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Jörg Bendix · Erwin Beck · Achim Bräuning
Franz Makeschin · Reinhard Mosandl
Stefan Scheu · Wolfgang Wilcke *Editors*

Ecosystem Services, Biodiversity and Environmental Change in a Tropical Mountain Ecosystem of South Ecuador

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Preface

Threat to biodiversity and ecosystem services by global change is meanwhile undisputed. Climate change, expansion of land use, atmospheric fertilization, and invasion by alien species have been identified as the main current and future drivers of ecosystem deterioration (Sala et al. 2000; Pereira et al. 2010). The Millennium Ecosystem Assessment (MEA 2005) connected for the first time the interdependence of ecosystem functioning and human interference with nature in a well-arranged, comprehensive manner by defining specific categories of services which the earth's ecosystems provide for their own stability and in particular for the benefits of their human inhabitants. While acknowledging those services as a major precondition for human well-being, the aim of the report was to assess the consequences of (predominantly) man's impact on ecosystems for human well-being and to provide the scientific basis for a responsible, sustainable use of ecosystems, including conservation. Notwithstanding the appreciation of the impressive conceptual work condensed in that report, its focus on the global dimension of ecosystem services inevitably generates scarcity of regional and local assessments. Thus, e.g. for the biodiversity hotspot of Ecuador information on the current or the predicted states is completely lacking (Fig. 6.1 in MEA 2005). At the same time, the report deplores insufficient knowledge, among others, on (1) long time series of local environmental data, (2) quantitative relationships between biodiversity and ecosystem services, particularly regarding regulative, cultural, and supporting services of specific ecosystems, which would allow predictions, and (3) the incapability to derive regional and local projections of the future development of ecosystem services (MEA 2005).

This book will contribute to fill such local gaps for one of the "hottest" biodiversity hotspots of the world, the south-eastern Andes of Ecuador. Assessment of the current and future state of biodiversity and ecosystem services in the valley of the Rio San Francisco is based on 15 years of comprehensive interdisciplinary ecosystem research, producing a wealth of data, and profound as well as far-reaching information on ecosystem structure and functioning, covering the biotic, abiotic, and socioeconomic spheres. A basis to this endeavor is the predecessor volume ("Gradients in a Tropical Mountain Ecosystem of Ecuador" in the same Series, Vol. 198, edited by Beck et al. 2008), which has been published five years ago. A special advantage of the selected study area is the direct spatial vicinity of the protected mountain rain forest as the natural ecosystem of the region on the one side of the valley and an anthropogenic agricultural replacement system on the opposite side. While the natural forest appears to be fairly resilient to climate changes, the agricultural systems, mostly pastures, turned out to be non-sustainable. The unique opportunity to conduct comparative field surveys and ecological experiments in both manifestations of the ecosystem allowed the authors to gather quantitative information on current ecosystem services which are subjected to the impacts of an ongoing climate and land-use change. With regard to ecosystem services, the book is based on an approach adapting the MEA (2005) service categories, as described in detail in Sect. 4.2.

Part II presents the current state of the different service categories. Naturally this part cannot claim to be exhaustive regarding the immense complexity of the tropical ecosystems. Thus, the authors have focused on services which are of major importance for the country, e.g., biodiversity as the main preserving but also cultural service, the regulation of climate, the water, carbon, and nutrient cycles, considering abiotic and biotic elements, the provision of water, the deposition of airborne nutrients, and various options of agricultural provisioning services (forestry and pasture management). The latter have been analyzed in a holistic way, ranging from ecological aspects to socioeconomic issues, in particular the sustainability of indigenous land-use systems.

Regarding prospective approaches, ecological intervention experiments on the one hand and numerical models calibrated and parameterized by a multitude of measured data on the other provide the basis for scenarios for the future development of the investigated ecosystems and ecosystem services. This is the concern of Part III. Special attention is given to derive a sustainable land-use portfolio from an ecologically adapted combination of suitable agricultural strategies and managements.

The main synthesis (Part IV) summarizes the accumulated comprehensive knowledge, culminating in a science-directed recommendation of sustainable land-use system for the hotspot area, which was the overarching aim of the past 6 years of research. Although the book reports projects of basic research, there is one major point which must not be overlooked. In the spirit of the Access and Benefit Sharing (ABS) principle publicized by the CBD (Convention on Biological Diversity), research in a developing country should address the needs of the local communities and should be conducted together with the local people, scientists, and stakeholders for the sake of building capacity. After 15 years of joint German–Ecuadorian research, a multitude of benefits have been achieved and are communicated in Part IV. This holds in particular for the academic scene of southern Ecuador. Furthermore, the compiled results and developed technologies of several projects are now ready for transfer into application to serve the local society. Consequently, the potential of the research results for knowledge transfer has been assessed here, too.

