans, peas) and are most efficient in transferring the inert N_2 to reactive mineral nitrogen (ammonium, NH_4^+ , fixed in organic compounds, decomposition of which yields finally nitrate, NO_3^-). A further minor source of N is lightning as well as natural vegetation fires, oxidizing atmospheric N_2 to NO_x (i.e. $NO + NO_2$ which are quickly converted into each other in the atmosphere) or converting plant-N to gaseous NO_x which can then be (re-)deposited into ecosystems. In the last century, humans have dramatically enhanced the emission of reactive nitrogen species to the atmosphere, which in turn led to an increased deposition into the ecosystems. Thereby, the whole world was and still is increasingly „N-fertilized“. The reasons for this are manifold. First, humans have combusted fossil fuels which resulted in the emission of NO_x to the atmosphere, either because N was contained in the fuels or, to a larger part, because atmospheric N_2 was oxidized during the hot process of combustion. Secondly, at the beginning of the 20th century the Haber-Bosch process was invented, by which mineral N fertilizers were produced from atmospheric N_2 at an

industrial scale. The fertilizers were purposefully added to soils to increase food and fodder yields for humans and animal husbandry. Livestock farming usually causes high emissions of NH_3 , which is converted to NH_4^+ in the atmosphere and re-introduced into ecosystems (Galloway et al., 2008). Another anthropogenic increase in N input to soils was the cultivation of legumes. Finally, humans also increased considerably the number of wild-fires, thereby releasing a lot of reactive N into the atmosphere. With respect to our study site in southern Ecuador, forest burning in the Amazon basin has been shown to be a major source of N deposition into the forest (Boy et al., 2008; Figure 1).

In the South Ecuadorian mountain rain forest, the deposition of reactive nitrogen (i.e. NH_4^+ and NO_3^-) steadily increased since the beginning of our measurements in April 1998 (Wilcke et al., 2013;). This was particularly true for the NH_4^+ deposition, which has almost quadrupled, while deposition of NO_3^- has doubled during the last 15 years. Increasing N deposition is globally expected. However, we observed a particularly strong increase in a short time at a very remote site, which was not expected. In parallel to the increasing N deposition, we also observed a tendency of decreasing soil humidity as a result of increasing temperatures in the last ca. 15 years. Because the study ecosystem is usually very wet and the wetness hampers the release of N by mineralization of organic matter, a reduction of soil moisture favors the microorganisms, which then release more reactive N into the soil solution. The latter effect would cause an even stronger increase in N availability in the forest, thus enhancing the fertilization effect. In the long run, more favorable growth conditions in the forest could have an impact on the competition between tree species because the available N might favor those trees which are more responsive to N and could finally out-compete others. Therefore, it is important to closely monitor what is happening in the ecosystem with the introduced N.

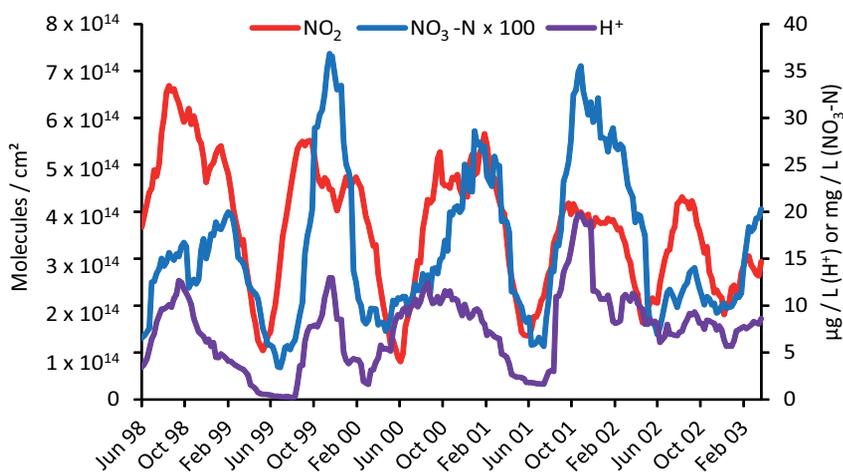


Figure 1. Course of H^+ (purple line) and nitrate-N (blue line) concentrations in rainfall at the tropical mountain rain forest in South Ecuador along with the course of NO_2 concentrations measured by a satellite as indication of fire activity in the pixel in which the forest is located (Boy et al., 2008).

N-Fluxes in a catchment area of the mountain rain forest

We therefore record all major N fluxes in the study forest in high resolution (Figure 3). We weekly collect samples of rainfall, throughfall (i.e. the water that passes the canopy), stemflow (i.e. the water that runs down on the trunks of the trees), litter leachate (i.e. the water that passes through the thick organic layer on top of the mineral soil), soil solutions at 0.15 and 0.3 m depth and stream water. The samples are filtered in the field laboratory of the Estación Científica San Francisco, frozen and exported to Germany, where the various N forms are measured in the laboratory in Karlsruhe. The data are representative for the entire ca. 9-ha large water catchment.

The first question is what happens with the deposition of the reduced N, once it reaches the forest canopy (the leaves, twigs, flowers and fruits, epiphytes, soil-like dust accumulations that together form the "surface" of the forest). A large portion of the NH_4^+ is converted to NO_3^- by microbial oxidation in the canopy ("nitrification", Schwarz et al., 2011). The nitrification process is reflected by the fact that there is much more NO_3^- than NH_4^+ in the canopy throughfall while in the rainfall, the opposite is true. Oxidation of ammonium produces protons which acidify the ecosystem. The NO_3^- is passed on to the

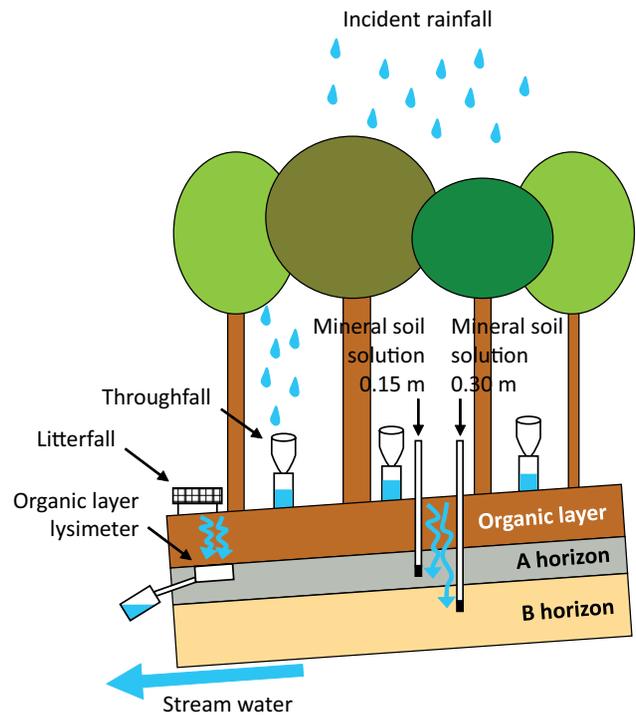


Figure 3. Sampled ecosystem solutions and selected sampling devices.

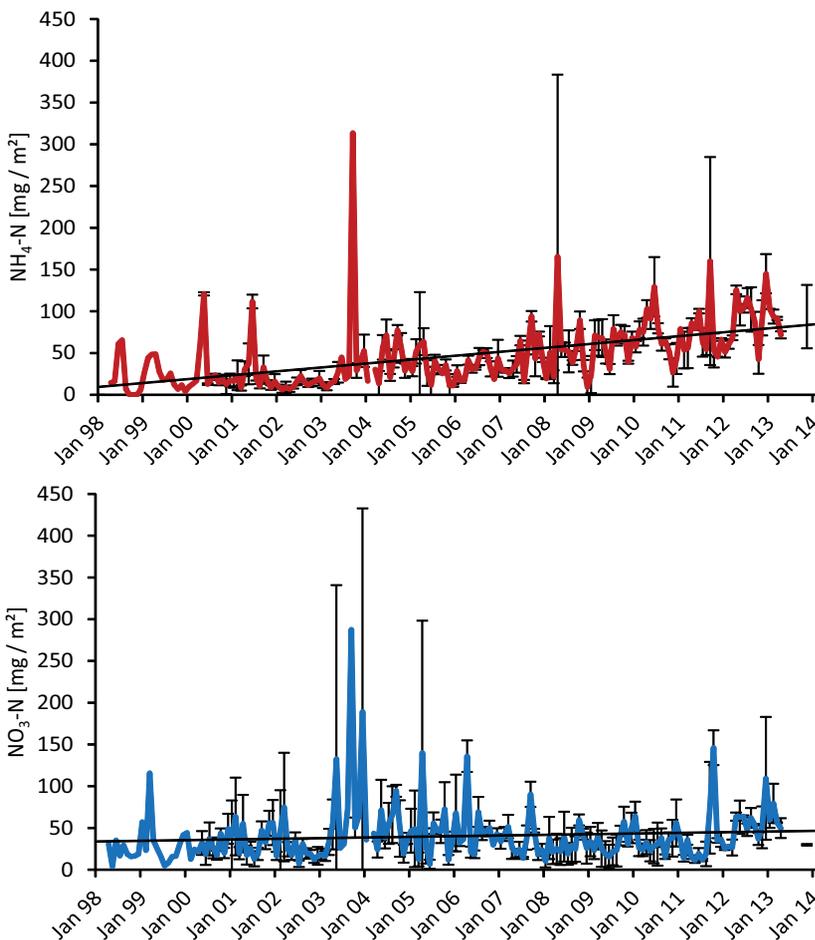


Figure 2. Course of ammonium-N (top) and nitrate-N (bottom) deposition to the tropical mountain forest in Ecuador between 1998 and 2014. Error bars indicate standard deviations of 2-4 rainfall measurement stations (Wilcke et al., 2013, extended).

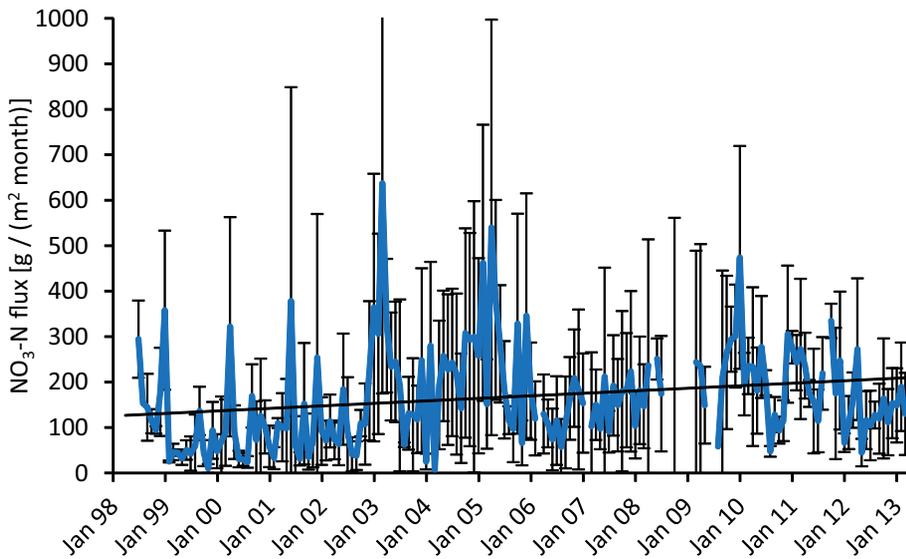


Figure 4. Course of the monthly $\text{NO}_3\text{-N}$ leaching from the organic layer between 1998 and 2013. Error bars indicate standard deviations of the three measurement stations.

organic soil layer where even more NO_3^- is produced, so that we almost only find NO_3^- in the mineral soil solutions and in the stream water. Because NO_3^- is little retained in the soil, there is an increasing risk of NO_3^- losses to the surface waters, which is indeed reflected by increasing NO_3^- fluxes from the organic layer into the mineral soil between 1998 and 2013 (Figure 4). Up to now, this NO_3^- hardly reaches the stream water, possibly because it is converted to gaseous N forms in a process called denitrification which can occur in oxygen-deficient soils (but probably only to a small extent), in the riverine area (close to the stream) and in the stream itself.

Acidification as consequence of the atmospheric N-input

Coming back to the acidification of the system, both the oxidation of NH_4^+ to NO_3^- and the uptake of NH_4^+ by plants or microorganisms release acids into the soil, which consume buffer compounds (i.e. the acids accelerate the weathering of the soil). In addition to the ox-

idation of NH_4^+ , there are also direct inputs of nitrous acid which could be traced back to the forest fires in the Amazon basin and also acidify the soils of the study forest. The consequence is increasing acid fluxes from the organic layer into the mineral soil (Figure 5). Fortunately, from time to time there are also inputs of acid-neutralizing compounds which have been shown to be transported from as far as the Sahara desert in North Africa to the study site in Ecuador and which partly consist of lime (CaCO_3). The deposition of this desert dust slows down acidification and during some time even result in transitory alkalization (Boy and Wilcke, 2008). Nevertheless, in the long run, the soils might become increasingly acid.

Responses of the forest to enhanced N-input

Besides the changes in the N fluxes, in chemical N forms and in soil acidity, we also observed a number of biological responses of the forest, which can be related to the

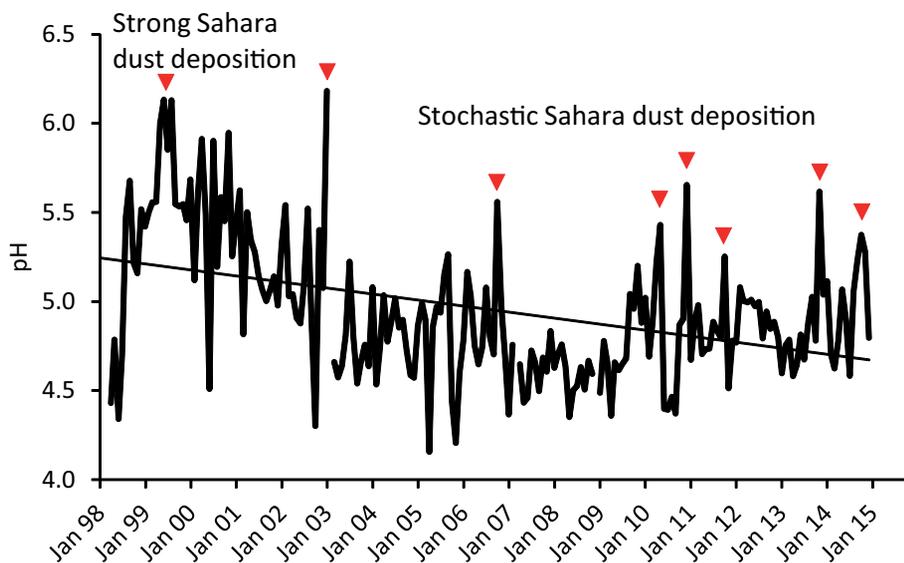


Figure 5. Course of the pH in litter leachate between 1998 and 2015.

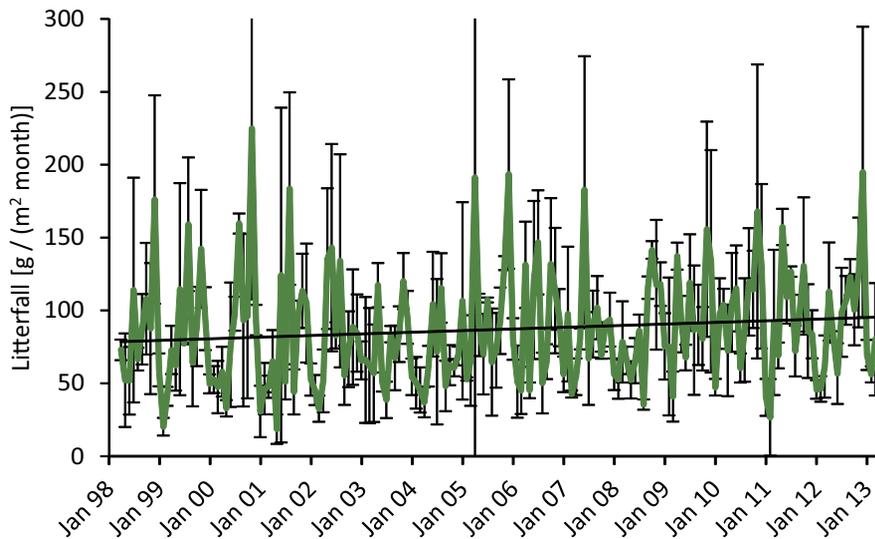


Figure 6. Course of the monthly litterfall between 1998 and 2013. Error bars indicate standard deviations of the three measurement stations.

atmospheric nitrogen deposition. One marked effect is the increase in litterfall (i.e. the leaves, twigs, flowers, and fruits which fall from the canopy to the ground (Figure 6). Another effect is that some trees grow faster, while others grow slower, which means that there are winners and losers among the tree species. In the very long run, losers might disappear.

In conclusion, our study system serves as a real-world laboratory, which allows us to follow the consequences of one of the major current global change effects, the deposition of reactive N. There are many clearly visible changes in element cycles and biomass productivity, which shift the ecosystem from a previous steady state to a new unknown future state. We observed marked changes in the N cycle in the past 15 years which could become a problem for surface and drinking water quality, accelerated soil acidification which in the long run could reduce growth of acid-sensitive plants, while stimulating growth of others and thus might finally change the extraordinary biodiversity of the study forests. It is alarming that these trends can be observed in a very remote near-natural ecosystem in such a short time.

References

- Boy J, Wilcke W (2008) Tropical Andean forest derives calcium and magnesium from Saharan dust. *Glob Biogeochem Cycle* 22: GB1027
- Boy J, Rollenbeck R, Valarezo C, Wilcke W (2008) Amazonian biomass burning-derived acid and nutrient deposition in the north Andean montane forest of Ecuador. *Glob Biogeochem Cycle* 22: GB4011
- Galloway JN, Townsend AR, Erismann JW, Bekunda M, Cai Z, Freney JR, Martinelli LA, Seitzinger SP, Sutton MA (2008) Transformation of the nitrogen cycle: recent trends, questions and potential solutions. *Science* 320: 889-892
- Schwarz MT, Oelmann Y, Wilcke W (2011) Stable N isotope composition of nitrate reflects N transformations during the passage of water through a montane rain forest in Ecuador. *Biogeochemistry* 102: 195-208
- Wilcke W, Leimer S, Peters T, Emck P, Rollenbeck R, Trachte K, Valarezo C, Bendix J (2013) The nitrogen cycle of tropical montane forest in Ecuador turns inorganic under environmental change. *Glob Biogeochem Cycle* 27, 1194-1204







Increased Nutrient Depositions affect Arbuscular Mycorrhizal Fungi in a Tropical Montane Forest

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Arbuscular mycorrhizal fungi

Mycorrhizae represent a symbiosis of fungi associated with plant roots, in which the fungal partner improves plant nutrient uptake in exchange for carbon fixed during photosynthesis. Different forms of mycorrhizal types exist, termed ericoid, ecto- or arbuscular mycorrhizae. In tropical forests arbuscular mycorrhizal fungi (AMF) clearly dominate. AMF, a phylogenetic monophylum – the Glomeromycota, represent an important mycorrhizal group showing worldwide distribution and an association with 80% of land plants. Morphologically, these fungi form arbuscules and coils (Figure 1a, b) inside the plant root cells thus enabling plant-fungus nutrient exchange. Outside the root, these fungi form a large mycelium literally extending the root surface beyond the nutrient depletion zone (Figure 2). This allows enhanced nutrient uptake, especially of phosphorus (P) and nitrogen (N), representing the main function of AMF. Additionally, they play an important role in pathogen protection, water uptake and the stabilization of soil structure.

Mycorrhizae in the context of future nutrient depositions

As a contribution to a multidisciplinary nutrient manipulation experiment (NUMEX) (Figure 2) in the tropical montane forest we analyzed the effects of nutrient additions on AMF abundance. In this experiment the future

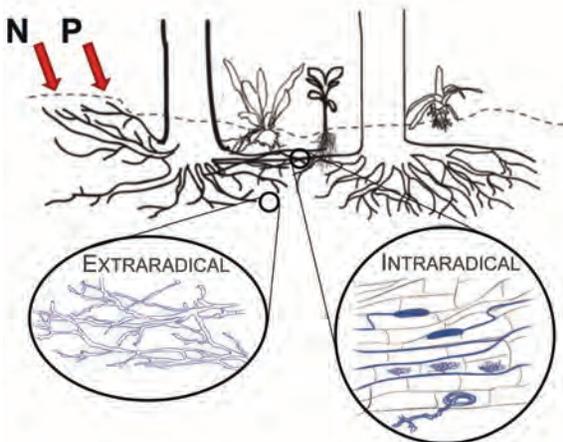
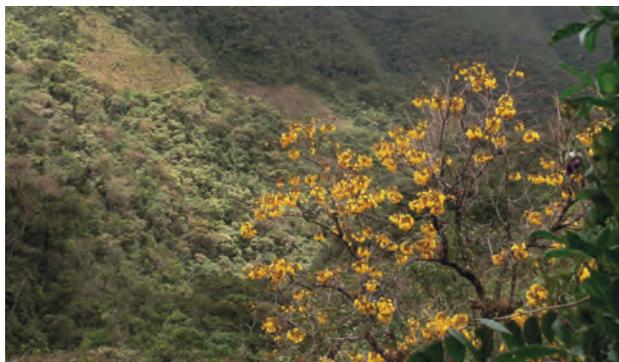


Figure 2: Image of the study area and conceptual illustration of our study design. © T. Camenzind

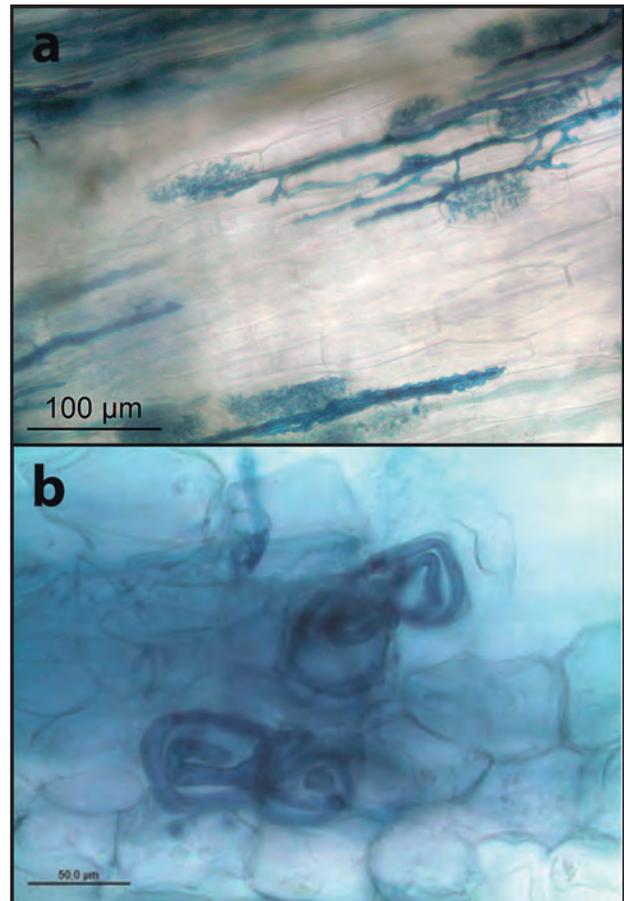


Figure 1: Intraradical AMF structures found in roots after staining with Trypan Blue: (a) arbuscules, (b) coils. © T. Camenzind

anthropogenically caused increased nutrient deposition is simulated. Since AMF play an important role in nutrient uptake, effects on the abundance and diversity of this symbiotic group can be expected, as it has been demonstrated previously for temperate areas. Upon improved nutrient availability plants can down-regulate mycorrhizal abundance to balance the costs of mycorrhizal symbionts (namely carbon investment) with their benefits. On the other hand, at very low nutrient availability AM fungi themselves may respond positively to nutrient additions since direct nutrient limitations of the fungi will be eliminated.

Study design

We focused on study sites located at 2000m (3°98'S, 79°08'W) and analyzed intra- and extraradical AMF abundance as well as AMF diversity in response to N and P additions (Figs. 2, 3). For intraradical AMF abundance data the percentage of AMF root colonization was determined under the microscope based on roots stained with Trypan Blue (Figure 1a, b). For extraradical AMF abundance the neutral lipid fatty acid (NLFA) biomarker 16:1ω5 was used that is specific for AM fungi. In addi-



Figure 3: Sampling in the NUMEX. (a) Extracted soil core. (b) One of the NUMEX subplots at 2000m. © T. Camenzind

tion hyphal length measurements and spore counts were performed. AMF community analyses were conducted by 454 pyrosequencing of the large subunit rDNA (LSU), which allows for in-depth analyses of AMF diversity.

Results

In general, we confirmed that AMF clearly represent the dominant mycorrhizal form in this system. On average 40% of roots were colonized by AMF. Coils are the predominant morphological form found in roots (Figure 1a), whereas the classical arbuscules were only rarely observed (Figure 1b). This type is known as Paris type AM. Examining the effects of fertilization, we observed a significant negative effect of N addition on AMF abundance, both in intra- and extraradical abundance. In contrast AMF abundance increased upon fertilization with phosphorus (Figure 4a, b). The negative effect of N addition was quite stable across sampling times, whereas the positive effect of P emerged after five years of nutrient additions.

Concerning AMF diversity, we found a highly diverse AMF community, comprising 74 operational taxonomic units (OTUs, a molecular approximation of a phylogene-

tic species that has not yet been described). Interestingly, this number does not reflect the steep diversity increase towards the tropics as it is still at the upper end of richness values found in temperate grasslands. All OTUs were placed within the Diversisporales and Glomerales, with Diversisporales representing a high proportion of AMF taxa, which is surprising compared to findings in temperate regions. However, this observation is in line with other AMF spore community studies in tropical forests and might be related to the acid soil. Both, N and P additions significantly decreased AMF richness and diversity, with the strongest effects of the com-

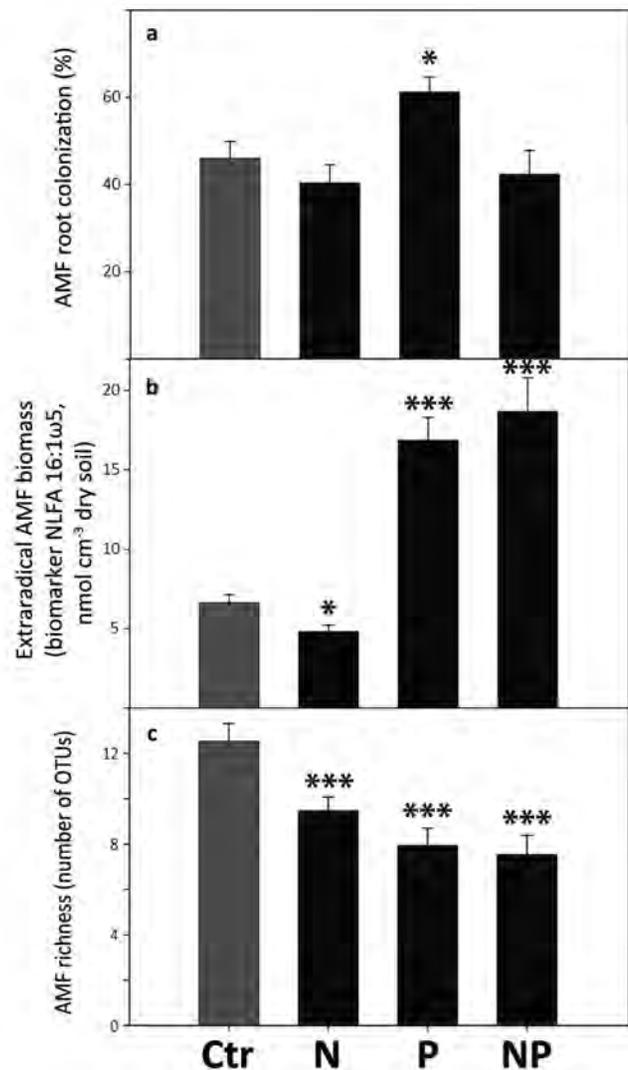


Figure 4: Responses of AMF abundance and diversity to nutrient addition. Bars represent mean values of (a) intraradical AMF abundance measured as the percentage of AMF root colonization, (b) extraradical AMF abundance given as an estimate of the biomass of the AMF NLFA biomarker and (c) AMF richness as the number of observed operational taxonomic units (OTUs). Asterisks indicate significant differences between the respective treatment and the control. © T. Camenzind

bined application (Figure 4c). Interestingly, further statistical analyses suggested that mainly rare species were affected by fertilization, whereas the few dominant OTUs were less sensitive. AMF community composition was also affected by nutrient addition, with a general shift in the AMF community mainly in response to P addition. This shift was driven by differential responses of the phyla Diversisporales and Glomerales to N versus P addition: OTUs placed within Diversisporales were only negatively affected by N addition, whereas Glomerales were solely affected by P addition.

Conclusions

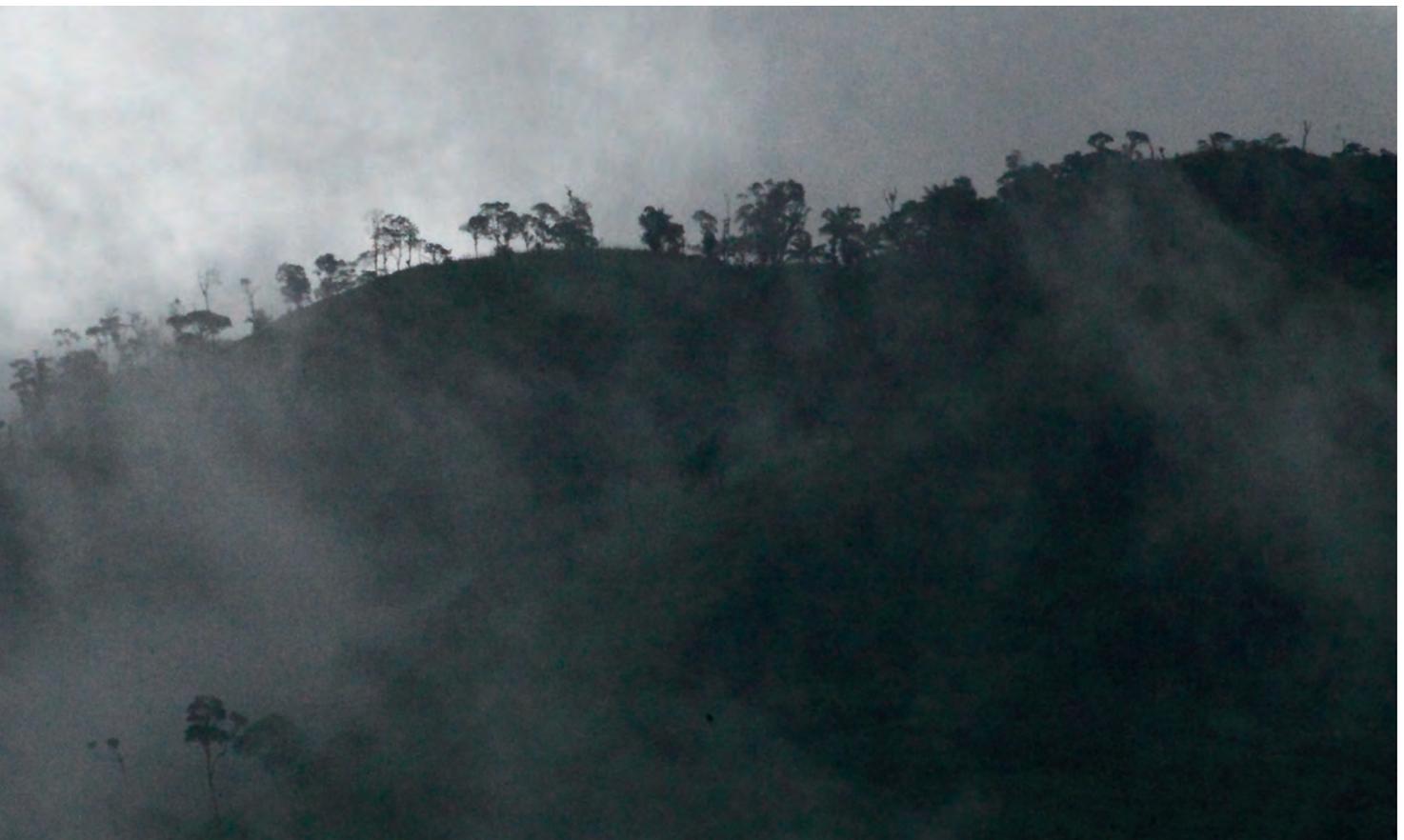
In summary, our study, representing one of the first deep-sequencing approaches conducted in the tropics show interesting new patterns on AMF abundance and diversity in a so far understudied biome. Our results clearly indicate vulnerability of AM fungal abundance and diversity in the response to nutrient deposition expected in the future, which in turn might affect further ecosystem processes. AMF play an important ecological role affecting nutrient cycling, plant community composition, microbial activity in soils and finally ecosystem productivity. These ecosystem parameters are all differentially affected by nutrient depositions and exert reciprocal effects. Thus, the NUMEX project, where several working

groups analyze different ecosystem aspects provides an exciting opportunity to monitor these effects simultaneously and potentially answer the question how nutrient depositions will influence the whole system.

References

- Homeier J, Hertel D, Camenzind T, Cumbicus NL, Maraun M, Martinson GO, Poma LN, Rillig MC, Sandmann D, Scheu S, Veldkamp E, Wilcke W, Wullaert H, Leuschner C (2012) Tropical Andean forests are highly susceptible to nutrient inputs - rapid effects of experimental N and P addition to an Ecuadorian montane forest. *PloS one* 7:e47128. doi: 10.1371/journal.pone.0047128
- Camenzind T, Rillig MC (2013) Extraradical arbuscular mycorrhizal fungal hyphae in an organic tropical montane forest soil. *Soil Biol Biochem* 64: 96-102. doi: 10.1016/j.soilbio.2013.04.011.
- Camenzind T, Hempel S, Homeier J, Horn S, Velescu A, Wilcke W, Rillig MC (2014) Nitrogen and phosphorus additions impact arbuscular mycorrhizal abundance and molecular diversity in a tropical montane forest. *Global Change Biology* 20: 3646-3659. doi: 10.1111/gcb.12618.









Global Change Impacts on Hydrological Ecosystem Services

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1.1 Introduction

A changing environment means usually changing hydrological ecosystem services. Day to day benefits, which we retrieve from hydrological services, will change due a lack or an increase of water. Starting with identifying those hydrological services that will be affected by global change, we will then assess the likely extent of those changes on a selected range of the hydrological services provided by the tropical mountainous rainforests (TMR) in Ecuador. The water related services provided by TMR not only play a crucial role for the ecosystem itself, but also for the Ecuadorian people living downstream of those regions, using the water resources directly as drinking water or indirectly as electricity from hydropower plants. Land use and climate change have been identified as the major forces driving global change in the tropics and will therefore be closer examined.

1.2 Hydrological ecosystem services

The Millennium Ecosystem Assessment (2005) classifies ecosystem services into supporting, provisioning, regulating and cultural services. Following a water droplet through the water cycle of TMR, a series of possible hydrological ecosystem services can be identified (Table 1).

1.3 Global change impacts on hydrological services

Land use and climate change are the mayor drivers of global change in the South American tropics. Studies by Breuer et al. (2013), Windhorst et al. (2013) and Exbrayat et al. (2014) in the TMR headwater catchment of the San Francisco river, show a detailed picture of land use and climate change impact on hydrological fluxes and related ecosystem services. In general, the hydrological services provided by the San Francisco catchment are manifold,

including water purification and nutrient transport, hydropower generation, net primary production of feed and timber. Frequently the extent of those services are difficult to be directly evaluated and indicators to describe the benefit retrieved from those services are more straightforward in application (see 1).

For the upcoming evaluation, we exemplarily chose two hydrological ecosystem services, which are important in the San Francisco catchment: (I) Hydropower production inferred from potential discharge. (II) Potential to mediate soil erosion inferred from the amount of surface runoff.

While hydropower production from the local hydro power plant directly generates an economic revenue, it would be difficult to assess the monetary cost of soil erosion. In order to compare the effects of different land uses and climate conditions on hydrological ecosystem services, we therefore decided to use the quantitative water flux in mm a-1 as means to describe the expected changes.

1.3.1 Land use change

Due to the ongoing urbanization of the cities Zamora in the south-east and Loja in the west of the San Francisco catchment, the TMR is increasingly affected by anthropogenic disturbances. Prior to human activities (mostly infrastructure constructions, timber production or the creation of new pasture sites by slash and burn), the catchment was exclusively covered with pristine TMR and Subpáramo. Large shares of the catchment are protected by the Podocarpus National Park since 1982. However, in 2001 55% of the area in the more accessible parts below 2200 m were already affected by anthropogenic disturbances, while above 2200 m 85% of the TMR remained intact (Göttlicher et al. (2009); Figure 1).

Stage in water cycle	Associated service	Example of indicator
precipitating in the atmosphere	<ul style="list-style-type: none"> ■ controls the energy content of atmosphere (regulating) ■ binds particles and cleans air (regulating) 	<ul style="list-style-type: none"> ■ air temperature ■ particulate matter content in air
percolation through the soil	<ul style="list-style-type: none"> ■ delivers nutrients to plants (supporting) ■ purifies water (regulating) ■ regulates habitat conditions (supporting) ■ soil storage buffers rainfall events (regulating) 	<ul style="list-style-type: none"> ■ nutrient content of soil water ■ water quality ■ soil moisture ■ peak flow volume
transpired by a plant	<ul style="list-style-type: none"> ■ drives net primary production (supporting) 	<ul style="list-style-type: none"> ■ biomass production
seeped from the soil	<ul style="list-style-type: none"> ■ taken from holy wells (cultural) ■ triggers land slides and erosion (regulating) 	<ul style="list-style-type: none"> ■ number of visitors ■ turbidity
streamflow	<ul style="list-style-type: none"> ■ hydropower generation (provisioning) ■ serves as a scenic waterfall or fishing site (cultural) ■ generates drinking water (provisioning) 	<ul style="list-style-type: none"> ■ produced electricity ■ number of visitors ■ revenue

Table 1: Hydrological ecosystem service provided by Tropical Mountainous Rainforests and suitable indicators describing the retrieved benefits.

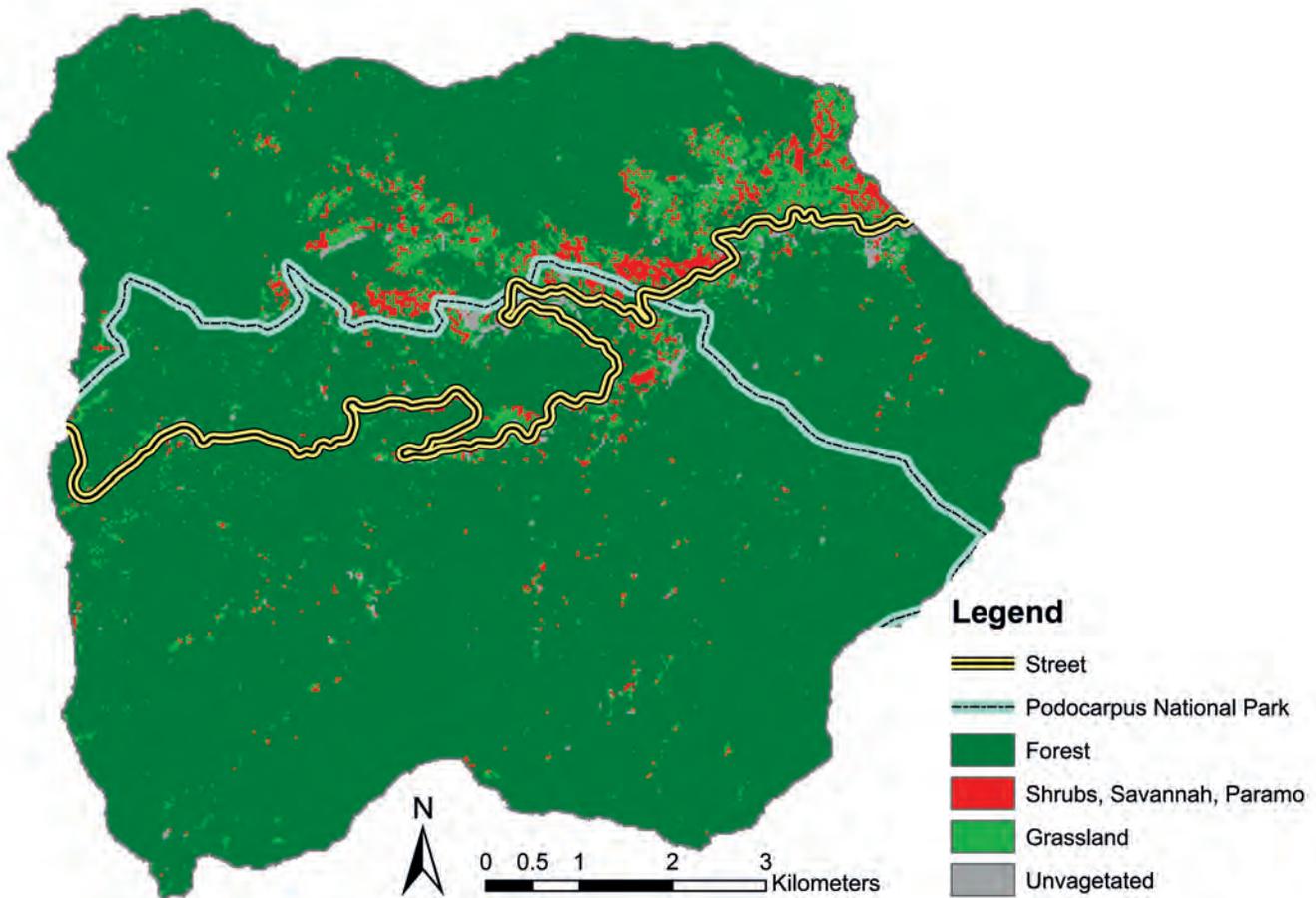


Figure 1: Land use of the Rio San Francisco catchment in 2001 showing evidence of the anthropogenic disturbances (based on Göttlicher et al., 2009).

The hydrological cycle is interwoven with a series of processes and states, which change in the wake of a changing land use. By coupling a hydrological model to a Soil-Vegetation-Atmosphere-Transfer model, Windhorst et al. (2013) assessed the effect of different land use and management types on hydrological ecosystem services. They accounted for plant specific properties of forest and pasture vegetation as well as feedback mechanisms in the soil, such as rooting depth and saturated conductivity. To separate site specific from land use specific effects, the site-specific parameterization (e.g. terrain, climate and soil conditions) in the simulation runs are the same for two simulated land use types (forest and grass land). This is feasible as both vegetation types occur under the same topographic conditions within the San Francisco valley. Species-specific physiological model parameters were changed according to field measurements. Converting a TMR into pasture reduced the evapotranspiration by 34% (from 1,433 to 945 mm a-1), while the potential discharge (sum of surface runoff and groundwater recharge) increased from 17 to 47% (from 302 to 835 mm a-1). The overall importance of surface runoff remained marginal with 3% (87 mm a-1) for

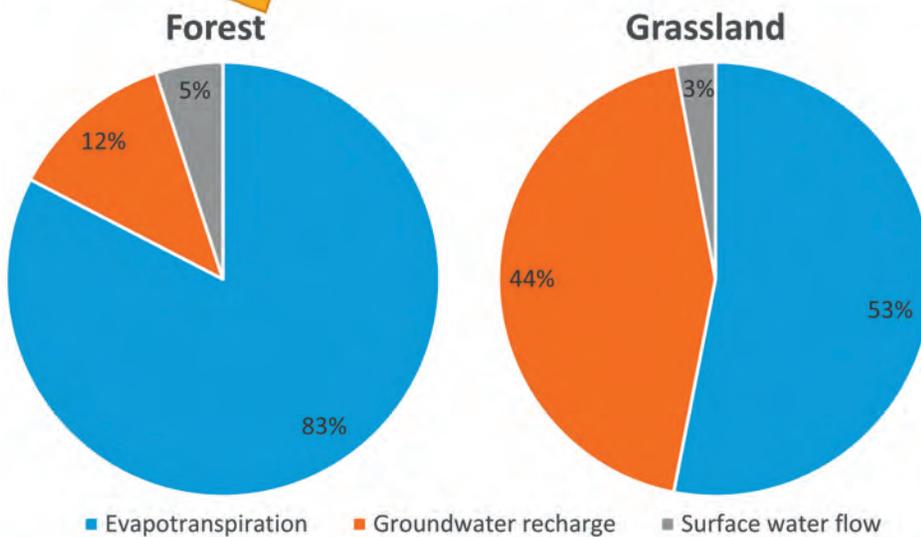
forest and 5% (52 mm a-1) for the pasture scenario. (). Even though deforestation increases the risk of surface runoff and therefore erosion, the bulk of the additional water, due to lower evapotranspiration rates, infiltrates into the soils. How will these results effect landscape scale hydrological ecosystem services? Thies et al. (2014) estimated a decline in forest cover by almost 50% with simultaneous doubling in grassland cover until 2050. The projected change for the study area was estimated extrapolating the observed change in two Landsat scenes from 1987 and 2001. Based on the predicted change, Windhorst et al. (2013) estimated an increase in water availability for hydropower production by 33%, assuming that the sum of groundwater recharge and surface runoff is available for hydropower generation in the downstream hydroelectric power station of the San Francisco river. In accordance with the results in Figure 2, a slight, but minor decrease of erosion is expected with increased pasture coverage.

1.3.2 Climate change

It has been shown that the global climate change will likely be accompanied with an intensification of the



Figure 2 Changes in flow path induced by different land use types. View to the west of the San Francisco river valley with the Podocarpus National Park to the left and pasture sites to the right of the road from Zamora to Loja. Obvious are the large erosion structures along the road (photo: D. Windhorst).



water cycle, due to changing patterns in precipitation and transpiration. As a consequence the hydrological ecosystem services will also change. Using eight statistically downscaled General Circulation Models (GCM) for emission scenarios A1B and A2 from 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Exbrayat et al. (2014) run seven hydrological models for the San Francisco river. Breuer et al. (2013) used the same results to evaluate the effects on hydrological ecosystem services in the catchment. Compared to the reference period at the beginning of the 20th century, the mean air temperature will increase by +2.9 °C and the mean precipitation by +522 mm a-1 from 1,873 mm a-1 to 2,395 mm a-1 until the period 2070-2099 (mean estimated from 16 projections; 2 emission scenarios times 8 GCM). The potential evapotranspiration of the TMR in the San Francisco valley is not limited by water availability (Ortiz et al., 2006) and thus will only slightly increase due to the increased water holding capacity of warmer air masses. The vast majority of

the additional precipitation will therefore directly generate discharge. We will therefore see a positive effect on hydropower production. Nevertheless, the observed increase in seasonality and the more likely occurrence of extreme events in the future needs to be accounted for and will most likely increase soil erosion and landslides.

1.4 Concluding remarks

The hydrological ecosystem services of TMRs are manifold. In the Rio San Francisco catchment those services are mostly associated with supporting services for ecosystem functioning and regulating services controlling the water cycle. Due to the low population density provisioning services are less important. The predicted global change, namely climate and land use change, will further intensify the hydrological cycle and alter the associated services. Even though the investigated hydrological services will remain stable or even benefit from the predicted changes whereas other services might behave differently.