At this point, it should be stressed that the results of this book not only hold for the ecosystem of the Rio San Francisco Valley but *mutatis mutandis* show transferability to other forested tropical mountain areas of the Andes (and beyond), if located in a comparable altitudinal range of approximately 1,000–3,500 m a.s.l. The environmental background conditions of the study area are comparable to many other sites at the tropical eastern Andean ranges. The altitudinal level of the study area is subjected to the influence of a belt of high cloudiness and precipitation, the so-called Andes-Occurring System (AOS), ranging from Columbia to Peru (Bendix et al. 2006). As in the study area, the population pressure in the biodiversity hotspot of the entire tropical Andes is one of the highest in the world. This causes ongoing land-use changes, i.e., clearing of the natural forest to increase livelihood by exploiting provisioning services as revenues from agriculture. However, the needed conversion of natural forest into arable land at the same time deteriorates ecosystem services at other levels. As in the study area, the removal of forest for pastures is the current land-use practice everywhere in the tropical Andes (Mulligan et al. 2009). This type of land-use change is generally suspected to threaten cultural, supporting, regulating and provision services, and also knowledge which is associated with functional biodiversity.

However, many uncertainties of ecological, economic, and social nature remain with respect to the bouquet of ecosystem services from the natural and the man-made ecosystems in the research areas and beyond. The book takes up all these uncertainties and attempts to provide exemplarily transferable comments on the state of current ecosystem services and their management.

Last but not least, the endeavor of compiling an interdisciplinary book of this extent is a major challenge. This had not been possible without the extraordinary commitment of the 103 authors who contributed their excellent knowledge, creativity, and enthusiasm during the compilation of the manuscript. Many thanks go also to our editors for moderating partly controversial but fruitful discussions in order to match the individual chapters and to the publisher for supporting the publication of our results in the Ecological Studies series. Our assistant editor, Dr. Esther Schwarz-Weig (Mistelgau), deserves a special praise for her outstanding perseverance and patience in collecting, editing, and commenting on the chapters. Without her help, this book would certainly never have been realized. The authors would also like to thank the German Research Foundation (Deutsche Forschungsgemeinschaft DFG) for generously funding the research and the external board of advisors/reviewers for their help to refine the research program. For the achievement of the knowledge compiled in this book, the excellent cooperation with Ecuadorian colleagues and local people was instrumental, who became good friends over the time. The foundation Nature and Culture International (NCI) provided the facilities, in particular the very well-equipped research station ECSF (Estación Científica San Francisco) together with the surrounding research area. The effective running of this station by NCI in cooperation with the German scientific coordinators Dr. Felix Matt and Dipl. Geoecologist Jörg Zeilinger must be considered a stroke of luck for the entire enterprise "Ecosystem Studies in South Ecuador." The support of our counterparts from the Ecuadorian Universities, above

all from the Universidad Técnica Particular de Loja (UTPL), the Universidad Nacional de Loja (UNL), and the University of Cuenca, also deserves special acknowledgment. The authorship and coauthorship of many Ecuadorian collaborators in this book witness the excellent cooperation. Last but not least, we thank the Ecuadorian governmental administration for enabling this exciting research and, on behalf of others, the Ecuadorian Ministry of Environment (MAE) for issuing the research permissions. As the space of this preface is limited, it is not possible to thank all people by names who have contributed to the success of our research and in turn to the realization of this book. Nevertheless, we are very grateful to them and their support of our venture is well appreciated.

Marburg, Germany Jörg Bendix
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Contents

Part I
Introduction

Chapter 1
The Study Area

Michael Richter, Erwin Beck, Rütger Rollenbeck, and Jörg Bendix

1.1 Why the Andes of Southern Ecuador?

The Andes of southern Ecuador are considered as one of the "hottest" global hotspots of vascular plant (Barthlott et al. 2007; Brummitt and Lughadha 2003; Jørgensen and Ulloa Ulloa 1994) and bird diversity (Orme et al. 2005). The major proportion of the biological diversity is found with the native mountain forest which as a rather stable ecosystem provides a multitude of services. However, this ecosystem is severely threatened by on-going deforestation which takes place at the highest annual deforestation rate (−1.7 %) of entire South America (Mosandl and Günter 2008). The forces driving forest decline in Ecuador are manifold (Rudel and Horowitz 1993; Pichón 1996; Mena et al. 2006). As main drivers in southern Ecuador the colonisation laws and land reforms, the population pressure and transmigration, the existence of state-owned land and unclear property regimes as well as the recently improving accessibility (road construction) could be identified (cf. Chap. 16).