References

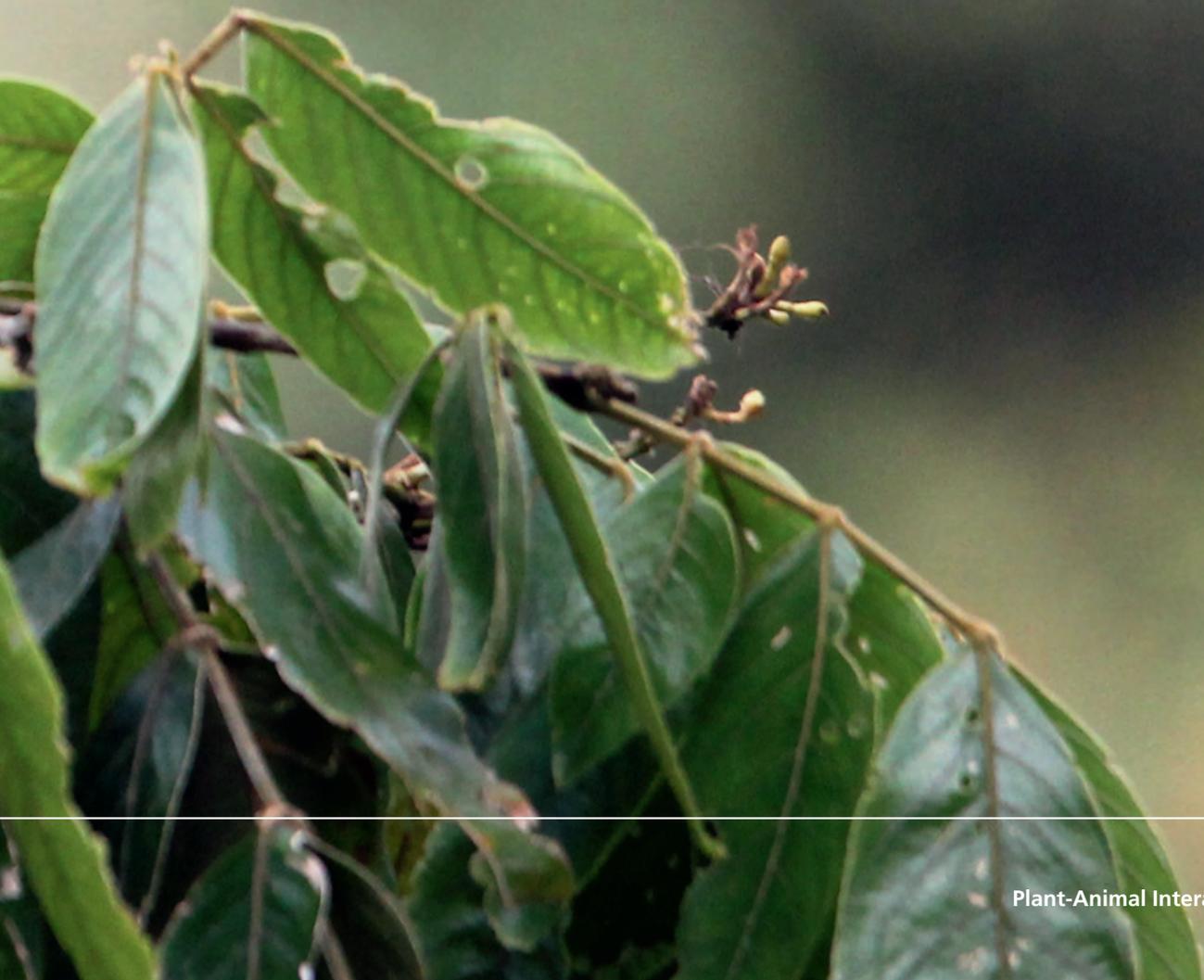
- Bagley, J.E., Desai, A.R., Harding, K.J., Snyder, P.K., Foley, J.A., 2013. Drought and Deforestation: Has Land Cover Change Influenced Recent Precipitation Extremes in the Amazon? *J. Climate* 27, 345–361. doi:10.1175/JCLI-D-12-00369.1
- Bosilovich, M.G., Schubert, S.D., Walker, G.K., 2005. Global Changes of the Water Cycle Intensity. *J. Climate* 18, 1591–1608. doi:10.1175/JCLI3357.1
- Breuer, L., Exbrayat, J.-F., Plesca, I., Buytaert, W., Ehmann, T., Peters, T., Timbe, E., Trachte, K., Windhorst, D., 2013. Global Climate Change Impacts on Local Climate and Hydrology, in: Bendix, J., Beck, E., Bräuning, A., Makeschin, F., Mosandl, R., Scheu, S., Wilcke, W. (Eds.), *Ecosystem Services, Biodiversity and Environmental Change in a Tropical Mountain Ecosystem of South Ecuador*, Ecological Studies Vol. 221. Springer, Berlin, Heidelberg, New York, pp. 265–274.
- Curatola Fernández, G.F., Obermeier, W.A., Gerique, A., López Sandoval, M.F., Lehnert, L.W., Thies, B., Bendix, J., 2015. Land Cover Change in the Andes of Southern Ecuador—Patterns and Drivers. *Remote Sensing* 7, 2509–2542. doi:10.3390/rs70302509
- Exbrayat, J.-F., Buytaert, W., Timbe, E., Windhorst, D., Breuer, L., 2014. Addressing sources of uncertainty in runoff projections for a data scarce catchment in the Ecuadorian Andes. *Climatic Change* 1–15. doi:10.1007/s10584-014-1160-x
- Foley, J.A., Asner, G.P., Costa, M.H., Coe, M.T., DeFries, R., Gibbs, H.K., Howard, E.A., Olson, S., Patz, J., Ramanakutty, N., Snyder, P., 2007. Amazonia revealed: forest degradation and loss of ecosystem goods and services in the Amazon Basin. *Frontiers in Ecology and the Environment* 5, 25–32. doi:10.1890/1540-9295(2007)5[25:ARFDAL]2.0.CO;2
- Goerner, A., Gloaguen, R., Makeschin, F., 2007. Monitoring of the Ecuadorian mountain rainforest with remote sensing. *J. Appl. Remote Sens* 1, 013527–013527–12. doi:10.1117/1.2784111
- Göttlicher, D., Obregón, A., Homeier, J., Rollenbeck, R., Nauss, T., Bendix, J., 2009. Land-cover classification in the Andes of southern Ecuador using Landsat ETM+ data as a basis for SVAT modelling. *International Journal of Remote Sensing* 30, 1867–1886. doi:10.1080/01431160802541531
- Huntington, T.G., 2006. Evidence for intensification of the global water cycle: Review and synthesis. *Journal of Hydrology* 319, 83–95. doi:10.1016/j.jhydrol.2005.07.003
- Intergovernmental Panel on Climate Change, 2014. Central and South America, in: *Climate Change 2014: Impacts, Adaptation and Vulnerability*. Cambridge University Press, pp. 1499–1566.
- Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-Being: Synthesis*. Island Press, Washington DC.
- Oritz, E.C., Homeier, J., Breckle, S.-W., Bendix, J., Emck, P., 2006. Seasonality in an evergreen tropical mountain rainforest in southern Ecuador. *Ecotropica* 69–85.
- Peters, T., Drobnik, T., Meyer, H., Rankl, M., Richter, M., Rollenbeck, R., Thies, B., Bendix, J., 2013. Environmental Changes Affecting the Andes of Ecuador, in: Bendix, J., Beck, E., Bräuning, A., Makeschin, F., Mosandl, R., Scheu, S., Wilcke, W. (Eds.), *Ecosystem Services, Biodiversity and Environmental Change in a Tropical Mountain Ecosystem of South Ecuador*, Ecological Studies. Springer Berlin Heidelberg, pp. 19–29.
- Spracklen, D.V., Arnold, S.R., Taylor, C.M., 2012. Observations of increased tropical rainfall preceded by air passage over forests. *Nature* 489, 282–285. doi:10.1038/nature11390
- Thies, B., Meyer, H., Nauss, T., Bendix, J., 2014. Projecting land-use and land-cover changes in a tropical mountain forest of Southern Ecuador. *Journal of Land Use Science* 9, 1–33. doi:10.1080/1747423X.2012.718378
- Urrutia, R., Vuille, M., 2009. Climate change projections for the tropical Andes using a regional climate model: Temperature and precipitation simulations for the end of the 21st century. *Journal of Geophysical Research: Atmospheres* 114, D02108. doi:10.1029/2008JD011021
- Windhorst, D., Brenner, S., Peters, T., Meyer, H., Thies, B., Bendix, J., Frede, H.-G., Breuer, L., 2013. Impacts of Local Land-Use Change on Climate and Hydrology, in: Bendix, J., Beck, E., Bräuning, A., Makeschin, F., Mosandl, R., Scheu, S., Wilcke, W. (Eds.), *Ecosystem Services, Biodiversity and Environmental Change in a Tropical Mountain Ecosystem of South Ecuador*, Ecological Studies Vol. 221. Springer, Berlin, Heidelberg, New York, pp. 275–286.





Plant-Animal Interactions in Tropical Mountain Forests

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Mutualism and ecosystem services

Mutualistic interactions between plants and animals are the backbone of biodiversity. Mutualism is the interaction between two organisms that both perform better because of their interaction. Famous examples of mutualistic interactions are the interactions between plants and animals. Plants are sessile organisms therefore they need vectors, such as wind or water, to transport pollen from one flower to the other and seeds away from the mother plant. Insects, birds or mammals can transfer pollen or seeds, and therefore animals have an important function in ecosystems. While plants benefit from the animals' mobility, animals benefit from the nutritious food provided by the plants, for instance, in the form of nectar or fleshy fruits. Many of the ecosystem functions that animals provide in ecosystems are also beneficial for humans and thus, can be called an "ecosystem service". Crop plants, such as pumpkin (*Curcubita spec.*), papaya (*Carica papaya*) or passion fruit (*Passiflora spec*) need pollination by insects to produce high yields.

Pollination

In the rain forests of South America, hummingbirds (*Trochilidae*) play a major role in the pollination of flowers (Figure 1). Hummingbirds have the fastest metabolism on earth, which means that they require a rapid and constant uptake of energy. The main diet of hummingbirds



Figure 1. The sparkling violetear (*Colibri coruscans*) is a frequently seen hummingbird at Podocarpus National Park. Photo: Vinicio Santillán



Figure 2. Paradise tanager (*Tangara chilensis*), a very colourful frugivore. Photo: Vinicio Santillán.

is nectar, which they find in flowers of many tropical plant species. These little birds hardly sit still and one very often only detects a rapid buzz through the understorey, before recognising which hummingbird species was passing by. Some hummingbird species show so-called "traplining" behaviour, which is a feeding strategy in which birds repeatedly track flowers on regular pathways through the forest. Typical hummingbird flowers have a red colour and a long, tubular shape. Many species of hummingbirds feed on and pollinate only specific flowers. The length and curvature of the bill of each bird indicate the type of plant flowers they prefer to visit (Maglianesi et al. 2015). For instance, hermits (*Phaethornithinae*), a subfamily of the hummingbirds, with mostly long and bent bills, are typically associated with the curved flowers of heliconias (*Heliconia spec.*).

Beside birds, many other groups of animals pollinate flowers in tropical rain forests. Some bat species are, for instance, specialized on nectar and pollen as food sources. Bat-pollinated flowers have a very different appearance compared to bird flowers. They are often less conspicuous and whitish, but exude a strong musty-sweet odour. This makes sense because bats are nocturnal animals that, in the darkness, cannot be attracted by bright colours but rather by strong odours.

The largest group of animal pollinators worldwide are insects, such as bees, wasps, flies, butterflies and beetles.

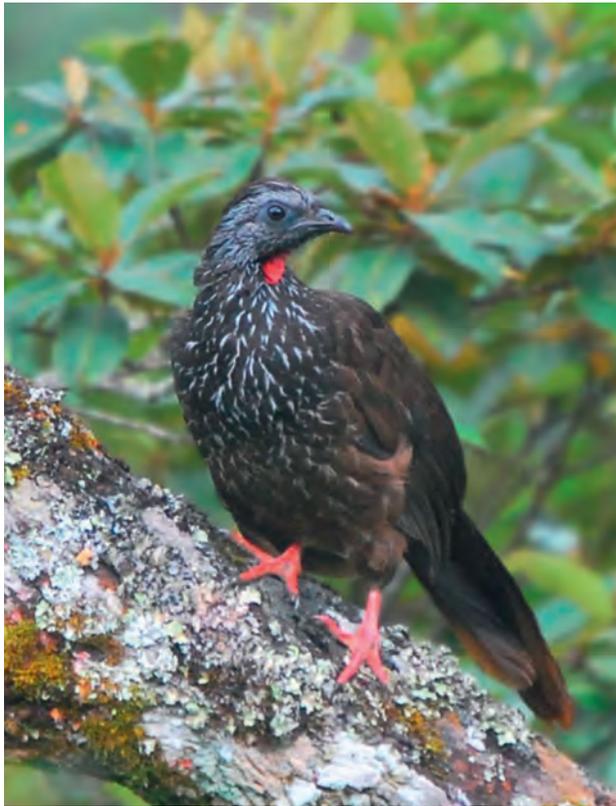


Figure 3. The Bearded Guan (*Penelope barbata*) occurs at Podocarpus National Park across an elevational gradient from 1000 to 2000 m above sea level. Photo: Agustín Carrasco.

However, expert entomologists suggest that only a tiny fraction of insect diversity has been described so far. In particular in tropical mountain regions, new insect species are being constantly discovered (see contribution by Brehm et al.).

Seed-dispersal

Another frequent animal-plant interaction in the tropics is seed dispersal. Seeds dispersed by animals can escape from competition for resources near their mother plant and colonize new habitats. Therefore, seed dispersal by animals is very important for the regeneration of many plant species. There are different ways in which animals may disperse seeds. If seeds are transported in the fur of animals (mainly mammals) this process is called “epizoochory”. Epizoochorous seeds very often show small appendices or hooks on their seed coat to effectively attach to the animal’s fur. The dispersal of seeds can also happen following ingestion by animals, so called “endozoochory”. In tropical ecosystems, over 90 % of fleshy-fruited plant species are dispersed by animals (Howe & Smallwood 1982). Many birds and mammals eat fleshy fruits that after a certain time in the gut are deposited at another location. Previous studies have shown that the passage through an animal’s gut can increase the germination success of plant seeds (Traveset 1998).

Seed-dispersal by frugivorous birds in the Podocarpus National Park

In the study area of Podocarpus National Park, birds are the main seed dispersers. In 2014, researchers counted birds in 18 study sites located at three elevations, 1000, 2000 and 3000 m above sea level. They recorded 2031 bird individuals of 188 bird species, by counting the birds seen or heard for a total time of 108 hours. Based on the limited time of monitoring, one can assume that more species are present in the study area. Fifteen percent (29 species) of the bird species recorded were nectarivorous birds that consume nectar as their main food resource and thus are important flower pollinators. Thirty percent (57 species) of the birds recorded were frugivorous birds, feeding mainly on fruits and hence acting as important seed dispersers. An important group of frugivores are the tanagers (*Thraupidae*, Figure 2). Most tanagers are very colourful birds that range the forest in small groups, mostly in mixed flocks with other bird species, searching for food.

The researchers found relatively little overlap in the bird community along the elevational belts. Most species which one encounters at the lowland forest at 1000 m altitude are absent in the elfin forests at 3000 m (Figure 3). Not a single bird species was present at all three elevations.



Figure 4. White-breasted parakeets (*Pyrrhura albipectus*), here feeding on *Miconia* fruits, are endemic to Southern Ecuador and Northern Peru. Their main threat is the loss of their habitat, tropical mountain forest. Photo: Marta Quitián.

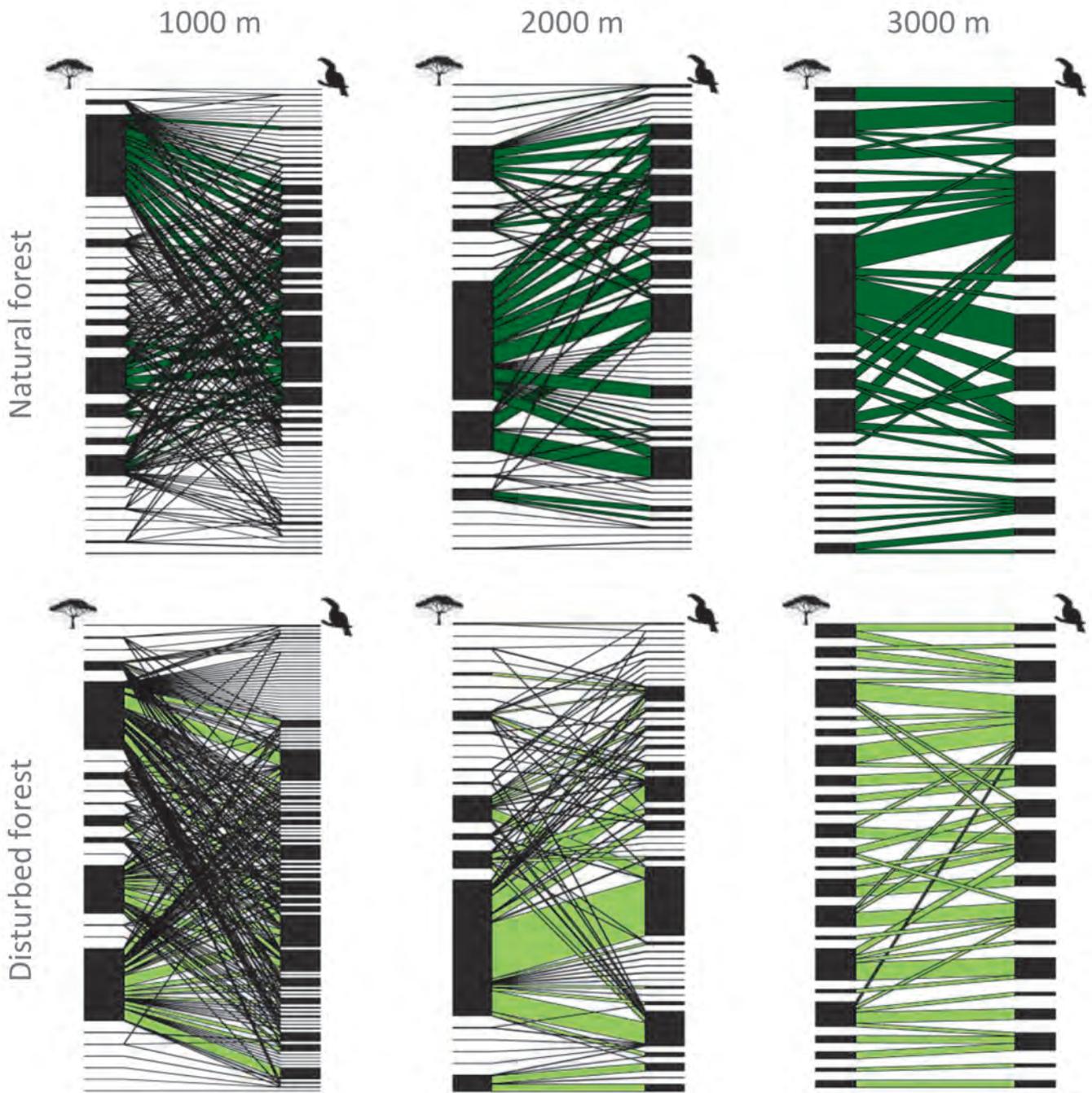


Figure 5. Plant-frugivore interaction networks across three elevations (1000, 2000 and 3000 m above sea level) and two habitat types (top: natural forest in dark green, bottom: disturbed forests in light green) in the Podocarpus National Park. Plant species are depicted as black bars on the left side of the plot; frugivorous bird species are depicted as black bars on the right

side of the plot. Each line between a plant and a bird species represents that the respective bird species consumes fruits of the plant. The thicker the line, the more feeding events have been recorded of the two mutualistic partners, relative to the other species interactions in the network.

Figure by Marta Quitián.

A very special frugivore in the Podocarpus National Park is the White-breasted parakeet (*Pyrrhura albipectus*, Figure 4). The bird species is endemic to the region of southern Ecuador and small areas of northern Peru, which means that its global distribution is limited to this small zone. Groups of White-breasted parakeets can regularly be heard or seen at the Podocarpus National Park in the drier season when the birds feed on fruits in the canopy. Their main threat is the loss of their habitat, the tropical mountain forest.

Messages of species interaction networks

Tropical mountain ranges, which are a global hotspot of biodiversity, harbour a high diversity of interacting species. Such a high diversity also leads to high complexity of interactions among the species. The greater the number of species that interact with each other, the more difficult it is to understand their role in the functioning of the ecosystem. Mapping of species interaction networks help to disentangle the complexity of mutualistic interactions (Schleuning et al. 2011). Interaction networks are built in a way that both plants and animals that are present in an ecosystem are separately listed (Figure 5). If two partners, a bird and a plant, interact e.g., the bird eats the fruits of a particular plant, this interaction would be indicated by a straight line in the network, linking the two mutualists (Figure 5). Interaction networks provide a relatively easy tool to visualize how species are interlinked with each other. Some species, such as *Miconia* species in plants or the tanagers in birds, show many links in interaction networks. These may be considered key species for the ecosystem because many birds feed on *Miconia* fruits and tanagers may disperse the seeds of many plant species.



Figure 6. Fragments of the tropical mountain forest surrounded by pastures in the research area.

Interaction networks can also reveal the degree of specialisation of the interactions within a species community. Birds that consume many different fruit species, such as tanagers, are generalist species. In contrast, birds that only feed on a particular plant species are much more specialized in their feeding behaviour. Species living at high altitudes tend to be more specialized than species at low altitudes. In other words, bird species at high altitudes mostly feed on a small subset of the plant species available, whereas birds at low altitudes consume a wide variety of the available fruit species (Figure 5).

Habitat degradation and ecosystem services

One important question resulting from current global changes is what happens if we remove important elements, a plant or a bird, from an interaction network? Human impacts, such as habitat degradation or fragmentation, have severe consequences for topical ecosystems worldwide (e.g., Neuschulz et al. 2011). The area covered by tropical mountain forests is continuously shrinking at an alarming rate.

Researchers at the Estación Científica San Francisco (ECSF) study how habitat destruction and fragmentation affect bird diversity and seed dispersal interactions at the Podocarpus National Park. So far, the results indicate that seed-dispersal interactions can, to some degree, be maintained also in human disturbed forests islands (Figure 6). However, the researchers find strong changes in the local bird communities. Sensitive forest species often disappear in disturbed forest “islands”. The long-term consequences for the mountain forest ecosystem are still not clear. Conservation plans must focus on mutualistic plant-animal interactions to maintain the functioning of tropical mountain forest ecosystems.

References

- Howe F, Smallwood J (1982) Ecology of seed dispersal. *Annu Rev Ecol Syst* 13: 201–228
- Maglianesi MA, Böhning-Gaese K, Schleuning M (2015) Different foraging preferences of hummingbirds on artificial and natural flowers reveal mechanisms structuring plant-pollinator interactions. *J Animal Ecol* 84: 655–664
- Neuschulz EL, Botzat A, Farwig N (2011) Effects of forest modification on bird community composition and seed removal in a heterogeneous landscape in South Africa. *Oikos* 120: 1371–1379
- Schleuning M, Blüthgen N, Flörchinger M, Braun J, Schaefer HM, Böhning-Gaese K (2011) Specialization and interaction strength in a tropical plant-frugivore network differ among forest strata. *Ecology* 92: 26–36
- Traveset A (1998) Effect of seed passage through vertebrate frugivores' guts on germination: a review. *Perspectives Plant Ecol Evol Syst* 1/2: 151–190



Benefits of Remote Sensing Data for Biodiversity Monitoring Birds, Ants and their Role as Predators

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Biodiversity describes the variability of all living organisms and comprises the variability of ecosystems, of species, and within species (genetic diversity). One of the most diverse, important, and threatened biodiversity hotspots of the world are tropical mountain rainforests. Especially the Andean mountain rainforests are known for high numbers of endemic species such as trees, moths, and birds. Land use intensifications often threaten mountain ecosystems through a loss of biodiversity – e.g. extinction of certain species. As every species plays a specific role within an ecosystem a loss of diversity can lead to the degradation of important ecological functions. One important ecological function is herbivory of insects on seedlings, which influences the ability for forest regeneration. For instance, a compositional change of insects and/or their predators can strongly alter forest regeneration. Simultaneously, herbivores depend on the diversity of occurring plants and are regulated by their predators – e.g. insectivorous birds, ants, and wasps. High numbers of insectivorous predators have cascading effects on forest regeneration: Decreasing numbers of herbivores reduce herbivory leading to enhanced plant seedling survival. A continuous monitoring of all aspects of biodiversity is

therefore important. This means to monitor different measures of biodiversity and not only selected important or attractive species (often called flagship species). Instead, integrative indicator systems are urgently needed that comprise species as well as functional diversity measures.

A continuous monitoring of herbivory and predation can provide important insights into the status of forest ecosystems. Nevertheless, the quantification of those functions is time consuming and cost intensive, especially for large areas. A simple indicator system that can be applied over large scales is therefore urgently needed for conservation planning and the development of management strategies. Recent improvements of remote sensing technologies offer possibilities to develop indicator systems at a landscape scale with high resolutions. Remote sensing data – such as aerial pictures – can be used to predict certain aspects of biodiversity such as species richness. The development of indicator systems for ecosystem functions – such as herbivory, predation, or seed dispersal – would allow a continuous and convenient monitoring of the status of threatened ecosystems and the biodiversity therein.

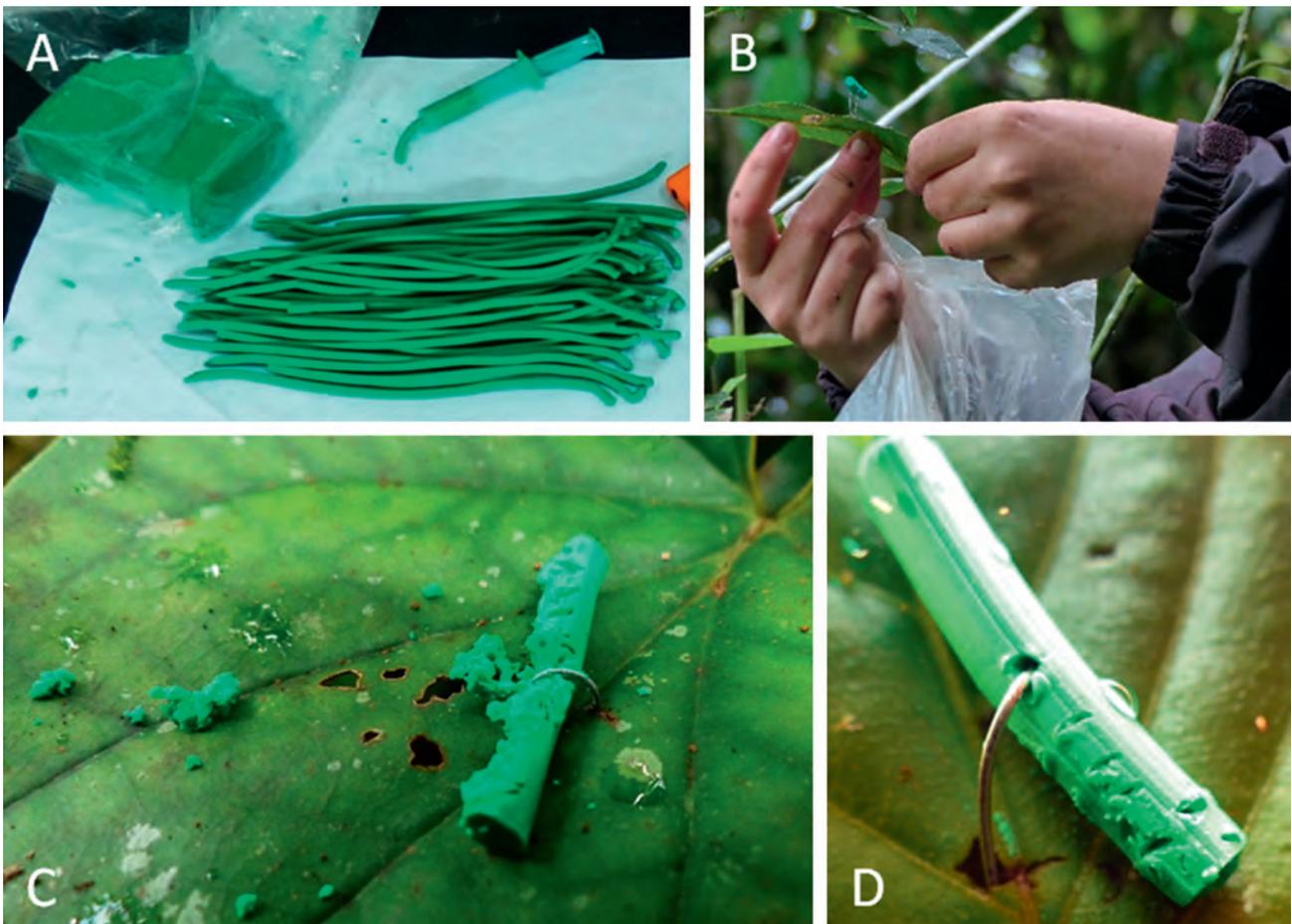


Figure 1. The artificial caterpillars approach. A: plasticine material for forming artificial caterpillars. B: The placement of these caterpillars on seedlings in the understory of tropical forests. C: Bite marks of bee(s) and D: Bite marks of ant(s).

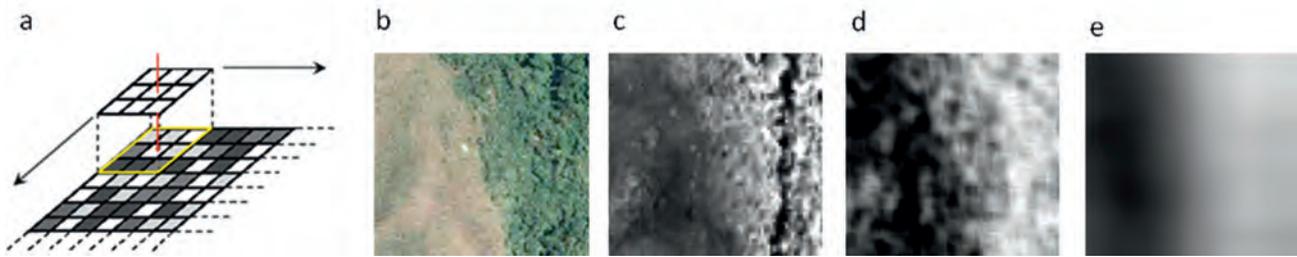


Figure 2. Image textural approach: (a) Recalculation of the centered pixel (red arrow) within a defined neighborhood in a 3 * 3 pixel window (yellow area). Black arrows define the movement in two directions; textures will be calculated for each shift. (b) True-color image of a pasture on the left lower panel and forest sites on the right upper panel. Near-infrared band of the same study site (c), light areas identify higher values and thus dense vegetation. Image textures (entropy) were calculated on the near-infrared band within a 5 * 5 pixel window (d) and within a 45 * 45 pixel window (e). Light areas define high heterogeneity and dark areas more homogeneous regions.

One aim of our current research is to map different measures of diversity. Our pre-liminary maps of species richness of birds and ants across our study area are found in Figure 2.

In addition to species diversity we aim to predict related processes such as herbivory and predation and their reciprocal interactions. For that purpose, we use a three-step approach for the development of a remote sensing indicator system for biodiversity and ecosystem processed within mountain rainforests. Here we exemplary present our approach for assessing predation on herbivorous insects. First of all the "field data" of the target function was needed. To quantify predation on herbivores it is possible to use artificial caterpillars. Artificial caterpillars were formed out of Plasticine so that they resembled real caterpillars of the area (Figure 1 A). The caterpillars were displayed on leaves in the monitoring area (Figure 1 B). After a certain period of time the caterpillars were recollected. During the time of exposure of the caterpillars insectivorous predators had the possibility to find their "artificial prey". Every attempt of predation left marks in the Plasticine material which could be assigned to specific predator groups due to specialized forms of jaws (insects) or beaks (birds) (Figure 1 C, D). The number and type of bite marks on the caterpillars was used to quantify and to qualify the predation process.

The second important part was the development of structural habitat indicators of the study area derived from remote sensing data. For this purpose we assessed airborne orthoimages which are geometrically corrected aerial photographs where each pixel has the same scale; in our case 0.3 m per pixel length. The images included four spectral bands: red, green, blue, and near-infrared. Vegetation differs in its reflection and absorption depending on characteristics such as species, leaf-pigments or healthiness. Specific vegetation indices such as the Normalized Difference Vegetation Index (NDVI) gave information on the vegetation greenness due to the reflection of near-infrared and the absorption of visible light for photosynthesis. To incorporate the spatial varia-

tion of reflection- or vegetation indices, we used texture analysis. Here, each pixel was recalculated by statistics of a defined surrounding called moving window (Figure 2 a). Depending on the statistics which ranged from simple (e.g. mean, variance) to complex (e.g. contrast, correlation) equations, image textures explained different aspects of vegetation heterogeneity. An example for image texture is shown in Figure 2 b-e.

The third step will be to intersect the field data on predation and the results of the remote sensing analysis. Based on the assumption that predation is linked to habitat structure, mathematical methods will allow using the remote sensing derived indicators to predict predation into new areas.

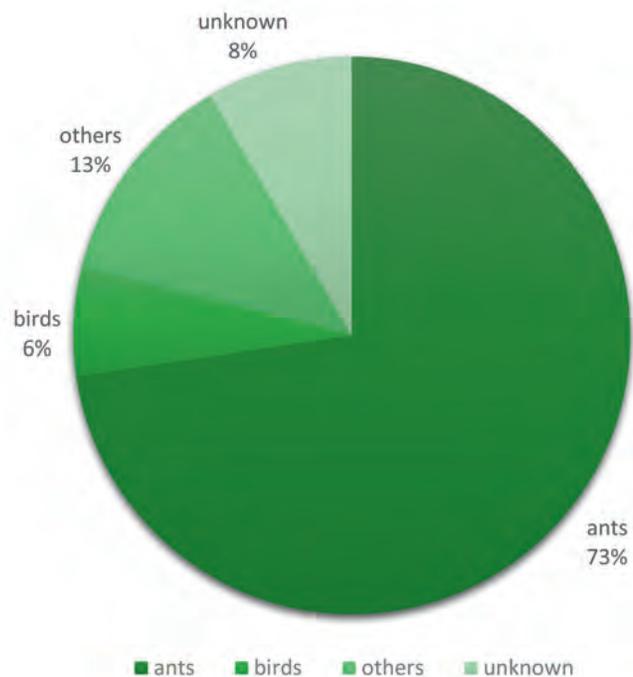
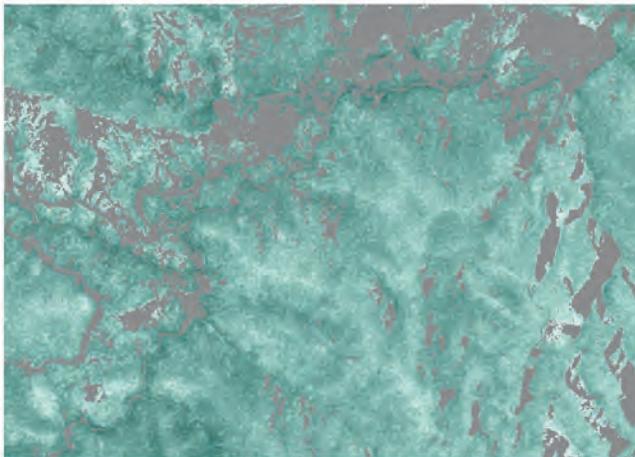


Figure 3. Results of artificial caterpillars field experiment. Number of bite marks was highest for ants, followed by others (mostly bees and wasps). Marks which were not identifiable were summarized in the class 'unknown'.

First results of the analysis of bite marks on artificial caterpillars revealed that ants and birds were the main predators of caterpillars in the understory of the mountain rainforest (Figure 3). The impact of birds on the predation on caterpillars was relatively small with only 6 % of the observed predation events. Ants accounted for about 73 % of predation events and thus seemed to be the major predator in the study area. In a next step we will focus on the distribution of the functional diversity of ant and bird communities and on the distribution of the ecological functions herbivory and predation. We want to link these spatial patterns to remotely sensed vegetation structure to test which textural metrics explain them best. Thus, the development of meaningful indicators based on remote sensing will enable continuous and cost-efficient monitoring of the status of forest ecosystems even for remote or harsh areas.



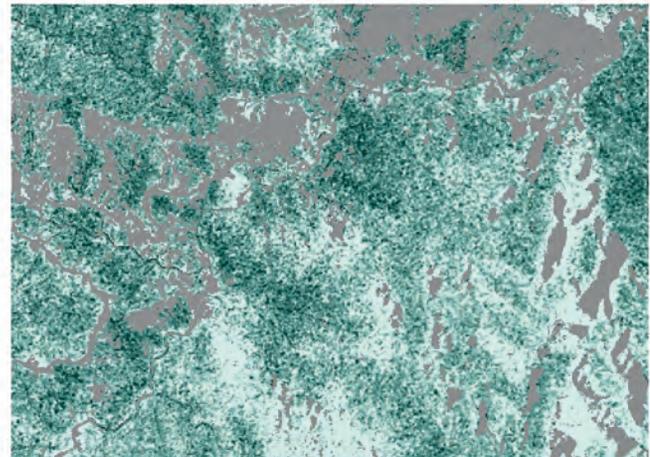
Ant species richness



No. of ant species



Bird species richness



No. of bird species

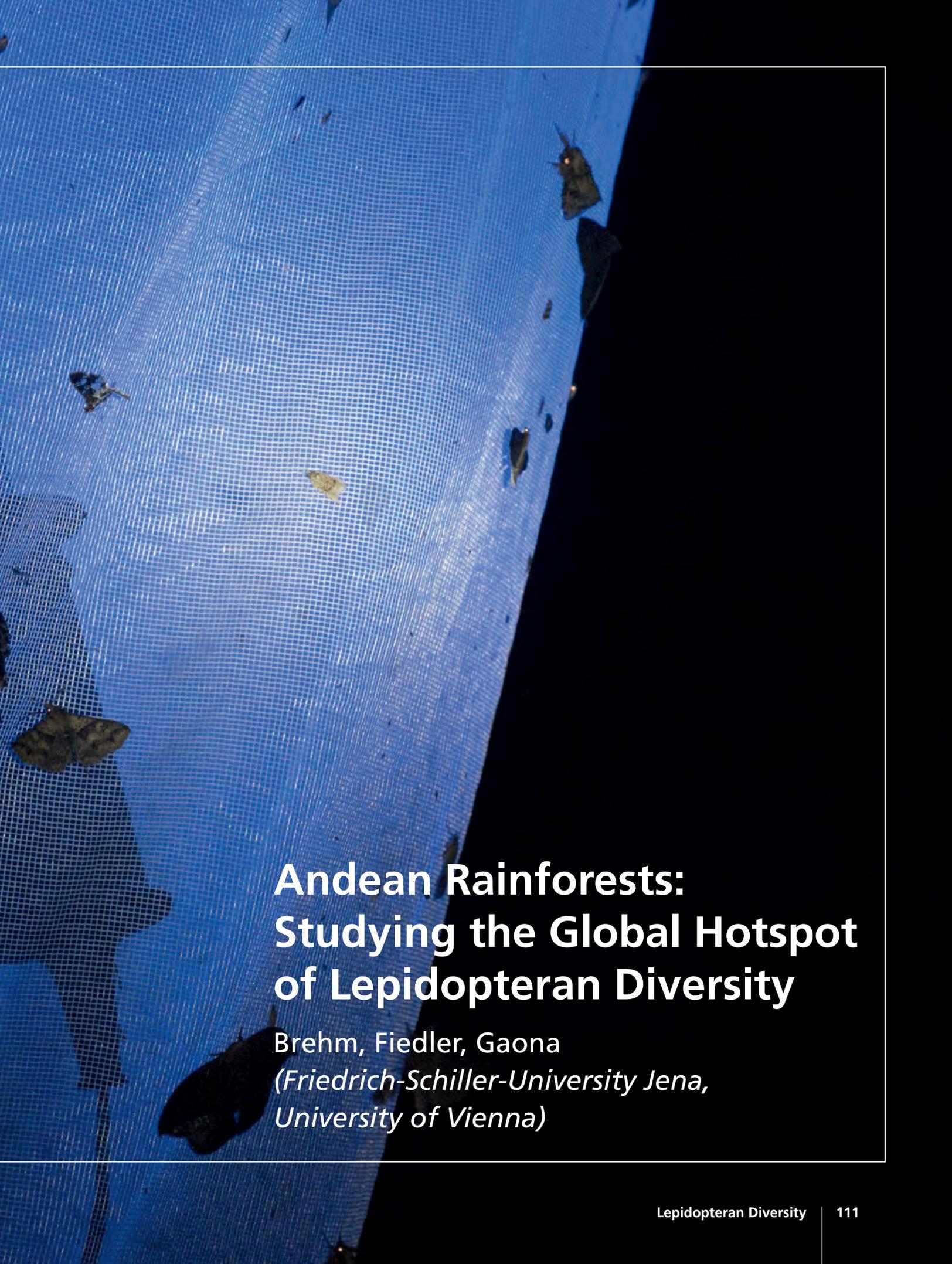


Non-forest or cloud mask

Figure 4: Study area in Southern Ecuador and prediction maps of species richness for birds and ants. Colors are scaled according to the minimum and maximum observed species richness.







**Andean Rainforests:
Studying the Global Hotspot
of Lepidopteran Diversity**

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Figure 1. A composite image of moth images – only a small fraction of the diversity found in southern Ecuador.

Andean rainforests have long attracted entomologists because of their stunning biodiversity. However, little is still known about most insects living in these forests. It is still not even possible to provide reasonable estimates of approximate species numbers thriving in these biota. Our research on insect diversity patterns along elevational and other environmental gradients in southern Ecuador has started in 1999 and has produced many new surprising and exciting results. Nowhere else in the world have so many different species of moths been recorded from a comparably small area. We have mainly focused on the very species-rich moth clades Geometridae (inchworms or looper moths) and Arctiinae (tiger moths and woolly bears). A subset of geometrid moths is illustrated in Figure 1.

Why do moths matter?

Due to their abundance and species richness in Andean montane rain forests, moths play an important role in these ecosystems, as defoliators of plants, detritivores, pollinators, and as food for other animals. Knowing more about the biology, species richness and abundance of moths is thus necessary for the understanding of ecosystem processes. The documentation of their diversity also helps in understanding regional and global biodiversity patterns, e.g. at which latitude and which elevation diversity peaks – fundamental questions both to biogeography and macroecology.

The insect order Lepidoptera (which means “scale wings”, i.e. butterflies and moths) comprises ca. 160.000 described species globally, and estimates of true richness



Figure 2. Adult of a *Ctenuchina* moth (Erebidae, Arctiinae).

exceed 250.000 species to exist worldwide. Like in all holometabolous insects, the development starts with an egg that is laid by the female – usually on a specific host plant. After one or two weeks, a caterpillar hatches and starts to feed on the host plant (Figure 2). Unless is attacked by a predator or parasitoid, the caterpillar regularly changes its skin a couple of times during its development until it reaches its final size after a few weeks. The larva then develops into a pupa, and after a fundamental metamorphosis, the adult butterfly or moth hatches. At this winged life stage, the butterfly or moth now no longer feeds on foliage of plants, but rather persists on drinking flower nectar, nutritious fluids from fruits, or relies entirely on fat reserves. The main biological tasks of these adult stages are to find a mate and to reproduce.



Figure 3. *Oenoptila anetteae*, a species found from Ecuador to Bolivia, recently described as a new species by G. Brehm.

The Lepidoptera consist of the relatively well known butterflies that can be observed at daytime, such as swallowtail butterflies and Neotropical *Morpho* and *Caligo*. However, butterflies are a smaller minority among the Lepidoptera and account for only ca. 10% of the known species. Most species are moths; they are often less conspicuous than butterflies, and mostly are active during the night. Although often neglected, moths are not only functionally important components of most ecosystems, they can also be very beautiful like the illustrated moth of the genus *Oenoptila* from Ecuador that was first described in 2005 (Figure 3).

How are moths collected and what happens then?

The most valuable data on individual moth species can be obtained when caterpillars are collected in the forest, their food plants identified, and the specimens carefully fed and reared until adulthood. Doing this, the early instars of the moths as well as the functional relationships to their hosts can be documented before the adult moth is finally pinned and placed in a permanent insect research collection (Figure 7). During our research, many hundreds of caterpillars have been found and recorded this way. This allowed us to uncover unexpected nutritional relationships, such as caterpillars feeding on epiphyllic mosses or dead plant tissues rather than on green foliage of living shrubs or trees. However, this approach is a very labour intensive work and is largely limited to species whose larval stages live on plants that are accessible to the researcher, thus largely precluding those many moth or butterfly species whose caterpillars feed on epiphytes or in high tree crowns.



Figure 4. A „light tower“ attracts many insects at night.

An easier way of sampling moths at the community level is using a “light tower” as illustrated in Figure 4. Using artificial light, ideally with a high share of ultraviolet radiation, is a very efficient way to attract nocturnal insects (Figure 5). It is often surprising to see how many well camouflaged insects, not detectable during daytime, come to light. Researchers can then collect their target groups. Our approach has always been quantita-

tive, i.e. all moths of the target groups were collected, processed and analysed. These samples are then amenable to statistical analyses employing up-to-date multivariate techniques which allow to detect signals of environmental drivers that regulate insect assemblages. How strongly are these animals regulated by climatic forces? What role does the vegetation play? Are these relationships between moths and their environments similar across different taxonomic or functional groups of moths? These and many other scientific questions have become tractable only on the grounds of standardized sampling and subsequent high-resolution taxonomic elaboration.

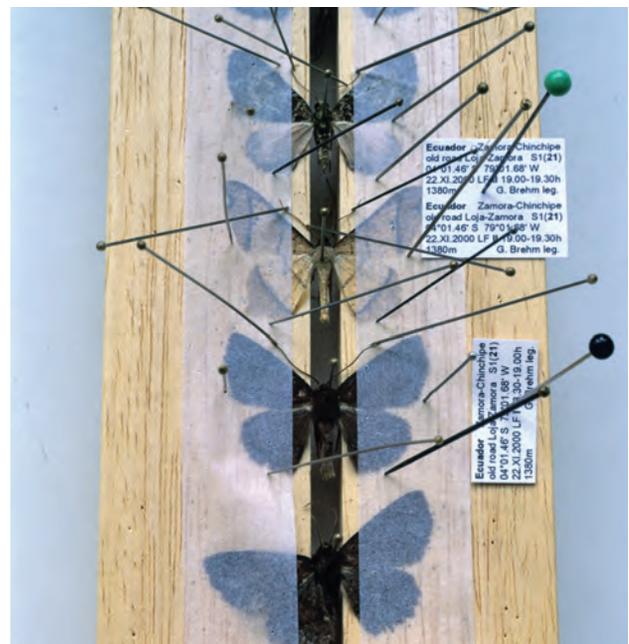


Figure 5. Many hundreds of moths are sometimes attracted to light.

Collecting moths at night often means that most of the work actually has to be done at daytime (Figure 6A). During three hours of standard sampling in the evenings, dozens or hundreds of individuals are sampled that need to be processed afterwards, i.e. they are prepared for the storage in the freezer until the moths are pinned and labelled (Figure 6B). Once the pinned moths are dry, they can be sorted, identified and individually databased. Long-term storage in museum reference collections is a prerequisite for sustainable work that will allow comparison, taxonomic updates and further exploration in the future (Figure 7).



Figure 6. Moth processing and preparation is labour intensive but produces high quality long-term reference collections for use by later generations of scientists. (top) Moth exploration (bottom) Moth preparation



Some important results

During more than 15 years of research on insect diversity in southern Ecuador, thousands of moths were collected – as caterpillars on their host plants, or as adults by light-trapping along ecological gradients of elevation, disturbance and microclimate. While still very little is known about the ecology of moths, and insects in general, in the tropical Andes, our results have shown that the montane forests are indeed the “hottest hotspot” of biological diversity on Earth for moths – at least for those groups that we have explored in depth. We are still counting new and undescribed species after each field trip. Using traditional and modern molecular methods for species delimitation, numbers of geometrid and arctiine moths combined now by far exceed 2,000 species from a small area around Podocarpus National Park. We have shown that local diversity of geometrid moths is equally high in the natural forest between 1,000 and



Figure 7. One result of ecological research: a long-term research collection for various purposes such as macroecology, biogeography and taxonomy.

3,000 m whereas diversity of tiger moths continually declines with elevation. There are fewer genera at high elevations, but some of them have radiated to a surprising extent. For example, we have sampled more than 270 species of *Eois* (Figure 7) in southern Ecuador and estimate that ca. 90% of these species are still scientifically undescribed. Our detailed documentation of larval life histories has also revealed that especially this species-rich genus *Eois* is largely made up of host plant specialists – which is important for understanding their evolution as well as for conservation prospects. Old-growth montane forest with its high plant species richness and structural complexity harbours far more moth biodiversity than abandoned pastures or otherwise deforested areas of the same region. The COI gene of thousands of geometrid and arctiine moths have been sequenced, and the data are now publicly available online on the Barcode of Life System.