More than 10 years of comprehensive interdisciplinary research in the San Francisco Valley in the eastern Andean Cordillera of southern Ecuador have proven the megadiverse character of the native mountain forest (Beck et al. 2008a). Apart from a high diversity of vascular plants (e.g. >280 tree and >337 orchid species) a variety of other organismic groups are represented with extraordinary species

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numbers (Liede-Schumann and Breckle 2007; Beck and Richter 2008). Records from the central part of the research area (natural forest area = 11.3 km^2, anthropogenic area = 1.91 km^2) revealed more than 500 species of bryophytes (mosses, liverworts, hornworts; up to 98 species on a single tree) and around 1,600 cormophytes. Even more diverse are insects, exemplified by a world record of 2,400 moth species. Birds and bats exhibit likewise extraordinary high diversity. A few organismic groups are nevertheless relatively poor in species, among them taxa of soil organisms, particularly the litter decomposers. Soil mites and earthworms are scarce or at least less abundant and diverse (Illig et al. 2005), probably due to nutrient limitations.

As in other parts of the country, the native forest has been and still is widely cleared in southern Ecuador for gaining pasture land. This particularly holds for well-accessible areas (e.g. close to roads) where there is no forest protection. Recurrent burning as the hitherto practised pasture management option is fostering the invasion and spreading of an aggressive weed, the Southern Bracken fern (*Pteridium arachnoideum* (Kaulf.) Maxon and *Pt. caudatum* (L.) Maxon) which outcompetes the pasture grasses, finally leading to the abandonment of the spoiled land (Roos et al. 2010; Hartig and Beck 2003). As expected, biodiversity of this highly disturbed sites ("Llashipa" = fern) is generally lower compared to the native forest, but this does not hold for all organismic groups (e.g. Haug et al. 2010).

The status of the mountain ecosystems encompassing native forests and pastures as the anthropogenic replacement systems shows that the current mode of exploiting the provisioning services in the Andean ecosystems of southern Ecuador is not sustainable. Hence there is serious concern that essential ecosystem services at all levels are affected particularly by the land use practices not refraining from further clearing of the natural forest. If no effective counter-measures are taken, biodiversity and ecosystem services are supposedly further declining, as they are additionally challenged by climate change for which evidence in the area will be presented (Bendix et al. 2010, Chap. 2). Based on the results of a comprehensive research effort in the Andes of southern Ecuador, this book aims to provide deeper insights into current and future ecosystem functioning and services in a mega-biodiverse hotspot area.

1.2 The Location of the Study Site

The entire research area comprises the Andean part of south-eastern Ecuador between the provincial capital Loja in the west, the provincial capital Zamora in the east and the town Vilcabamba in the South (Fig. 1.1). The main connection road between the two capitals runs along the valley of the Rio San Francisco (RSF). The core area of the research activities expands around the research station ECSF (Estación Científica San Francisco, lat. 3°58′18″ S, long. 79°4′45″ W, 1,860 m a.s.l.) and the focal experimental site in the natural forest RBSF (Reserva Biológica San Francisco) which ranges from 1,600 to 3,140 m a.s.l. The lower parts of the

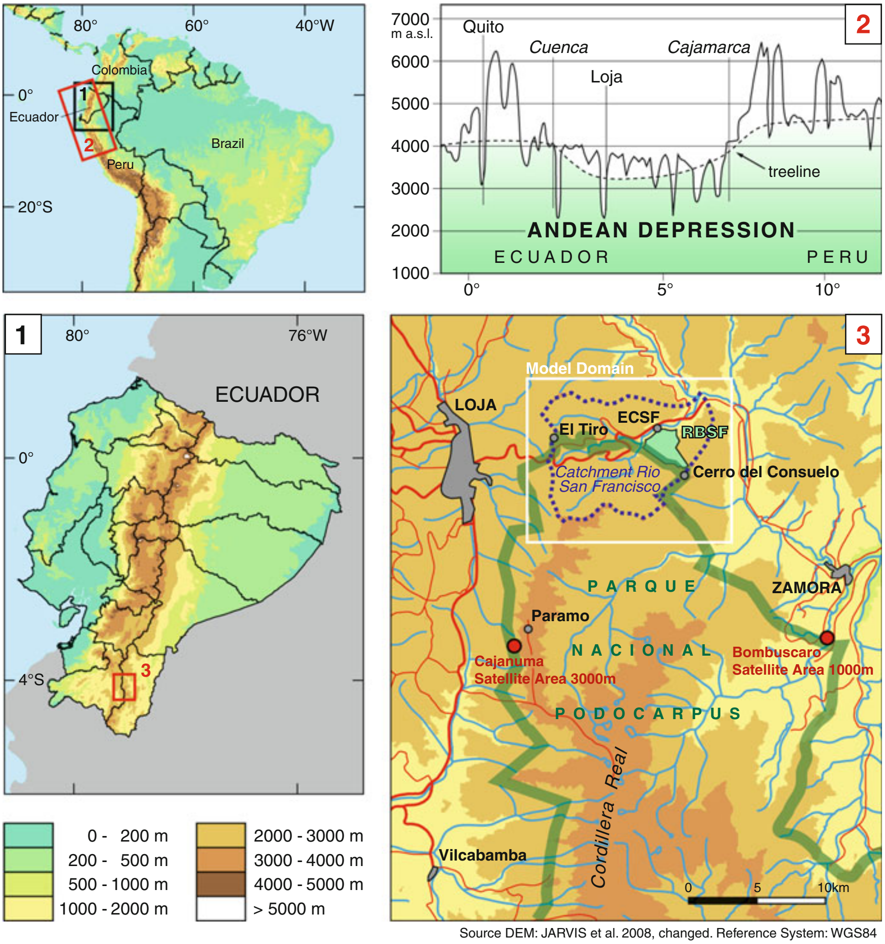

Fig. 1.1 Location of the research area. The image on *top* (*left*) shows the area of the map 1 and the site of the cross section of map 2 highlighting the Andean depression. Graph 3 shows the location of the research area (Reserva Biologica San Francisco, RBSF), the catchment of the Rio San Francisco and the two mountains El Tiro and Cerro del Consuelo at the borders of the research area. The satellite areas at Bombucaro and at Cajanuma were used to study altitudinal gradients. The digital elevation model (DEM) is based on Jarvis et al. (2008)

south-facing slopes opposite the forest are covered by active but also abandoned pastures. The border between the provinces Loja and Zamora-Chinchipe runs along the crest of the Cordillera Real (eastern cordillera range) which is the core of the Podocarpus National Park (PNP). For a complete altitudinal gradient (Beck et al. 2008a) over the natural forest, two experimental satellite areas (Bombuscaro at 1,000 m a.s.l. and Cajanuma at 3,000 m a.s.l., see Fig. 1.1) have been established near the western and eastern border of the PNP, respectively.

The elevation of the Cordillera Real does not exceed 3,900 m a.s.l. With this relatively low vertical extension, the Andes of southern Ecuador are the lowest part of the tropical Andes. As stressed, e.g. in Richter et al. (2009), this depression (the Amotape-Huancabamba Depression) forms a transition zone between the higher northern and the central tropical Andes in the South and in east–west direction between the moist Amazon rainforest and the dry Sechura desert. As such, it plays a major role in the development of the extremely high biological diversity of the ecoregion (see Sect. 1.4.3). Furthermore, the SE-Ecuadorian Andes are characterised by a high topographic fragmentation which results in numerous isolated basins and ridges, thus offering a great variety of habitats which might foster development and maintenance of a high organismic diversity, as well as of endemism (c.f. Oesker et al. 2008).

1.3 Ecological Measurements and Experiments

The scale concept of the research programme correlates with the clustering of the ecological experiments. The satellite research sites at 1,000 and 3,000 m elevation, respectively, allow comparative surveys and ecological experiments along a 2,000 m altitudinal gradient. The experimental sites have been equipped with sophisticated instrumentation and tailor-made ecological treatments produced the data and results which are presented in this book. The location of the research sites are shown in Fig. 1.2.