The *Eois* example also shows that the biological discipline of taxonomy is still needed urgently: Can we imagine doing research on *Drosophila melanogaster* or other animals without referring to a commonly accepted scientific name? Many moths collected for ecological research in Ecuador can be used in the future as type



Figure 8. *Hagnagora anicata*, a *Geometridae* species found from Colombia to Bolivia. Modern taxonomic and molecular work has shown that the species actually consists of at least five distinct but very similar species.

specimens of new species. This work has just started, for example with a revision of the *Geometridae* genus *Hagnagora* (Figure 8).

Threats to a diversity hotspot

Unfortunately, Andean forests are still being destroyed at an alarming rate. While we have been collecting moths in the Reserva Biológica San Francisco and in adjacent Podocarpus National Park, we have seen massive destruction of natural habitats in the vicinity of the area, increasing grazing and agricultural activities as well as the introduction of further exotic plant species. Experimental reforestations with native tree species have been initiated to reclaim abandoned pastures for ecological functions, but at least as long as these plantations are young, their moth faunas turned out to be distinctly depauperate. We still know too little about the Andean forest ecosystems; we have collected hundreds of new moth species that are not deposited in any scientific collection in the world while we see their habitats shrinking and vanishing. How many species have already been lost without ever having been seen or documented? We wish that future generations of biologists will still have the chance to explore these exciting forests, and that fires and chainsaws will be stopped – the sooner the better.

References

Brehm G, Hebert PDN, Colwell RK, Adams MO, Bodner F, Friedemann K, Möckel L, Fiedler K (2016) Turning up the heat at a hotspot: DNA barcodes reveal 80% more species of geometrid moths along an Andean elevational gradient. *PlosOne* 11: e0150327. DOI: 10.1371/journal.pone.0150327





Hidden Symbiosis conserves Plant and Fungal Diversity – Investigating Mycorrhizae of Trees and Orchids

Haug, Kottke, Suárez
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First recognized by A. B. Frank (1885) in forests around Berlin and later corroborated by hundreds of scientific studies in temperate regions, it was shown that most plants depend on fungi for nutrient especially phosphate uptake, and – by a symbiotic interaction called mycorrhiza – support these root inhabiting fungi by delivering carbohydrates and amino acids. Although these statements are well founded, mycorrhizae and their extraordinary importance in terrestrial ecosystems are only gradually recognized by the public and very little was known of mycorrhizae in tropical mountain forests. After 15 years of collaborative research of the Eberhard-Karls University Tuebingen, Germany, with the Universidad Tecnica Particular de Loja (UTPL), there is no doubt any more about the omnipresence of mycorrhizae in the tropical mountain forests of the Andes (Kottke et al. 2013). Importance of mycorrhizae for conservation of this ecosystem hotspot of diversity needs to be further unravelled.

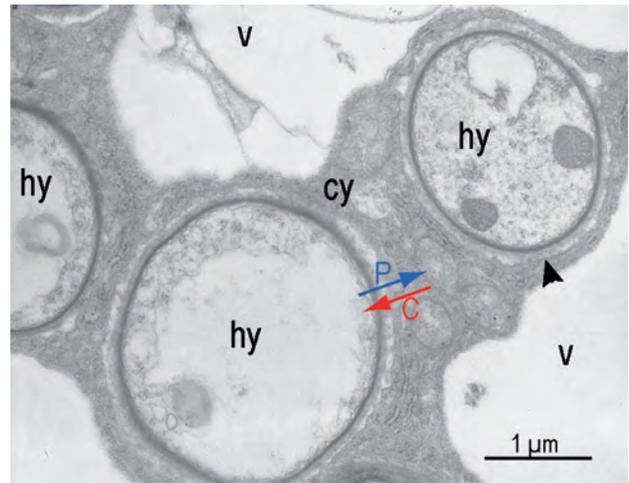


Figure 1. Hyphae (hy) of the mycobiont are inside the root cortical cell, separated from the cytosol (cy) by a membrane of the plant cell (arrowhead). V vacuole. Arrows indicate exchange of sugar against phosphate across the membranes of active hypha and root cell. TEM micrograph.

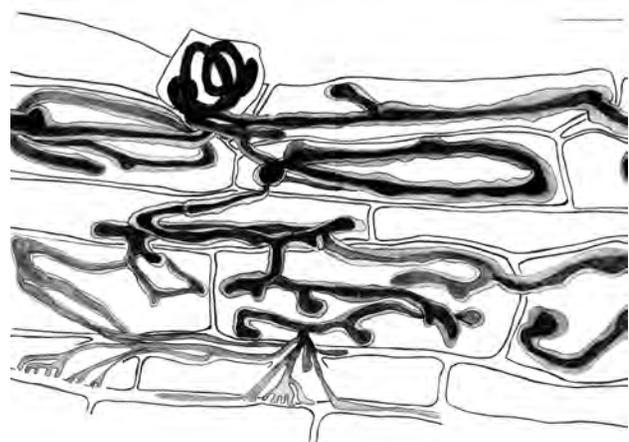
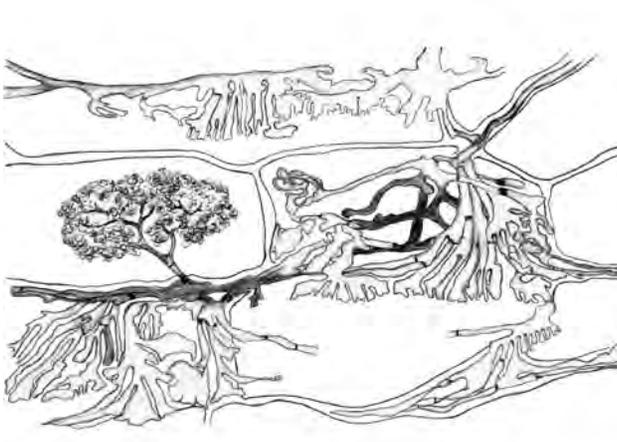
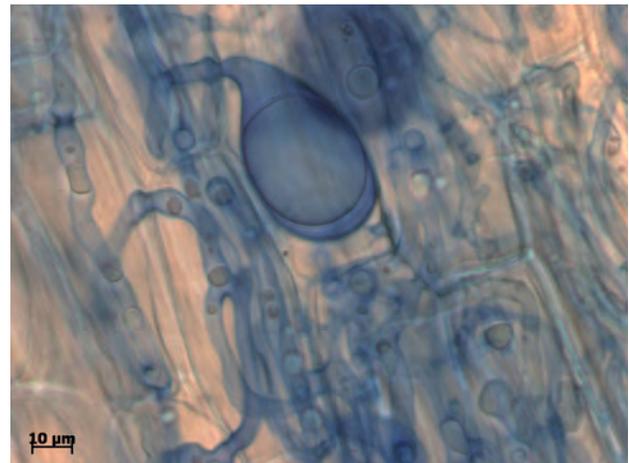
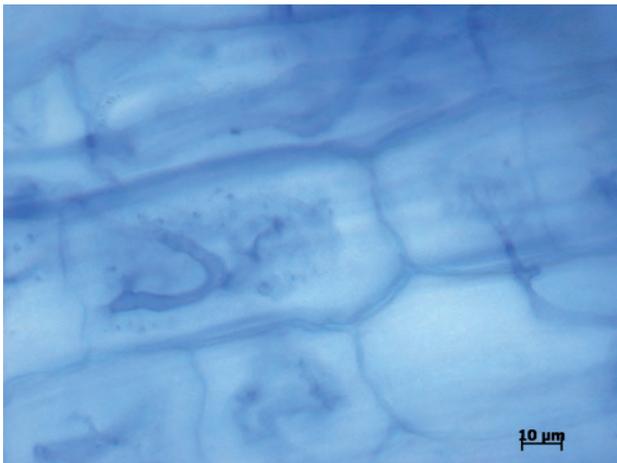


Figure 2. Examples of arbuscular mycorrhizal structures formed by Glomeromycota with tropical trees: Hyphae without septae form fine branched arbuscules (a, c), coils and vesicles or spores in the root cortical cells (b, d), (drawings by A. Beck, with personal permission).

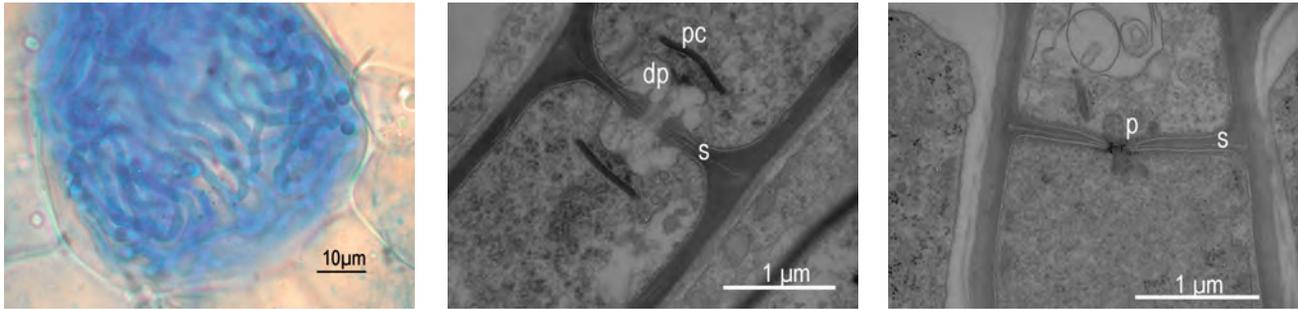


Figure 3. The orchid mycobionts form dense coils in the root cortical cells (a); (b) hyphae form straight walls, septae *s*, with the typical dolipore (*dp*) with pore cap (*pc*) (*Sebacinaceae* and *Tulasnellaceae*), (c) simple pore (*p*) with microbodies (*Atractiellaceae*).

How did we learn about mycorrhizae and their fungi?

Mycorrhizae are formed by the very fine roots and the symbiotic fungi (mycobionts) which are not visible by the naked eye. Microscopy, however, reveals complicated fungal structures in the cortical root tissue which are a safe tool to differentiate the symbiotic fungal – root interaction from parasitic and saprophytic interactions (Figure 1). The structures promote the exchange capacities of phosphate against carbohydrates, such as glucose across the plant and fungal membranes by a genetically controlled, bidirectional transport.

The fungal structures differ among mycorrhizae of trees and orchids indicating different mycobiont groups, the arbuscular mycorrhizal fungi *Glomeromycota* associated with trees and the *Basidiomycota* groups *Tulasnellaceae*, *Sebacinaceae*, *Ceratobasidiaceae* and *Atractiellaceae* associated with orchids (Figs. 2 and 3).

These mycobionts do not form conspicuous fruit bodies which could be used for identification of the species. *Glomeromycota* may occasionally form vegetative, multinucleate spores in soil or roots, difficult to determine. The fungal structures observed in the mycorrhizae of the Andean trees are surprisingly diverse and still not suffi-

ciently known for species identification (Figure 2) (Beck et al. 2007). The orchid mycobionts form thin layers of hyphae on bark or rotten wood, and only occasionally produce basidia and sexual spores (Figure 4) (Cruz et al. 2014).

The only possibility to learn about the fungal diversity is to extract the DNA directly from the mycorrhizae and sequence the DNA of the mycobionts to differentiate “phylogenetic species” (Figure 5).

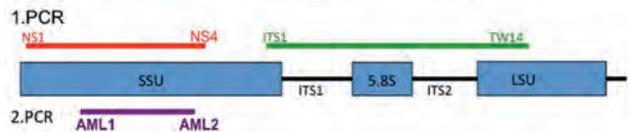


Figure 5. DNA sequences are used to differentiate mycobionts. For *Glomeromycota* conventionally a part of SSU (ribosomal gene coding for the small subunit) is amplified by a nested PCR, primers indicated in red and magenta; ITS region (spacer between the ribosomal genes) and part of LSU (ribosomal gene coding for the large subunit) is amplified for orchid mycorrhizal fungi; primers indicated in green. Sequences are further classified by phylogenetic programs for defining species.

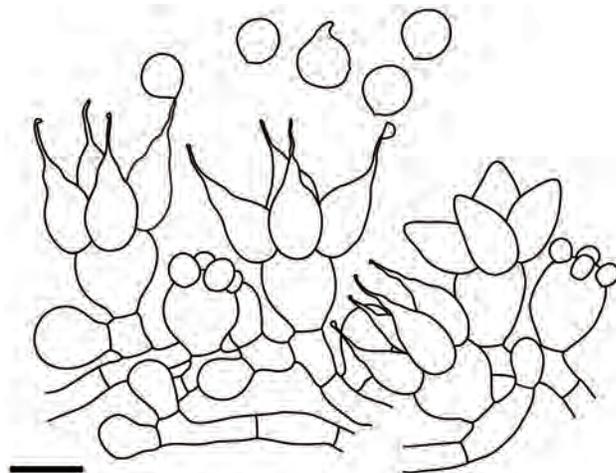


Figure 4. *Tulasnella violea* forming basidia and spores on a thin layer of septate hyphae. (Herbarium of National Botanic Garden of Belgium 6616612, collected by Van de Put and illustrated by D. Cruz; personal permission)

Are the Andean tropical forests a hotspot of mycobiont diversity?

To answer this question, the first challenge was sampling of mycorrhizae from identified tree and orchid species in this hotspot of plant diversity along altitudinal and disturbance gradients. This was accomplished in cooperation with Ecuadorian and German botanists who identified the plants. The material was screened for mycorrhizae by light microscopy in the laboratories of the Estación Científica San Francisco and the UTPL (Figure 8). Suited material was prepared for DNA extraction and transmission electron microscopy (TEM) in Tuebingen and Loja. TEM was used to confirm that the fungi found by molecular methods were true mycobionts. By this combination of methods we detected a new mycobiont group in orchids, belonging to the *Atractiellaceae* (Kottke et al. 2010), previously considered as solely saprotrophic fungi (Figure 3c).



Figure 6. Roots from the tree base were followed to collect the finest rootlets by thorough manual excavation.



Figure 7. Orchid roots were sampled from terrestrials and epiphytes by cutting off small portions of rootlets in contact to the substrate.

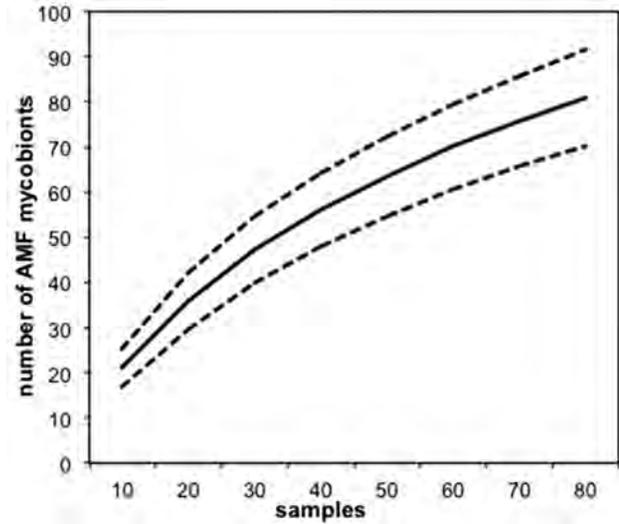


Figure 10. Rarefaction curve for AMF mycobionts found in the pristine forest (RBSF) with 95% confidence intervals. The curve does not reach its asymptote.

Molecular results show that plants and their mycobionts interact in multiple networks. Figure 9 demonstrates that the number of mycobionts in these local networks appeared as equally high as the number of investigated tree or orchid species. There are only few frequently occurring mycobionts with links to many plants and large numbers of rare ones with just one or two links. Most importantly, plants and mycobionts associate in a “nested” manner. This means that rare mycobionts and rare plants associate with groups of highly linked, more common and not with rare partners. Rare plant species are thus not depending on rare symbiotic partners, but are powered by the symbiosis with more widespread partners. Consequently, we found broad sharing among the tropical trees or orchids and their respective mycobionts. Network theory shows that such networks are fundamental for diversity conservation and highly resistant against disturbances.

Are there methodological constraints to our data sets?

So far, we could not find strong influence on the occurrence of the mycobionts by the altitudinal gradient (1900 – 2100 m), forest type, epiphytic or terrestrial life strategy, landslide or abandoned pastures (Kottke et al. 2013, Haug et al. 2013). This is rather difficult to understand as we would expect that fungi readily react to changes in the environment. Several constraints could have influenced our results.

(1) Estimation of numbers of mycobionts by our sampling efforts does not show saturation (Figure 10). Presumably ten times the sample numbers would be necessary to reach 95% of orchid mycobionts. Comparison of differently large data sets revealed strong influence of number of samples on results (Haug et al. 2013).

Thus, quantitative data and sampling on additional sites with a larger altitudinal gradient and diversity in habitats are needed.

(2) Delineation of fungal species is still problematic. Many cryptic species are found by molecular tools and need further analysis (Cruz et al. 2014).

Perspective: We finally aim to see how much the plants of the tropical biodiversity hotspot and their mycobionts may respond to climate change and anthropogenic influence. Knowledge of the appropriate mycobionts with respect to plant species and habitat will also help selecting the right partners for an improvement of seedling growth in nurseries.

References

Beck A, Haug I, Oberwinkler F, Kottke I (2007) Structural characterisation and molecular identification of arbuscular mycorrhiza morphotypes of *Alzatea verticillata* (Alzateaceae) a prominent tree in the tropical mountain rain forest of South Ecuador. *Mycorrhiza* 17: 607-625

Cruz D, Suárez JP, Kottke I, Piepenbring M (2014) Cryptic species revealed by molecular phylogenetic analysis of sequences obtained from basidiomata of *Tulasnella*. *Mycologia* 106: 708-722

Frank AB (1885) Ueber die auf Wurzelsymbiose beruhende Ernaehrung gewisser Baeume durch unterirdische Pilze. *Ber Deutsch Bot Ges* 3: 128-145.

Haug I, Setaro S, Suárez JP (2013) Reforestation sites show similar and nested AMF communities to an adjacent pristine forest in a tropical mountain area of South Ecuador. *PLOS One* 8 (3) e6324

Kottke I, Setaro S, Haug I, Herrera P, Cruz D, Fries A, Gawlik J, Homeier J, Werner FA, Gerique A, Suárez JP (2013) Mycorrhiza networks promote biodiversity and stabilize the tropical mountain rain forest ecosystem: Perspectives for understanding complex communities. In: J. Bendix E. Beck, A. Bräuning, F. Makeschin, R. Mosandl, S. Scheu, and W. Wilcke (eds.), *Ecosystem Services, Biodiversity and Environmental Change in a Tropical Mountain Ecosystem of South Ecuador*, *Ecological Studies* 221: © Springer-Verlag Berlin Heidelberg, pp 187-203

Kottke I, Suárez JP, Herrera P, Cruz D, Bauer R, Haug I, Garnica S (2010) *Atractiellomyces* belonging to the 'rust' lineage (Pucciniomycotina) form mycorrhizae with terrestrial and epiphytic neotropical orchids. *Proc Roy Soc. B* 277: 1289-1296

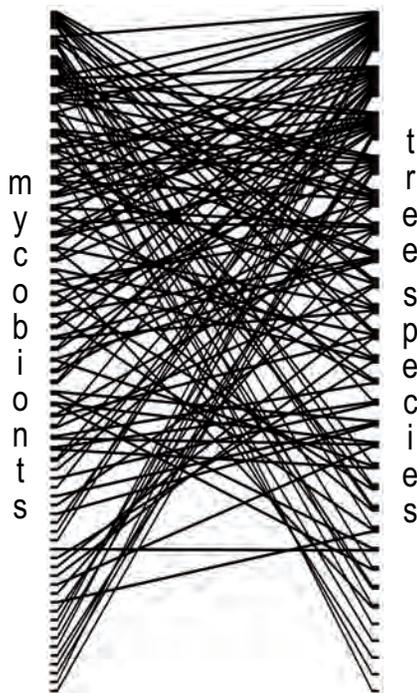


Figure 9 left: Local network formed by *Glomeromycota* with the tropical trees in the mega diverse forest of the RBSF in the San Francisco valley (Kottke et al. 2013);

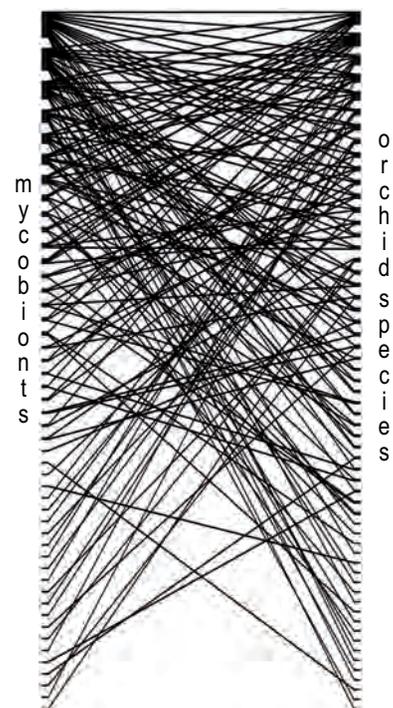


Figure 9 right: Local network formed by *Tulasnellaceae*, *Sebacinaeae* and *Atractiellaceae* with terrestrial and epiphytic orchids in the RBSF (Kottke et al. 2013).





Management of Natural Forests and Reforestation

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(Technical University Munich)

Introduction

The Ecuadorian policy is considering the extraordinary biodiversity of the country and aims on benefitting appropriately through its conservation and sustainable use. Ecosystem conservation and restoration is supported by the National System of Protected Areas (SNAP), the program of incentive payments for private forest owners (SocioBosque), and several multi-stakeholder initiatives (e.g. FORAQUA). Also, sustainable use involving the management of natural forests and reforestation of abandoned areas is considered in a normative and supporting framework. Nevertheless, there are still many knowledge gaps that are related to both topics.

Management of natural forests

Beside the high biodiversity and a variety of ecosystem services, the mountain rainforest ecosystem has also an



Figure 1. Distribution of 52 inventory plots (2500 m²; 13 ha in total) on three different micro-catchments Q2, Q3, Q5 in the study area.

important provisioning function for timber production (56.2 m³/ha commercial volume according to the national forest inventory; forest type: *Bosque Siempre Verde Andino Montano*). The normative framework for sustainable management of mountain forests was introduced in the year 2006 and is a valuable tool to prevent forest destruction. However, the measurable criteria and indicators defined in these norms are predominantly intended to limit harvesting operations to an ecologically compatible level. The development of an incentive program entitled *SocioManejo* is in progress, which will provide assistance for technical and marketing issues in order to enhance the sustainable management of natural forests.

Information about the impact of micro-site parameters on species distribution is basic for the consideration of specific conditions in management activities. In the RBSF area we have realized forest inventories in three micro-catchments (Figure 1): the spatial distribution of selected species has been analysed by digital terrestrial modeling and the impact of environmental variables on the spatial distribution was assessed by using two common modeling techniques (Figure 2). The results indicate elevation and topographic position as main determinants for the distribution of most of the species.

Stand dynamics and the effects of silvicultural management techniques have been investigated by thinning experiments and recurrent inventories: Improvement thinning is considered to enhance the growth of selected individuals as well as tree regeneration. We selected potential crop trees (PCTs) of nine valuable timber species in order to test the effects of removing competitor trees

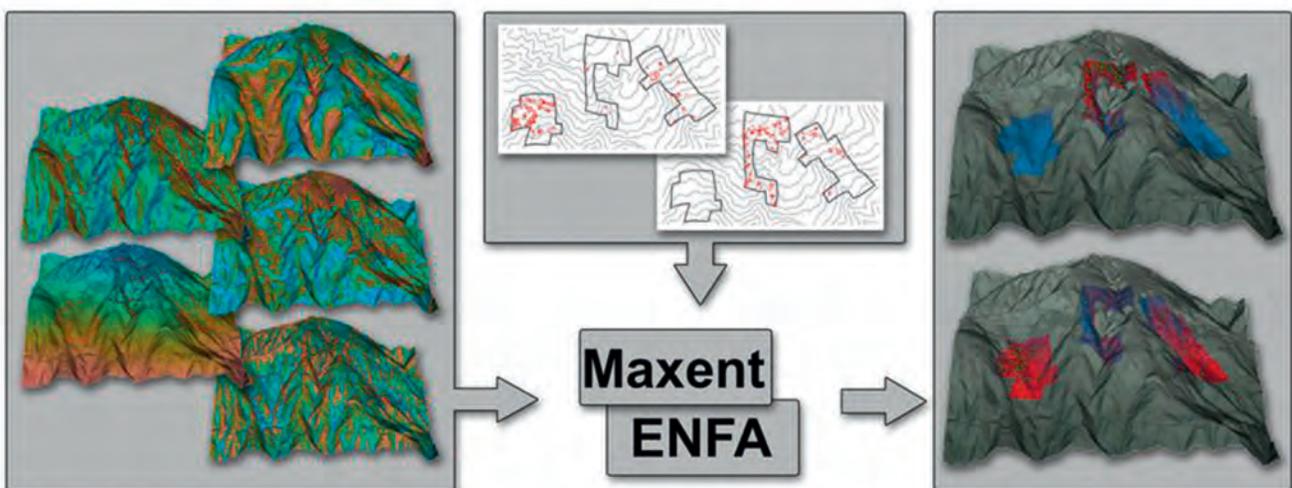


Figure 2. Analysis of the impact of environmental variables (left, top to bottom: elevation, slope, exposition, humidity, topographic position) on spatial distribution (center) of 16 most common tree species (*Alchornea grandiflora*, *Alzatea verticillata*, *Cecropia andina*, *Cecropia angustifolia*, *Cedrela montana*, *Clusia ducuoides*, *Graffenrieda emarginata*, *Guarea kunthiana*, *Heliocarpus americanus*, *Hyeronima asperifolia*, *Meriania franciscana*, *Nectandra lineatifolia*, *Nectandra membranacea*, *Sapium glandulosum*, *Tabebuia chrysantha* and *Tapirira guianensis*) using two common modeling techniques (Maxent, ENFA). The result illustrates the suitability of sites (right: red = good, blue = poor).

(Figure 3). After several years of monitoring, the results show in general an improved diameter increment for promoted individuals in comparison to untreated reference trees (Figure 4).

In addition, the recurrent inventories allow for evaluation of stand dynamics under natural and managed conditions: tree regeneration but also growth and mortality of remaining trees are still under observation (Figure 5) and the results will provide further insights on the possibilities of improving the management of natural mountain rain forests by silvicultural interventions.



Figure 3. Potential crop trees of 9 valuable timber species (*Cedrela montana*, *Podocarpus oleifolius*, *Tabebuia chrysantha*, *Ficus citrifolia*, *Nectandra membranacea*, *Hyeronima asperifolia*, *Hyeronima moritziana*, *Clusia ducuoides*, *Inga acreana*) have been selected and competitor trees have been removed.

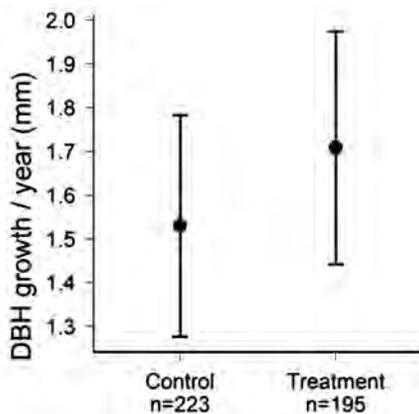


Figure 4. Effect of competitor removal on PCTs. In general the potential crop trees (Treatment) showed enhanced diameter increment in comparison to the corresponding reference trees (Control); however, we also detected a negative impact in case of three species and site effects.

Non-timber forest products

Non-timber forest products (NTFPs) are supposed to be a suitable option for generation of additional income. Former studies revealed that at least 589 species are used for NTFPs in Ecuadorian forests; the exports of NTFPs amounted to US\$ 13 million per year between 2006 and 2008. Ethnobotanical studies in the tropical mountain



Figure 5. Monitoring of tree regeneration

forest confirmed the substantial role of NTFPs for the people living in this ecosystem, demonstrating different intensities of use by several ethnic groups: Shuar communities for instance use 139 forest species whereas Saraguro (43 species) and Mestizo (51 species) communities indicated lower numbers. Own surveys in a limited area of the San Francisco watershed (Parroquia Sabanilla) revealed 75 species of trees, shrubs, herbs, lianas, and epiphytes that are used for various purposes like medicine, food, construction, and others. These results illustrate the importance of NTFPs for natural forest management and the potential for further development by e.g. domestication of selected species.

Another important topic is the role of natural forests as a source of reproductive material (seeds, seedlings, material for vegetative propagation). Exploitation and land use changes involve the risk of genetic degradation and the continuous supply with reproductive material of high quality is a basic part of sustainable forest management and a precondition for successful reforestation or restoration. Nevertheless, the knowledge about suitable seed sources, periods of flowering and fruiting, seed storage and germination for native species is limited (Stimm et al. 2008). We realized several seed storage and germination trials with native species and monitored the flowering and fruiting of the selected PCTs and the corresponding reference trees (Figure 6).

Reforestation

The Ecuadorian government also provides a program that includes incentive payments for reforestation with native and exotic species for commercial purposes in order to generate timber resources and reduce the pressure on natural forests. In that case, the establishment costs for plantations are covered by 100% (local autho-

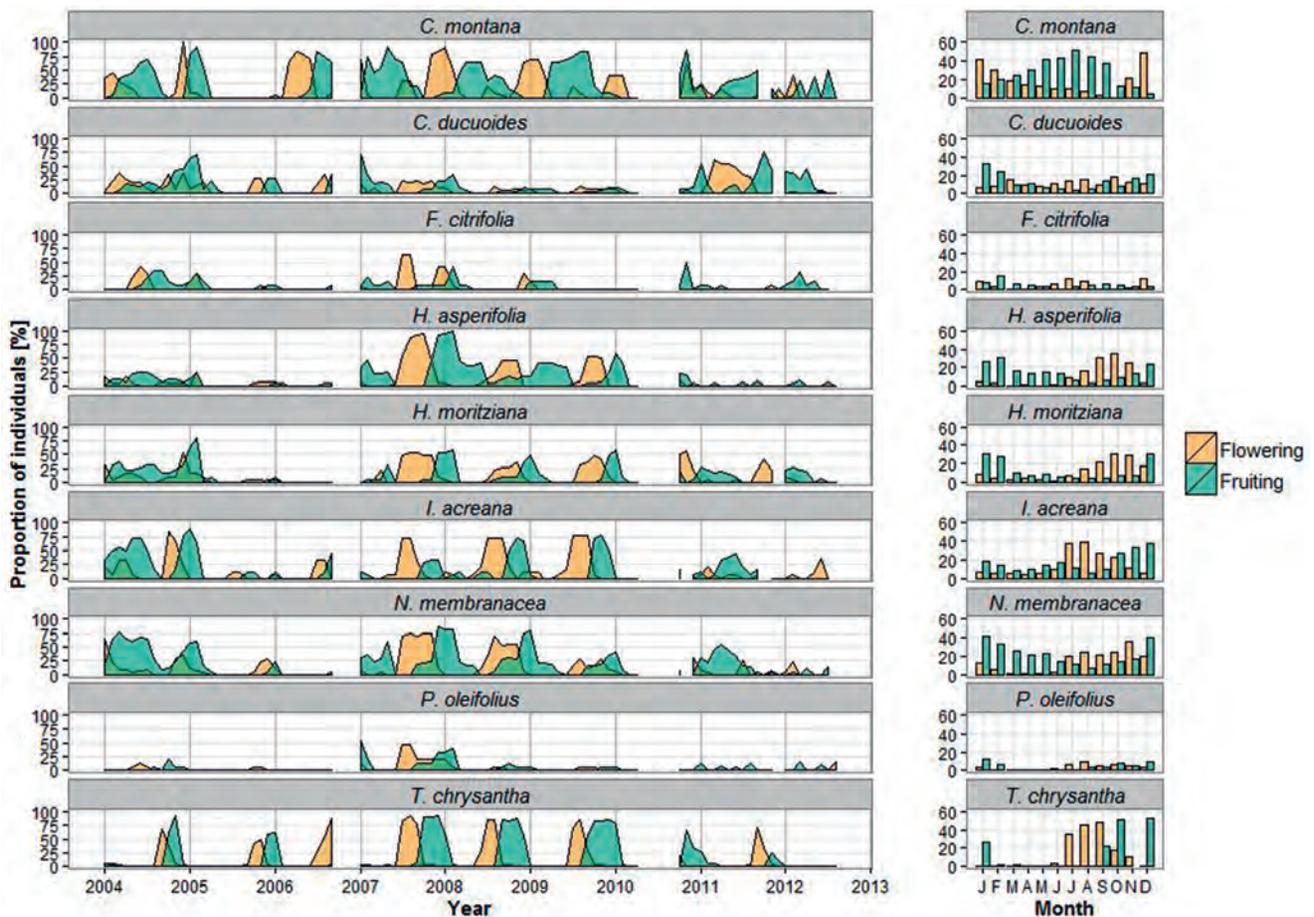


Figure 6. Monitoring of flowering (yellow) and fruiting (green) of 9 selected tree species; the monitoring period comprised almost nine years in order to detect annual variation (left) and to enable the estimation of consolidated probabilities of flowering and fruiting (right).

rities) or 75% (private landowners). However, reforestation with native species is still challenging in many cases: Because of the limited supply of reproductive material of high quality, widely lacking experiences regarding suitable silvicultural techniques for the diverse tree species, and the slow development of many native species on open areas, exotic species are often preferred. Thus, the incentive program considers for mountain regions *Alnus acuminata* as the only supported native species in addition to the exotic *Pinus patula*, *P. radiata*, *Eucalyptus globulus* and *Cupressus macrocarpa*. Our reforestation trials have also confirmed the competitiveness of *A. acuminata* with *P. patula* and *E. saligna*; nevertheless, *Tabebuia chrysantha* shows excellent survival rates and is supposed to improve its growth rate after an initial phase of establishing its root system. Moreover, a better timber quality resulting in higher timber prices could also compensate for longer production periods on the long run. As an alternative, native species could also be used for enrichment planting of plantations consisting of exotic species (Figure 7): the results of our trials in a plantation of *P. patula* are indicating that many native

species benefit from the shelter which is not available on open areas (Aguirre et al. 2006). Currently we are testing the concept on several sites, including a variety of native species (Figure 8) and with different thinning intensities in order to assess the development under different levels of shade. As a consequence, exotic species might also be used to establish a forest cover which is subsequently transferred into a more natural composition with native tree species.

References

- Aguirre N, Günter S, Weber M, Stimm B (2006) Enriquecimiento de plantaciones de *Pinus patula* con especies nativas en el sur del Ecuador. *Lyonia* 10: 33-45.
- Stimm B, Beck E, Günter S, Aguirre N, Cueva E, Mosandl R, Weber M (2008) Reforestation of abandoned pastures: Seed ecology of native species and production of indigenous plant material. In: Beck E, Bendix J, Kottke I, Makeschin F, Mosandl R (eds). *Gradients in a tropical mountain ecosystem of Ecuador. Ecological studies* 198. Springer, Berlin, pp 417-429



Figure 7a. Enrichment planting with *Iserfia laevis* in a plantation of *Pinus patula*.

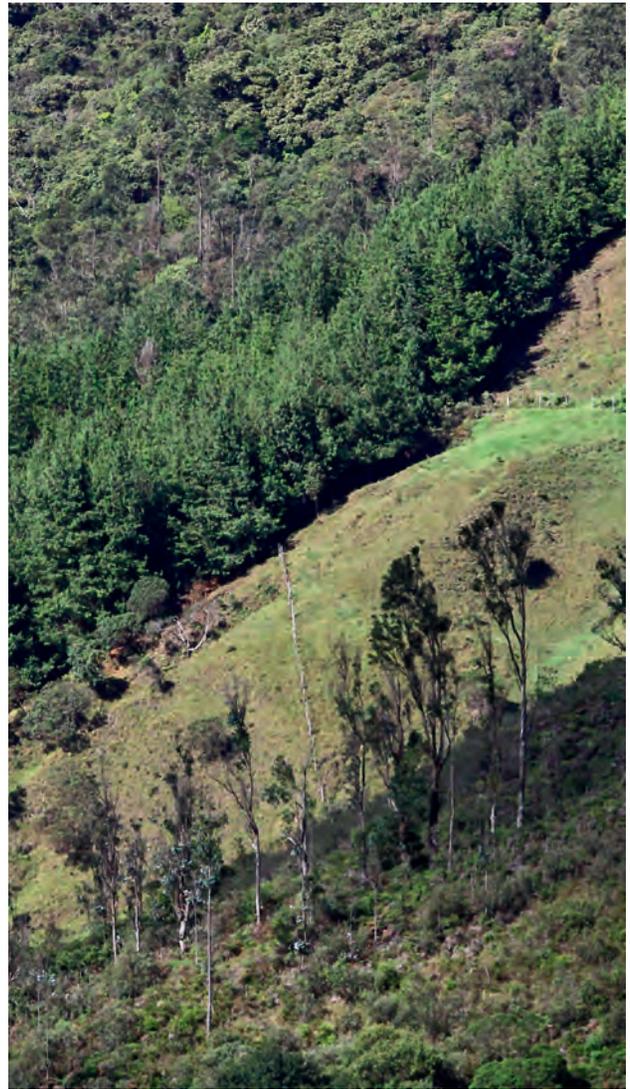
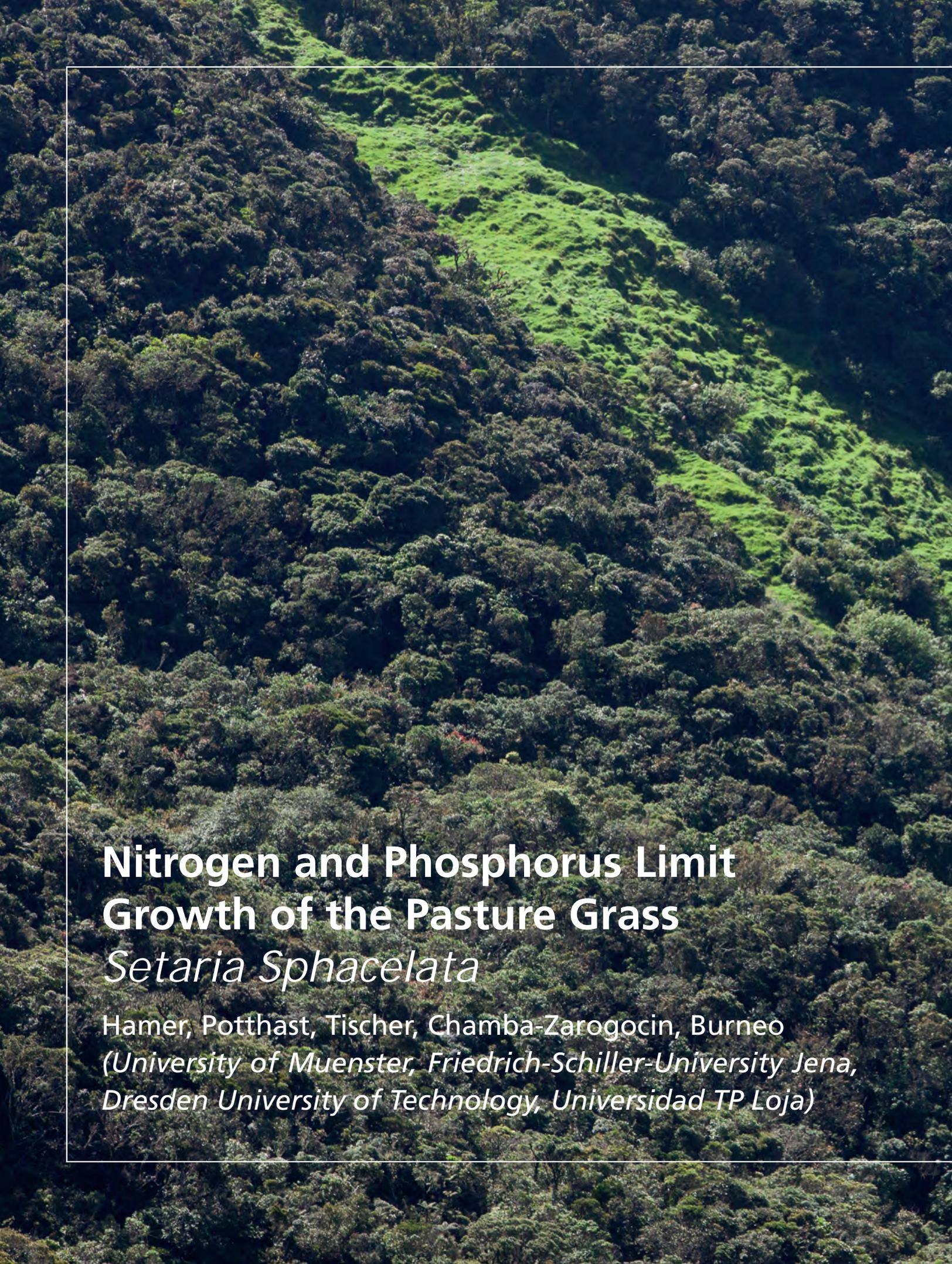


Figure 7b. An approximately 30 year old plantation of *Pinus patula* as afforestation of abandoned pasture land.



Figure 8. Production of seedlings of native tree species for enrichment planting on different sites.



**Nitrogen and Phosphorus Limit
Growth of the Pasture Grass
*Setaria Sphacelata***

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Introduction: Motivation to improve the growth of the pasture grass *Setaria sphacelata*

In the valley of the Rio San Francisco, about 50% of the slopes below 2200 m asl are covered by pastures for cattle ranching. These pastures have been established by slash and burn of the natural forest (Figure 1). Subsequently the farmers planted the tropical African grass species *Setaria sphacelata* (Mequerón) on most of the cleared sites (see also contribution by Adams et al., this Volume). Compared to other grass species it grows more rapidly, has a higher resistance to weed invasion, is largely fire-resistant and can tolerate high amounts of precipitation. However, at present about 50% of the pastureland is overgrown by bracken (*Pteridium arachnoideum* and *Pt. caudatum*) and various shrub species, and have been abandoned by the farmers (Figure 1). The decrease in pasture productivity forces farmers to clear more pristine forest (Knoke et al. 2014). One perspective to overcome this unsustainable land use is to improve the growth of the pasture grass *Setaria sphacelata* on the already existing pasture sites and to avoid pasture abandonment.

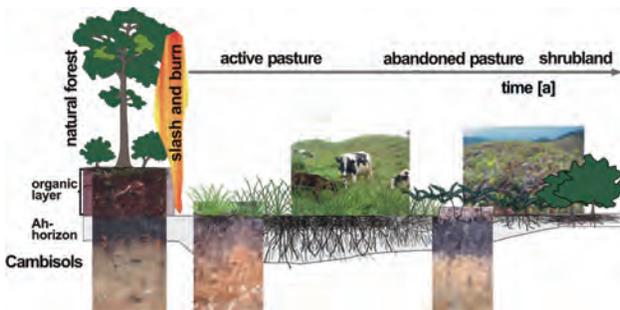


Figure 1. Scheme of the changes in land-use (natural forest – active pastures of different age – abandoned pastures – shrubland) and photos of the dominant soil type (Cambisol).

The Pasture Fertilization Experiment „FERPAST“

Previous investigations (Hamer et al. 2013a,b, Potthast et al. 2012b) have shown that the soils (Cambisols, Figure 1) of the research area are low in nutrients especially in plant-available phosphorus. In the region, farmers do not fertilize their pastures. Thus, it is most likely that the macronutrients nitrogen (N) and phosphorus (P) limit the growth of the pasture grass and hamper its competitive strength against weeds. To test this hypothesis the “Pasture Fertilization Experiment-FERPAST” was established on a 17 year old active pasture in November 2007. The FERPAST-experiment aims at improving pasture productivity by moderate application of fertilizers (urea and/or rock phosphate), thus avoiding pasture degradation and subsequent abandonment. The design of the FERPAST-experiment is shown in Figure 2. On six replicate plots of 5 m x 5 m urea as N-fertilizer (N), rock phosphate as P-fertilizer (P) and the combination of both (NP) was applied. Six additional plots served as control where no fertilizer was applied. It should be emphasized that we used moderate amounts of N ($50 \text{ kg ha}^{-1} \text{ a}^{-1}$) and P ($10 \text{ kg ha}^{-1} \text{ a}^{-1}$) and that we partitioned this dose into three applications per year (Figure 5) to avoid nutrient leaching.

The growth of *Setaria* is N and P limited

Grass samples were harvested by clipping inside three randomly chosen squares per plot (wooden frames of 50 cm x 50 cm, Figure 3). Biomass was determined as dry weight after drying of the grass at 40°C . To simulate the common rotational grazing used by the farmers, cutting intervals were between two and three months. From the dried grass samples the contents of nutrients such as N (as estimate for the content of crude protein), P, K, Ca, and Mg were determined in the laboratory (Potthast et al. 2012a; Tischer et al. 2015).

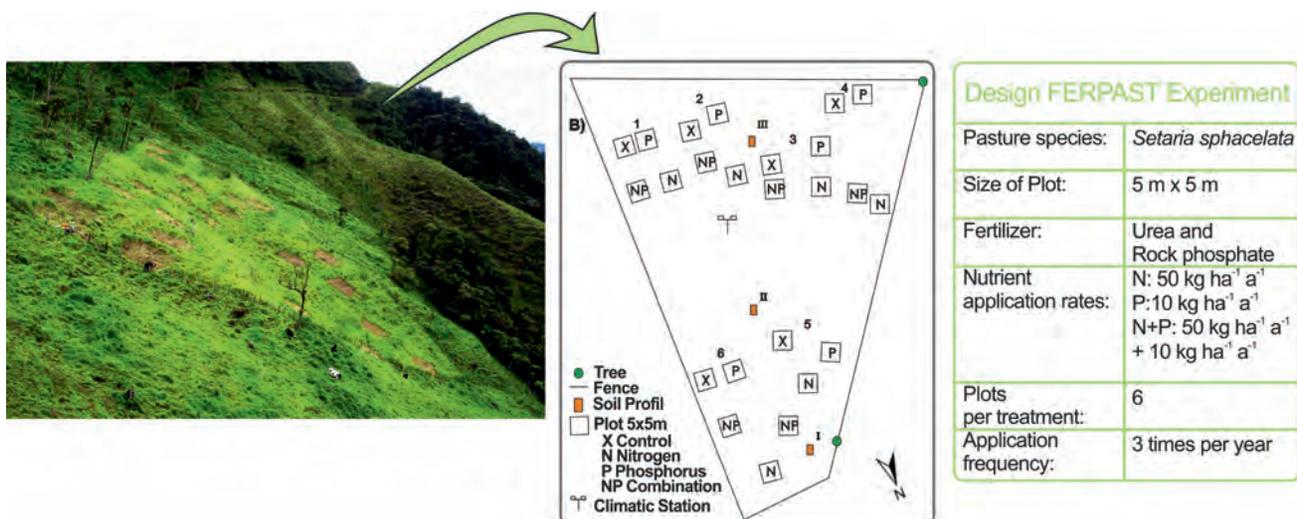


Figure 2. Photograph and design of the Pasture Fertilization Experiment (FERPAST) (Potthast et al. 2012a).



Figure 3. (a) Cutting of grass using a wooden frame of 50 cm x 50 cm, (b) collecting soil samples with a soil auger.

Figure 4 shows that only the combined fertilization with urea (N) and rock phosphate (P) significantly increased the yield of *Setaria sphacelata* (by 2.2 Mg dry matter ha⁻¹ a⁻¹ ≈ 25%) compared to the control. Thus, growth of the grass is N and P limited. Fertilization with N and P also improved the stocks of crude protein available for dairy cattle (by 134 kg ha⁻¹ a⁻¹ compared to the unfertilized pasture). Crude protein is a rough estimate of the nutrition value of fodder. Furthermore, fertilization with NP improved the P and Ca contents of the pasture grass. Based on these data it seems reasonable that the stocking rate in NP fertilized pastures can be increased from 1 to 1.6 cows ha⁻¹. An increase to 2 cows per ha is

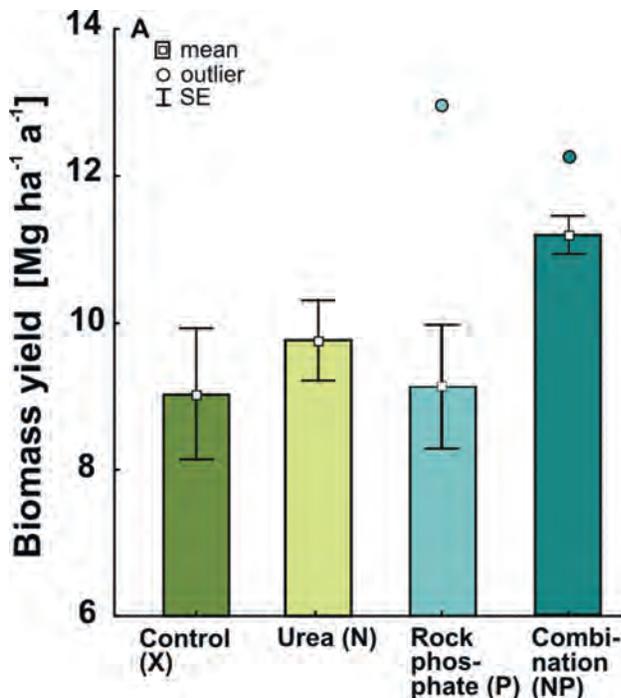


Figure 4. Effects of fertilizer application (control without fertilizer; urea application; rock phosphate application; urea and rock phosphate application in combination) on grass biomass yield. Shown are the weighted averages of specific cutting intervals between January 2009 and February 2010 ($n=36$) one year after the onset of fertilization (February 2008) (modified after Potthast et al. 2012a).

questionable due to large annual variations in biomass yield (Tischer et al. 2015) and the increasing risk of soil compaction and erosion on the steep slopes.