The following measurements and experiments were carried out:

1. The still on-going Nutrient Manipulation Experiment (NUMEX) investigates effects of nutrient input into the megadiverse natural forest, simulating the natural atmospheric deposition, however in selected constant amounts. Research objectives are the effects on biomass allocation of trees, species composition (biodiversity) and the biogeochemical cycle. The consortium operates main experimental sites at three elevations and several additional plots in the matrix area, to consider also the influence of the topographic variability (see Chaps. 22, 23 and 26).
2. On the pasture site, the corresponding FERPAST experiment investigates the effects of nutrient addition on pasture yields in relation to the biology and chemistry of the soils (Chaps. 22 and 26).
3. In the forest area, several long-term experiments monitor temporal oscillations of key components of the biogeochemical cycle (long term ecosystem study) or investigate the outcome and ecological impact of a moderate promotion of valuable timber species in the natural forest (natural forest experiment, Chap. 13).
4. On the abandoned land, experiments were performed (1) to understand the competition of bracken fern with the common pasture grass *Setaria sphacelata*, (2) to elaborate optimal pasture management protocols and (3) to study the

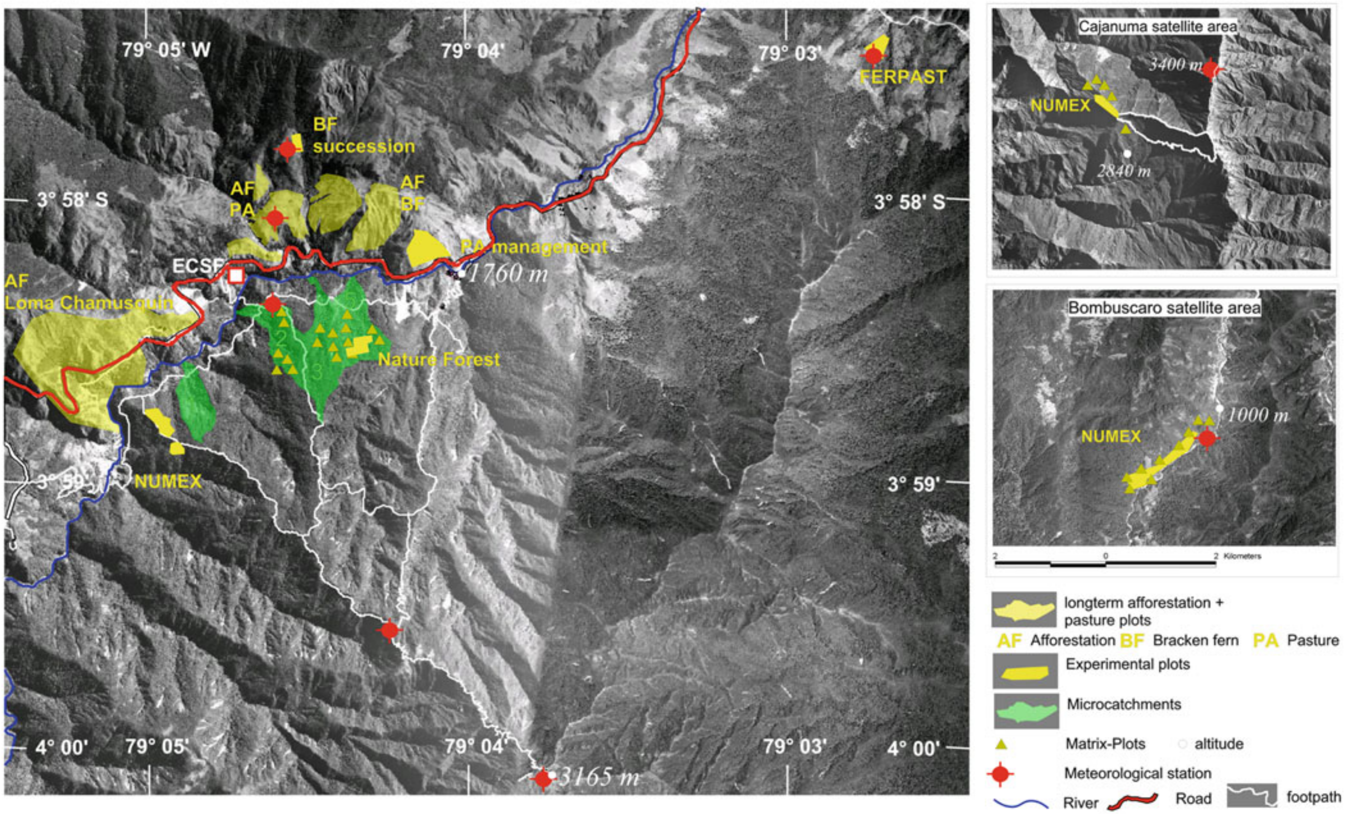

Fig. 1.2 Location of experimental sites and the research infrastructure. Further information about measurements, the Nutrient Manipulation Experiment (NUMEX, description in Chap. 23), the Fertilization of Pastures experiment (FERPAST, description in Chap. 22) and the Bracken Fern succession experiment (description in Chap. 26) is provided in the text. *ECSF* Estación Científica San Francisco

success of afforestation with indigenous tree species on active and abandoned pastures as well as under the shelter of exotic trees (see Chaps. 15 and 26).

5. The experimental setup is completed by basic research infrastructure as, e.g. a network of meteorological and hydrological stations.