Lessons learned from the fertilization experiment?

From all study plots soil samples (from 0-5, 5-10 and 10-20 cm depth) were collected with a soil auger (Figure 3b). Soil pH and nutrient content and availability were analyzed in the laboratory. Also, the effects of fertilization on the soil microorganisms, on mycorrhiza fungi and on grass roots have been investigated. In the field soil respiration (Figure 5a, 5c) was measured and the decomposition of grass leaves and bracken fronds was determined using the litterbag approach (Figure 5d).

Key findings relevant for farmers:

The results of soil pH measurement indicate that it is very important to apply the urea fertilizer together with rock phosphate to prevent acidification of soils. Only moderate amounts of urea-N should be applied since fertilization with urea causes a short-term increase in soil respiration (CO₂ efflux from soil) which in the long run can decrease the amount of organic matter in the soil and concomitantly soil fertility. In general bracken is a strong and successful competitor with regard to uptake of nutrients. The bracken rhizomes store large amounts of P. It is recommended to cut bracken fronds as early as possible. Bracken fronds should not be burned. Cutting of the young bracken fronds is recommended since they decompose faster than old fronds and release the major nutrients more rapidly for growth of the grass.

Key scientific findings:

Our results improve our understanding of the mechanisms of nutrient limitation. For example, they are in line with the concept of serially linked nutrients, introduced by Ågren (2004). Phosphorus is very important in regulating resource allocation in plants (e.g. transfer of organic material and particular nutrients from shoots to roots) in response to fertilization. A complex statistical analysis of our data set (IT-approach) gave evidence that the positive reaction of the soil microorganisms to the enrichment of N or P was an indirect effect, imposed by the respective adaptation mechanisms of *Setaria spha-*



Figure 5. (a) Measurement of soil respiration, (b) fertilization of plots, (c) fertilization in collars to investigate the effects of fertilization on soil respiration (soil CO₂ efflux) and (d) litterbags containing grass leaves or bracken fronds to investigate litter decomposition.

celata to nutrient enrichment. Fertilization with P increased the transfer of resources from the leaves into the roots (e.g. increased root biomass, changed C:N:P ratio of roots) and into the soil. This resulted in an increase of

the soil microbial biomass, especially of the group of so-called Gram-positive bacteria, leading to changes in C-sequestration and nutrient retention (Tischer et al. 2015).

Figure 6 and 7 (see also next page). Pasture grass (*Setaria sphacelata*) competes for nutrients, in the nutrient poor soil.



References

- Ågren GI (2004) The C : N : P stoichiometry of autotrophs – theory and observations. *Ecol Lett* 7, 185–191
- Hamer U, Potthast K, Burneo JI, Makeschin F (2013a) Nutrient stocks and phosphorus fractions in mountain soils of Southern Ecuador after conversion of forest to pasture. *Biogeochemistry* 112, 495-510
- Hamer U, Potthast K, Wilcke W, Wullaert H, Valarezo C, Sandmann D, Maraun M, Scheu S, Homeier J (2013b) Nutrient additions affecting matter turnover in forest and pasture ecosystems. In: Bendix J, Beck E, Bräuning A, Makeschin F, Mosandl R, Scheu S, Wilcke W (eds.): *Ecosystem Services, Biodiversity and Environmental Change in a Tropical Mountain Ecosystem of South Ecuador*. *Ecological Studies* Vol. 221, pp. 297-313, Springer, Berlin
- Knoke T, Bendix J, Pohle P, Hamer U, Hildebrandt P, Roos K, Gerique A, Sandoval ML, Breuer L, Tischer A, Silva B, Calvas B, Aguirre N, Castro LM, Windhorst D, Weber M, Stimm B, Gunter S, Palomeque X, Mora J, Mosandl R, Beck E, (2014) Afforestation or intense pasturing improve the ecological and economic value of abandoned tropical farmlands. *Nature Com* 5, 5612-5612
- Potthast K, Hamer U, Makeschin F (2012a) Nutrients in Ecuadorian pasture soils limit growth of *Setaria sphacelata* but not of soil microorganisms. *Appl Soil Ecol* 62, 103-114
- Potthast K, Hamer U, Makeschin F (2012b) Land-use change in a tropical mountain rainforest region of Southern Ecuador affects soil microorganisms and nutrient cycling. *Biogeochemistry* 111, 151-167
- Tischer A, Werisch M, Döbbelin F, Camenzind T, Rillig MC, Potthast K, Hamer U (2015) Above- and belowground linkages of a nitrogen and phosphorus co-limited tropical mountain pasture system – responses to nutrient enrichment. *Plant & Soil* 391, 333-352



A photograph showing a dense, healthy patch of green bracken ferns. The ferns have long, narrow, lanceolate leaves that are bright green and appear to be growing in a natural, somewhat shaded environment. The ground is covered with a mix of green ferns and some brown, dried-out vegetation. The overall scene is a close-up view of the plants, highlighting their texture and color.

Combatting the Bracken Problem – Restoration and Sustainable Use of Bracken Infested Pastures

Adams, Roos, Beck (*University of Bayreuth*)



Bracken (*Pteridium spp.*, local name “llashipa”) is a perennial vigorous and resistant fern that due to its rapid spreading by strong underground rhizomes (Figure 1) and its fast regeneration cycle it is one of the most aggressive weeds worldwide. It has a wide soil tolerance and grows particularly well on deep acidic soils but avoids waterlogged areas. Bracken is a major weed in tropical upland regions and is widely distributed in Southern Ecuador.



Figure 1. Above- and belowground organs of the tropical bracken fern. The dense rhizome plexus favors a rapid spreading of the fern.

Abandonment of pastures due to heavy weed infestation, particularly by bracken fern, is a general problem in the tropical Andes (Figure 2) prompting the farmers to clear more natural forest for gaining new pastures and croplands. Therefore pasture rehabilitation on abandoned areas plays an important role in terms of ecological and economic aspects (Knoke et al. 2014). On the one hand the pressure on primary forests can be mitigated and on the other, revitalization leads to an increase in revenues of the local farmers.

In the research area in the south-eastern Andes of Ecuador about 40% of the potential pastureland has been abandoned (Curatola et al. 2015) because of infestation

by two species of tropical bracken (*Pteridium arachnoideum* and *Pt. caudatum*). Infestation by bracken fern and later on by weedy shrubs is a consequence of the traditional use of fire for clearing the natural forest and for subsequent zero-input pasture management. Growth of both, bracken and woody weeds, is fostered by recurrent burning (Figure 3; Hartig and Beck 2003). Although complete eradication of bracken appears impossible, we nevertheless were able to demonstrate in our repasturisation experiment, now extending over ten years that rehabilitation of sites which were completely covered by bracken is possible.

The experiment performed on our study site “Llashipa” at 2000 m asl comprised three steps, ending with fertile grazing land (Figure 5):

The three consecutive steps were:

- 1) Combating bracken by intensive mechanical/manual or chemical treatment followed by
- 2) Replanting a highly competitive pasture grass (Roos et al. 2011) and
- 3) The application of an adapted pasture management.

In the first step, the efficacy of 13 bracken control treatments was examined. Two of the measures proved particularly successful, namely periodical cutting of the weed with a machete or repeated spraying of the locally available herbicide “Combo” (a mixture of metsulfuron methyl and picloram). In the second step, the commonly used pasture grass *Setaria sphacelata* was planted which by its fast and ample growth could compete against the slowly resprouting fern. Following our protocol, pasture rehabilitation requires about 2.5 years until the pastures can be used.

In the third step an experiment was started simulating pasture farming with low financial input or, alternatively with intense management. Our results reveal that a balanced combination of fertilization and grazing can lead to a sustainable re-utilization of the former abandoned areas. In this third phase, it is important to shift the equilibrium between fern and grass in favor of the pasture grass. Regular grazing on the one hand weakens the fern because of trampling by the cattle, while on the other stimulates re-growth of the pasture grass. Furthermore soil improvement is essential. A balanced supply of nutrients benefits the pasture grass more than the fern which under nutrient scarcity is superior to it. The soils of the pastures are very poor in phosphorus and also poor in nitrogen (see contribution “Nitrogen and Phosphorus limit Growth of the Pasture Grass *Setaria sphacelata*”) and fertilization with NPK increases the yields considerably (Figure 6).

However, *Setaria sphacelata* contains relative high concentrations of soluble oxalate which binds Calcium in the



Figure 2. A heavily bracken-infested infested farm in southern Ecuador is the main reason abandoning pastures in southern Ecuador.



Figure 3. In the long term, burning of infested pastures for rejuvenation provokes the opposite effect: Growth of the fern and its sexual reproduction is even stimulated by fire. After just one month, new fronds are sprouting from the rhizomes.

digestive tract and in case of a pure diet could cause hypocalcaemia and severe lameness of the cows (Cook et al. 2005). Unfortunately the oxalate content reacts positively to fertilization with nitrogen and potassium. Therefore there are limits to the use of fertilizers. We recommend a balanced rotation system that protects the pasture against overgrazing and allows a short regeneration time. Finally it is absolutely necessary to stop fire as an agricultural tool for “pasture rejuvenation”, because it favors the fern (Roos et al. 2010) while together with uncontrolled grazing weakens the grass. The current research aims at an up-scaling from the experimental plot to the farm level. To this end the local environmental conditions (e.g. soil, climate etc.) as well as the demands of the local population must be considered.

References

Beck E, et al. (2013) Future provisioning services: Repasturisation of abandoned pastures, problems, and pasture management. *Ecol. Studies* 221: 355-370
 Cook BG, et al. (2005) Tropical Forages: an interactive se-

lection tool. <http://www.tropicalforages.info>, visited 16.06.2012

- Curatola Fernández, G. F., Obermeier, W. A., Gerique, A., López Sandoval, M. F., Lehnert, L. W., Thies, B., & Bendix, J. (2015). Land Cover Change in the Andes of Southern Ecuador—Patterns and Drivers. *Remote Sensing* 7: 2509-2542
- Hartig K, Beck E (2003) The bracken fern (*Pteridium arachnoideum* (Kaulf.) Maxon) dilemma in the Andes of Southern Ecuador. *Ecotropica* 9: 3-13
- Knoke T, et al. (2014) Afforestation or intense pasturing improve the ecological and economic value of abandoned tropical farmlands. *Nature Communications* 5, Article number: 5612 doi:10.1038/ncomms6612
- Roos K, et al. (2013) Current provisioning services: Pasture development and use, weeds (bracken) and management. *Ecol Studies* 221: 205-217
- Roos K, Rollenbeck R, Peters T, Bendix J and Beck E (2010) Growth of tropical bracken (*Pteridium arachnoideum*): Response to weather variations and burning. *Invasive Plant Science and Management* 3:402-411

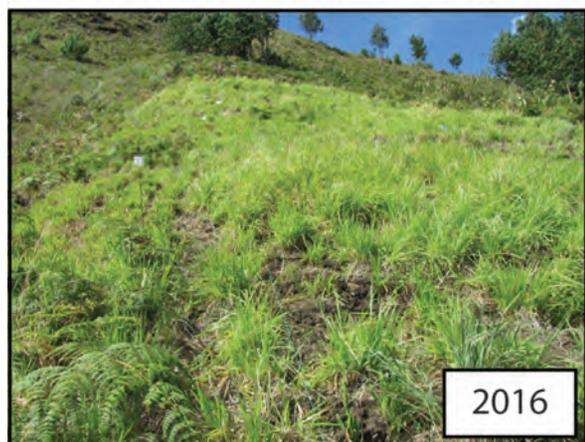
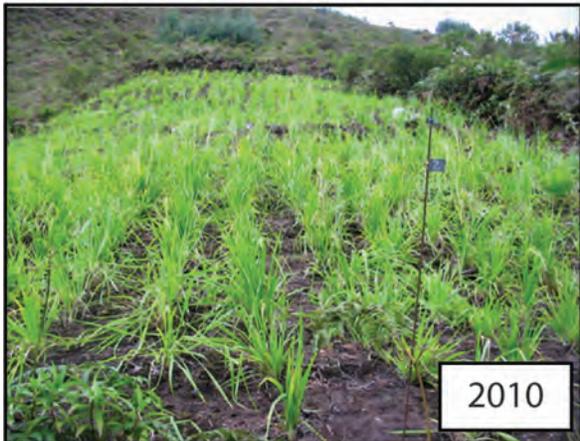
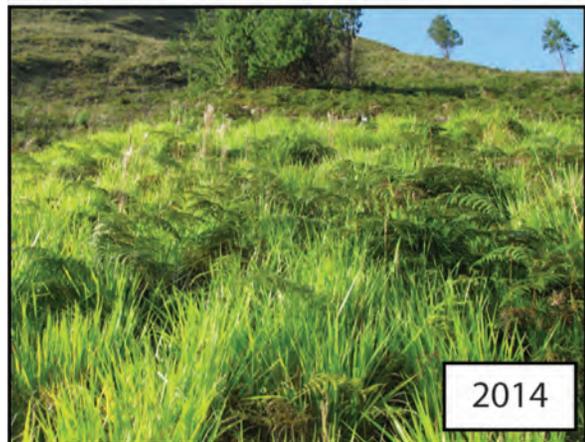
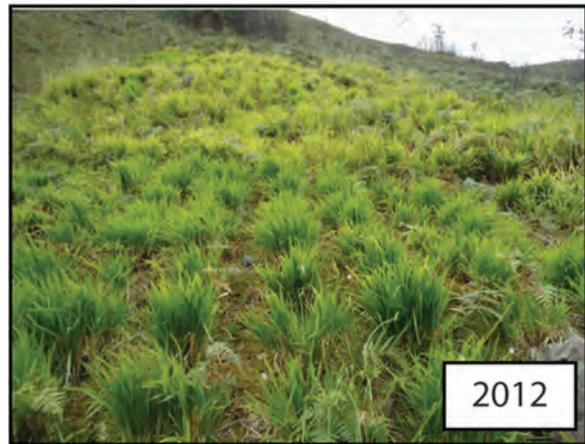


Figure 4. Development of the experimental area „Llashipa” since 2005. In 2008, the pasture grass *Setaria sphacelata* was planted on the former bracken infested site. Since 2010 various management strategies are examined. Photo 1 from 2015 shows the situation after a fallow year and Photo 2 pasture re-growth after the resumption of the management (see also fig. 6, right side).

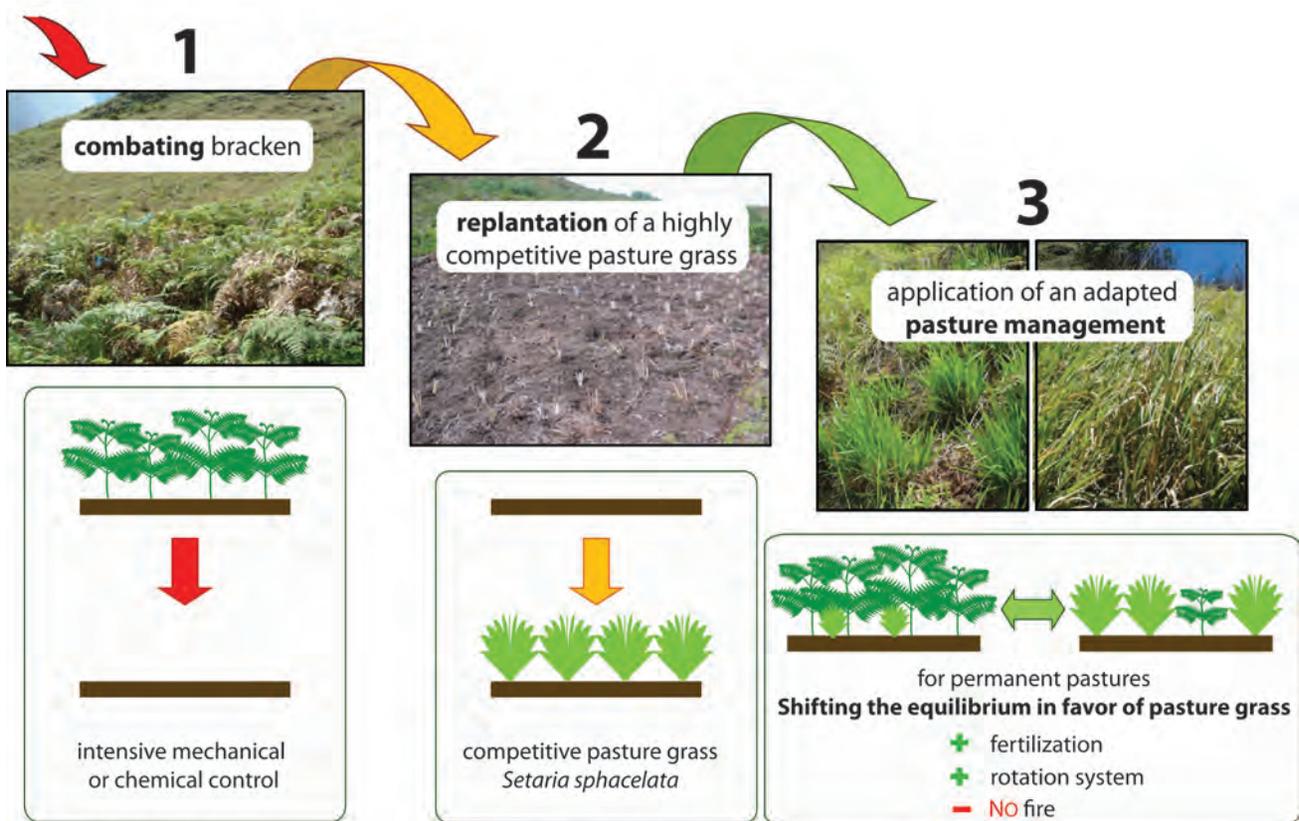


Figure 5. Summary: Three steps to the success: The strategy for repasturisation consists of 1) combating bracken mechanically or chemically, 2) replanting *Setaria sphacelata* and 3) application of an adapted pasture management.



Figure 6. The research area (“Llashipa”) for pasture regeneration in the San Francisco valley. Except the recultivated plots the entire slope is covered by bracken and shrubs.



Human Ecological Dimensions in Sustainable Utilization and Conservation under Global Change

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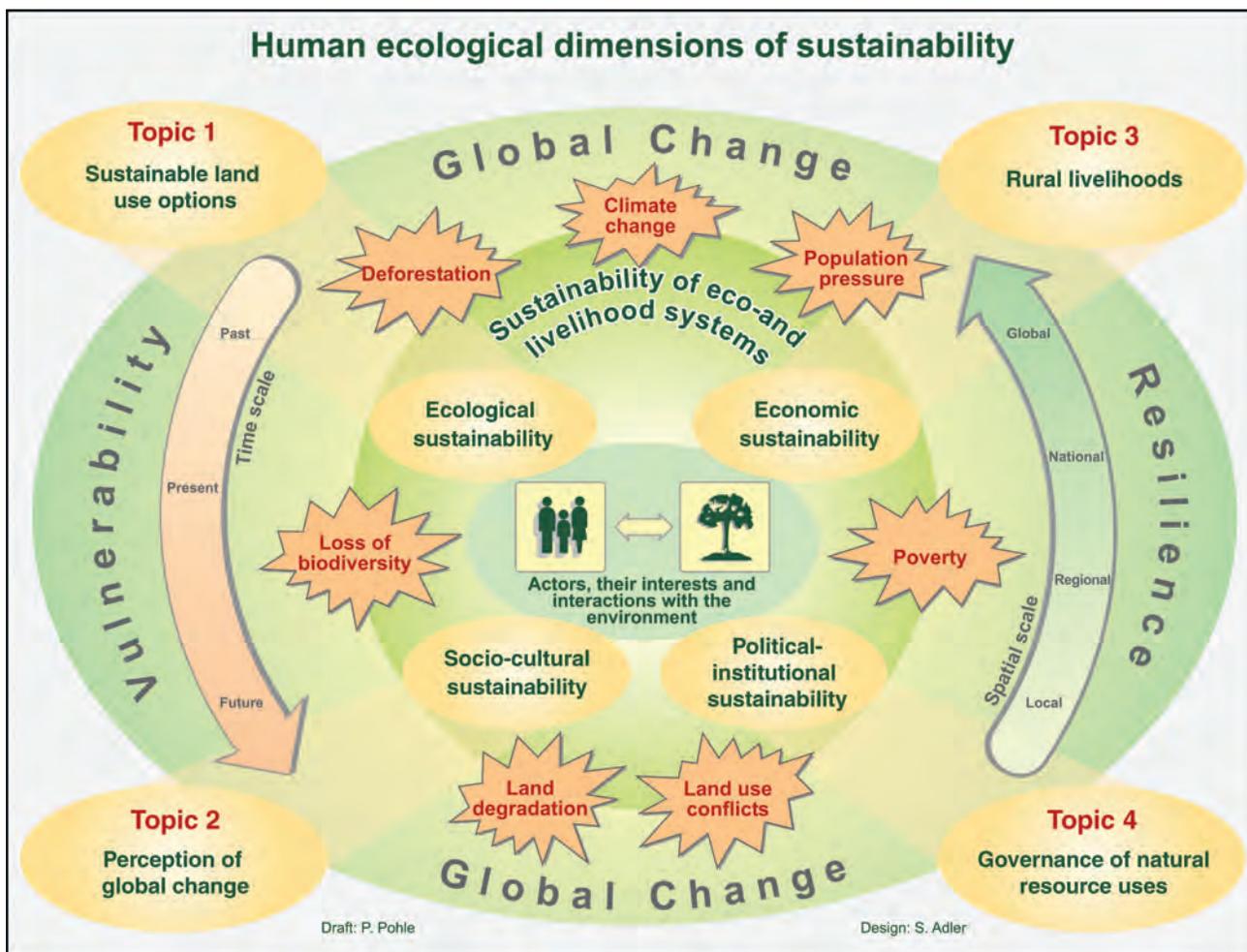


Figure 1. The human ecological approach towards sustainability of eco- and livelihood systems. The overall problems in the research area are deforestation, loss of biodiversity, land degradation, land use conflicts, and poverty – shown in their sometimes explosive character. In the centre of research are the local people – either individuals or social groups – in their interaction with the natural environment. The main goal of research is to identify development strategies how sustainability of ecosystems and livelihood systems may be gained. The four topics at the periphery are discussed in the following text. They are connected to the four aims in the inner circles.

In the scope of the DFG-supported Research Units 402 and 816 the human ecological approach towards sustainability of eco- and livelihood systems has been developed and applied in tropical mountain forest areas of southern Ecuador (Figure 1). For the sustainable development of land use, rural livelihoods and conservation options of biodiversity hot spot areas, the analysis of four human ecological parameters (topics) has proved to be indispensable. Selected results of these research topics explored in indigenous Shuar and Saraguro as well as local mestizo communities of southern Ecuador may be summarized as follows.

Topic 1: Development of sustainable land use options

To analyse the landscape transformation process, land use change detection was undertaken in sample communities of El Tibio and Los Guabos (Saraguros and mestizos, 1969-2001), in the watershed area of Tambo Blanco (Saraguros

and mestizos, 1976-2001) and in the Alto Nangaritza valley (Shuar, Saraguros and mestizos, 1986-2010). In all study sites (Tab. 1) a substantial loss of forest in favor of pasture has taken place reducing the forest coverage even below 40% (Alto Nangaritza). However, the trajectories of change are non-linear, showing high deforestation rates in the 1960s and 1970s as a result of national colonization policy and land reforms, but also various stages of vegetation succession and even some forest recovery. Today, the frontier of agrarian colonization is moving in both directions, from low to high altitude towards the Páramo (Tambo Blanco) as well as in the reverse direction towards the Oriente (Alto Nangaritza), which is currently most pronounced (Table 1). In areas, which are in a more advanced stage of the landscape transformation process (Los Guabos), forest clearing occurs side by side with land abandonment; the latter may give new possibilities for reforestation and rehabilitation measures.

Table 1: Change detection of tropical mountain forest cover in research areas of South Ecuador

Research area	Forest cover change (in %)		
El Tibio (1.770 m asl) ¹	1969: forest cover 68%	2001: forest cover 42%	- 26%
Los Guabos (1.900 m asl) ¹	1969: forest cover 58%	2001: forest cover 49%	- 9%
Tambo Blanco (1.800-3.200 m asl) ²	1976: forest cover 67%	2001: forest cover 52%	- 15%
Alto Nangaritzta (900-1.200 m asl) ³	1986: forest cover 87%	2010: forest cover 38%	- 49%

Source: ¹Pohle et al. 2013 ; ²Tutillo Vallejo 2011; ³Buitrón 2011,

Table 2: Potential plant species for market-oriented production in home gardens (Pohle et al. 2010 modified)

Family	Species	Local name	Use (plant parts used)
AMARANTHACEAE	<i>Alternanthera porrigens</i>	Lengua de gallina	Medicine, tea (leaves)
BUDDLEJACEAE	<i>Buddleja americana</i>	Salvia real	Medicine (leaves)
CANNACEAE	<i>Canna indica</i>	Achira	Food (leaves, tubers)
JUGLANDACEAE	<i>Juglans neotropica</i>	Nogal	Food (seeds), medicine (leaves)
MIMOSACEAE	<i>Inga</i> spp.	Guaba	Food (fruits)
MUSACEAE	<i>Musa</i> spp.	Plátano, maduro, orito etc.	Food (fruits)
PASSIFLORACEAE	<i>Passiflora</i> spp.	Granadilla	Food, juices (fruits)
PIPERACEAE	<i>Piper aduncum</i>	Matico	Teas (leaves)
ROSACEAE	<i>Fragaria</i> spp.	Frutilla	Food (fruits)
ROSACEAE	<i>Rubus</i> spp.	Mora	Food (fruits)
SAPOTACEAE	<i>Pouteria lucuma</i>	Luma	Food (fruits)
SOLANACEAE	<i>Physalis cf. peruviana</i>	Uvilla	Food (fruits)

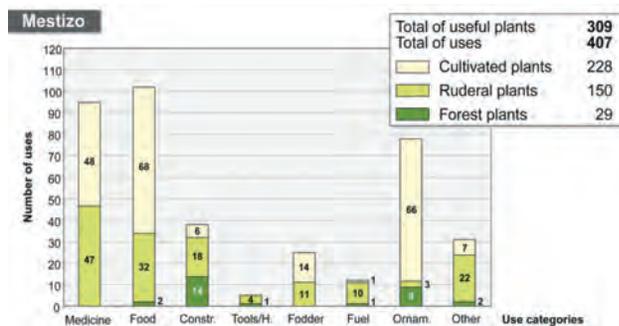
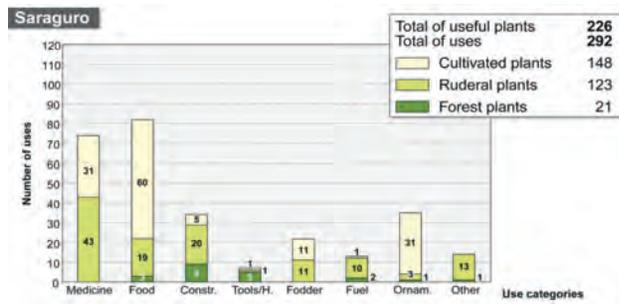
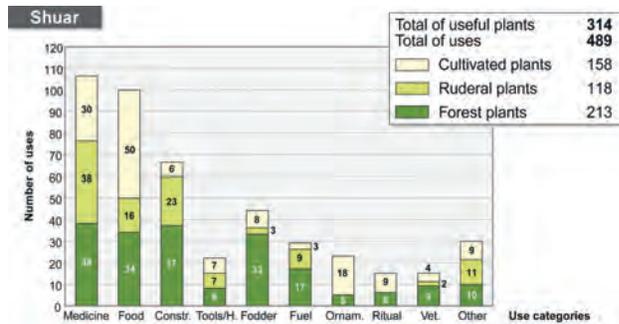


Figure 2. Plant utilization among the Shuar, the Saraguros and the mestizos in the research area according to main use categories (Constr. = Construction, Tools/H. = Tools/ Handicrafts, Ornam. = Ornamental, Vet. = Veterinary). Survey: A. Gerique

As traditional forest dwellers the Shuar of the Nangaritzta valley have the most comprehensive knowledge of forest plants and their utilization. The Saraguros and mestizos have considerable knowledge of cultivated plants, mainly used for food and medicine. For the mestizos, the ornamental use of plants is significant.

Mestizo home garden in Los Guabos (southern Ecuador - 1900m a.s.l.)

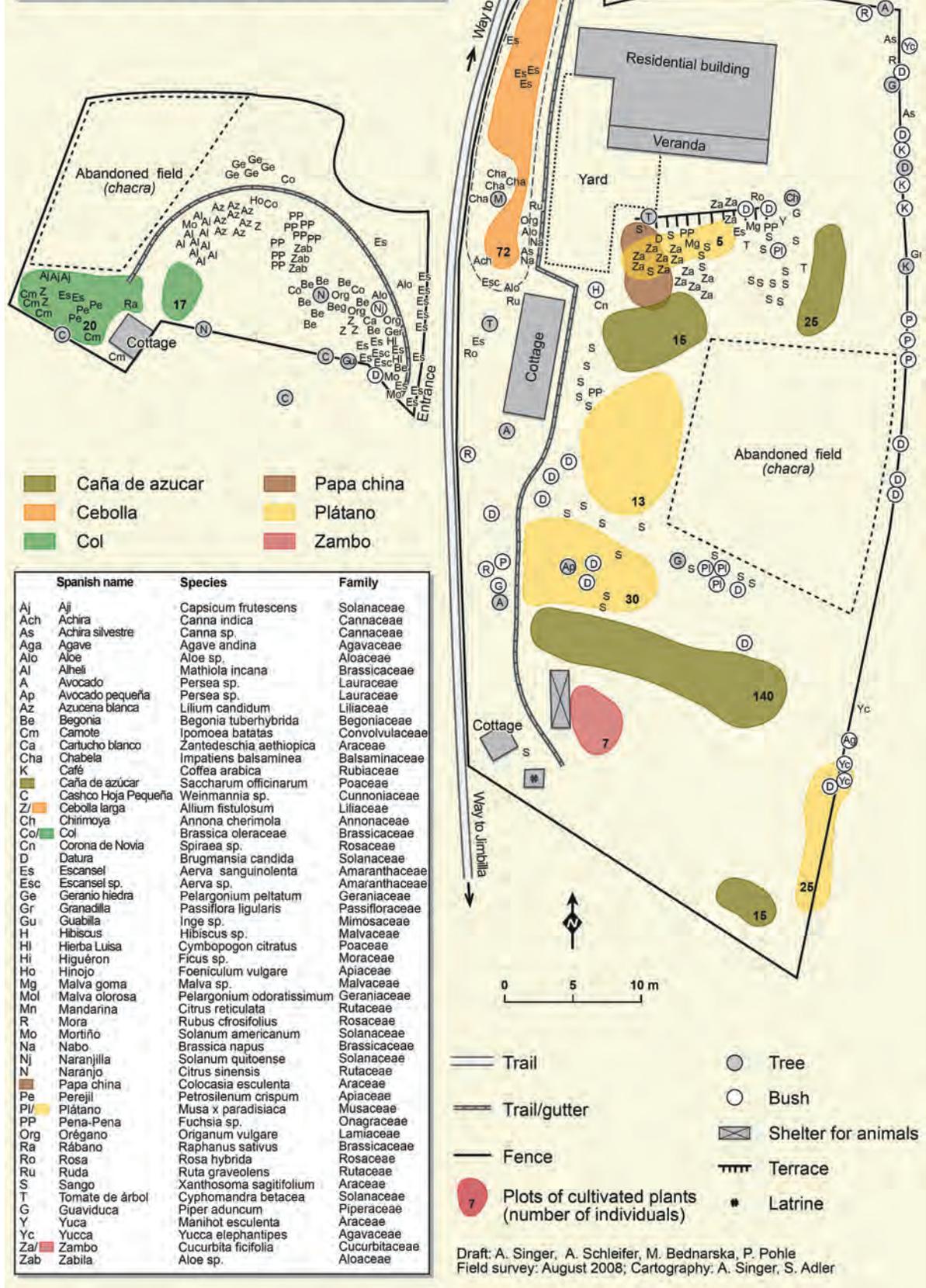


Figure 3. Setting of the Mestizo Homegarden in Los Guabos.

In the research area cattle ranching represents the main threat to forests and biodiversity. Thus, alternative activities for securing rural livelihoods are needed in order to reduce the pressure on the forests. To identify more sustainable land use options the use of non-timber forest products (NTFPs, Figure 2) and local agrobiodiversity of home gardens was investigated for the generation of additional income. Small in size, high in productivity and biodiversity, the home gardens of the three ethnic groups can be seen as an optimal form of exploitation in the region of tropical mountain forests. As the ethnobotanical and agrogeographical surveys indicate, there is a potential for the production of plant species in demand (e.g. medicinal herbs, fruits, vegetables, and ornamental flowers) for regional markets in home gardens (Table 2). From a conservation perspective, the challenge is to stop deforestation and to reduce the amount of cleared land going to pasture, while preserving or increasing farm incomes. Figure 3 delineates a draft of an alternative agroforestry system that could be implemented in the mestizo or Saraguro land use system in order to achieve a more diversified production.

Research also showed that land use among Saraguros and mestizos differ clearly from those of the Shuar. As typical forest dwellers the Shuar practice subsistence slash and burn agriculture, besides gathering, fishing and hunting. Due to recent agrarian mestizo and Saraguro colonization activities in the Alto Nangaritza, high stress is put on the Shuar's traditional forest and biodiversity conserving resource use system, especially by reducing available land for shifting cultivation, by over-exploiting food resources from the rivers and game but also by the contamination of rivers by increasing mining activities. Therefore, a main goal in terms of conservation of lower tropical mountain forests should be the protection of traditional Shuar territory and the recognition of the environmental services that forest-dependent peoples provide. Furthermore, the following alternative plant uses, as shown in Table 3, may be proposed for Shuar communities:

In any case, alternative land use options should incorporate existing sustainable practices, should be based on local knowledge and experience, and should take ethnocultural aspects and preferences into account.

Topic 2: Environmental perception and global change

To reveal the people's perception of their natural environment as well as global change induced stress/risk factors like deforestation, loss of biodiversity and land degradation, qualitative and quantitative data were collected in Saraguro (El Tibio) and mestizo communities (Los Guabos). In both communities farmers highly appreciated the multipurpose economic functions of the forests as well as their aesthetic and health related va-

lues. Furthermore, forests were seen as a safety net and a traditional risk-avoiding strategy because of their potential as agricultural reserves. Concerning the question whether forested areas are increasing or decreasing, the mestizos answered "it remains the same" whereas the Saraguros stated that the forest is decreasing. The mestizo perception reflects the more advanced stage of Los Guabos in the forest transition process where deforestation has slowed down and land abandonment with different stages of vegetation succession occurs. Regarding the perception of the loss of biodiversity due to deforestation, all interviewees could enumerate disappeared native tree species like Romerillo (*Prumnopitys montana*), Cedro (*Cedrela odorata*), Laurel (Aniba cf. *hostmanniana*), and Nogal (*Juglans neotropica*). Thus, afforestation was considered as an important task to protect nature, as a measure against species extinction, and to maintain fresh water supply and pure air.

Topic 3: Analysis of rural livelihoods

To identify ethno-specific livelihood strategies of rural farming households and their dependence and impact on natural resources a comprehensive household survey was conducted in rural communities of the Saraguros, mestizos and Shuar. The Saraguros and the mestizos of the research area are mainly engaged in agro-pastoral activities that combine both a market economy (cattle ranching for cheese, milk and meat production) and a subsistence economy (crop production, horticulture and cattle ranching for subsistence needs). Whereas corn and beans are cropped in shifting fields (*chacras*), vegetables, fruits, spices and other useful plants are cultivated in permanent home gardens (*huertas*). The main product drawn from cattle ranching is cheese, which is sold weekly in the markets of Loja. The distribution of monetary household incomes (Figure 5) clearly shows that revenues from employment are higher in the mestizo households than in those of the Saraguros, whereas revenues from cattle ranching (sales of cheese) are far higher in Saraguro than in mestizo households. The stronger engagement of Saraguros in cattle ranching becomes obvious also in the average share of pasture land per household (Saraguros: 11ha, mestizos: 8.4ha) and the average number of cattle per household (Saraguros: 11.4, mestizos 9.4).

Household types are very heterogeneous in the study area regarding their natural capital assets (Figure 6). A small number of privileged households owns a high number of cattle and maintains a big area of land (mainly pastures), whereas the majority of households has access to only small land holdings and owns very few head of cattle. There are also landless households and households with extremely small holdings (less than one



Figure 4. Actual land use and draft of an alternative agroforestry system

Left: Actual land use in the upper Zamora valley: Pasture land (a), including abandoned or over-exploited paddocks (b), and forest patches (c) dominate the landscape. Around the housings home gardens (d) and corn fields (e) are cultivated for subsistence. Right: A proposal for a more sustainable land use: The existing system is completed with plantations of (exotic and native) trees (f, g), improved pasture management including leguminous trees and living fences (h), the use of NTFPs from restored forest areas (i), and the cultivation of new agricultural products (j) at the expense of pasture and/or fallowed land (Gerique 2011).

ha) especially among the mestizos. Concerning the question of which household type contributes most to the deforestation process, these landless and poorest households are probably no relevant actors. Rather, the decision to clear forest is undertaken by the small number of more privileged landowners who also have the equipment and can afford to hire workers. Their decision is often based on a strong desire to improve livelihoods by integrating more into the market economy and this is realised especially by means of extensive cattle ranching. Concerning the “poverty-forest-debate”, these findings are not in line with the frequently held belief that poverty increases deforestation, at least on a household level.

Topic 4: Governance of natural resource uses

The research area has a remarkable history of conservation efforts: in 1982 the Podocarpus National Park was declared, in 2000 the Bosque Protector Corazón de Oro, and in 2007 the Biosphere Reserve Podocarpus – El Cónдор. However, only a few local inhabitants know about these conservation areas. The majority do not even know of the Podocarpus National Park and, although they are living within it, they do not know of the Bosque Protector Corazón de Oro. Interviewed people claimed to have no idea of what the specific conservation areas are for, where the borders are, and which resource use regulations and restrictions exist. Moreover, there are considerable jurisdiction problems between national in-

Tab. 3: Proposed alternative plant use for Shuar communities in the Alto Nangaritza Valley

Use of plants for / in	Plant species
Reforestation with commercial species within the community forests	<i>Terminalia amazonia</i> (yumbingue), <i>Platymiscium pinnatum</i> (almendro), <i>Cedrelinga cateniformes</i> (cedro)
Reforestation of pastures	<i>Trema micrantha</i> , <i>Inga</i> spp. (Revelo & Palacios 2005), <i>Oenocarpus bataua</i> (palma real), <i>Bactris gasipaes</i> (chonta) (Miller 2002), <i>Cordia alliodora</i> (laurel), <i>Cedrela odorata</i> (cedro) (Camargo 2003, Somarriba et al. 2001)
Improved production in forest gardens, diversification of the production	<i>Theobroma cacao</i> (cacao), <i>Coffea arabica</i> (café), <i>Solanum quitoense</i> (naranjilla)
Commercialization of non-timber forest products (previous market survey and external aid for certification needed)	<i>Caryodendron orinocense</i> (maní de árbol), <i>Carludovica palmata</i> (paja toquilla), <i>Croton</i> sp. (sangre de drago), <i>Uncaria tomentosa</i> (uña de gato), <i>Pourouma</i> sp. (uva de monte)

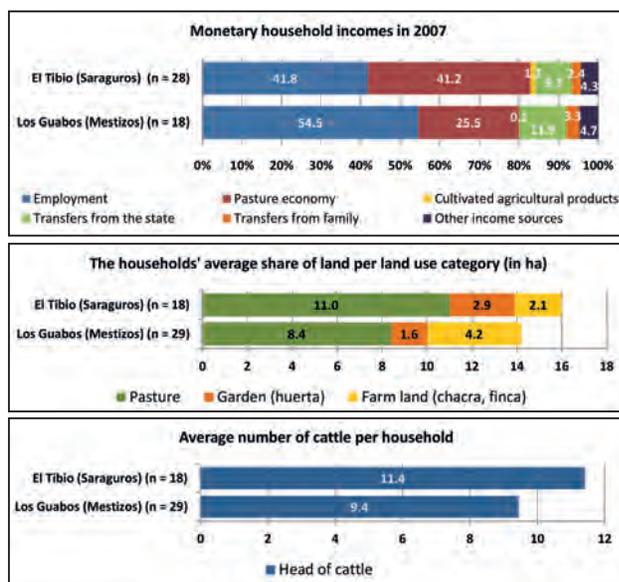


Figure 5. Monetary household incomes, average shares of land and number of cattle per household in Saraguro and mestizo communities. Survey: M. Park & P. Pohle

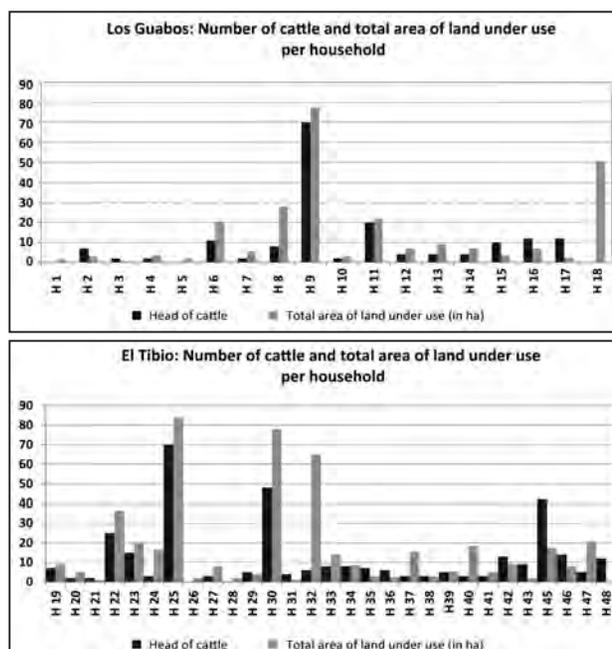


Figure 6. Head of cattle and total area of land in use (in ha) per household in Los Guabos (mestizo households 1-18) and El Tibio (Saraguro households 19-48). Survey: M. Park & P. Pohle

stitutions in the land legalization process within the Bosque Protector Corazón de Oro that in future will make local people very sceptical about conservation measures. By now it is well understood that nature conservation is only possible if the local population is included or, better yet, if conservation is co-managed by the local population. In this respect the local peoples' attitudes towards nature conservation and conservation measures are of major concern and form the basis for a sustainable development.

References

Buitrón V (2011) Cambios de usos del suelo (1986-2010) y estructura de asentamientos saraguros en el Alto Nangaritza. Diploma thesis PUCE, Quito

Gerique A (2011) Biodiversity as a resource: Plant use and land use among the Shuar, Saraguros, and Mestizos in tropical rainforest areas of southern Ecuador. PhD Thesis, Institute of Geography, University of Erlangen-Nuremberg

Pohle P, Gerique A (2008) Sustainable and Non-Sustainable Use of Natural Resources by Indigenous and Local Communities. In: Beck E, Bendix J, Kottke I, Makeschin F, Mosandl R. (eds): Gradients in a Tropical Mountain Ecosystem of Ecuador. *Ecol Studies* 198, Berlin: pp 331-345

Pohle P, Gerique A, Park M, López Sandoval MF (2010) Human ecological dimensions in sustainable utilization

and conservation of tropical mountain forests under global change in southern Ecuador. In: Tschardt T, Leuschner C, Veldkamp E, Faust H, Guhardja E, Bidin A (eds): Tropical rainforests and agroforests under global change. Springer, Berlin, pp 477-503

Pohle P (2013) Deforestation, environmental perception and rural livelihoods in tropical mountain forest regions of South Ecuador. In: Borsdorf A. (ed): *Forschen im Gebirge, Investigating the Mountains, Investigando las Montañas*, Christoph Stadel zum 75. Geburtstag. IGF Forschungsberichte 5, Austrian Academy of Sciences pp 190-210

Pohle P, Gerique A, López MF, Spohner R (2013) Current Provisioning Ecosystem Services for the Local Population: Landscape Transformation, Land Use, and Plant Use. In: Bendix J, Beck E, Bräuning A, Makeschin F, Mosandl R, Scheu S, Wilcke W (eds): *Ecosystem Services, Biodiversity and Environmental Change in a Tropical Mountain Ecosystem of South Ecuador*. *Ecol Studies* 221, Berlin pp 219-234

Pohle P, Gerique A, López MF (2013) Human Ecological Dimensions in Sustainable Utilization and Conservation of Tropical Mountain Forests. *Tropical Mountain Forest (TMF) Newsletter* 19: 22-25 DOI: 10.5678/lcrs/for816.cit.1233

Tutillo Vallejo A (2011) Nutzung und Management der natürlichen Ressourcen bei den Saraguros und Mestizos im Wassereinzugsgebiet des Tambo Blanco in den Anden Südecuadors. PhD Thesis, Institute of Geography, University of Erlangen-Nuremberg





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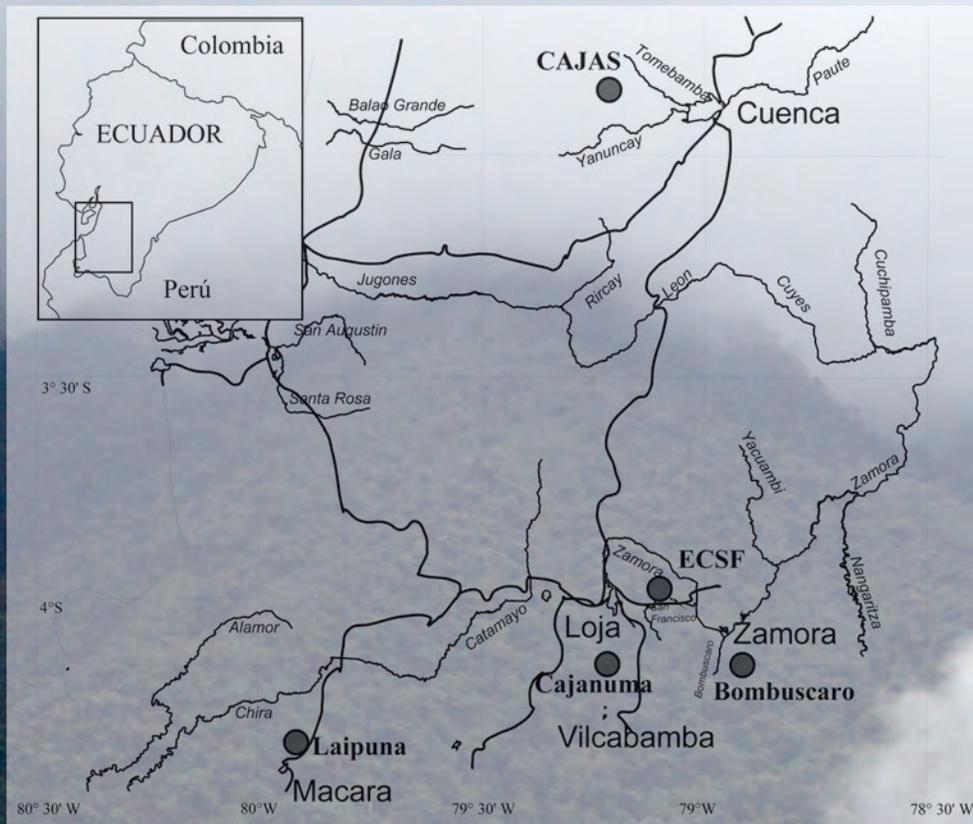


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