6. In order to upscale the experimental findings to the landscape scale, numerical models have been developed and/or parameterized on the scale of the (1) experimental sites, (2) the RBSF (model domain 1) or (3) the total catchment of the Rio San Francisco (Fig. 1.1, framed in blue) and beyond. The adapted models are used to understand ecosystem processes and to generate future scenarios as presented in Part III of the book.

1.4 Selected General Features of the Study Area

The general abiotic and biotic zonation, as well as the geology, topography, the soils and the entire biogeography of the area including population features of southern Ecuador has already been described in Beck et al. (2008a) and Beck and Richter (2008). However, selected new findings which are completing the overall knowledge of the study area deserve special attention with regard to the following aspects: (1) the complex dynamics of rainfall formation in the study area and other climate peculiarities, (2) the natural disturbances as an internal trigger of biological megadiversity in the tropical mountain forest system and (3) the reasons for the megabiodiversity of the area.

1.4.1 Climate Peculiarities

The climate of the study area is generally characterised by extreme horizontal gradients. Over a very short distance of ~25 km, annual rainfall increases from less than 500 mm in the semi-arid inter-Andean basin of Catamayo west of Loja to more than 6,000 mm (including cloud water deposition) at the top region of the Cordillera Real (Emck 2007; Richter 2003), where the crest of the cordillera constitutes a clear weather divide with extremely wet conditions on the eastern escarpment (see Fig. 1.3). At the same time, the seasonality changes from two rainfall maxima in austral spring and autumn at Loja to one rainfall peak in austral winter (JJA: June to August) for the Rio San Francisco Valley.

In austral winter quasi-permanent easterly winds (>70 %) lead to rainfall maxima and a high diurnal persistence of the rain from relatively shallow cap clouds (cloud top between 4 and 5 km; Bendix et al. 2006b) resulting from forced convection and condensation of moist Amazonian air masses impinging on the eastern slopes of the Andes (Fig. 1.3). From October to January (austral summer), dry periods but also strong convective, thermally induced rainfall events are mostly combined with (north-) westerly weather conditions (WWCs) and with

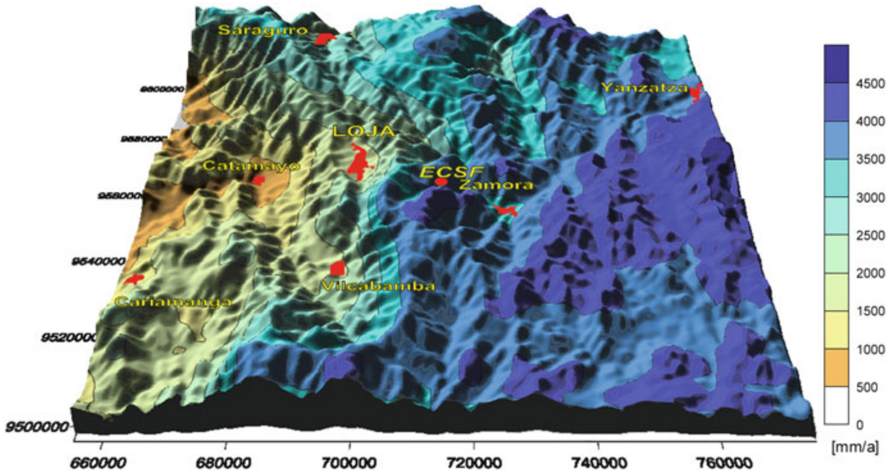

Fig. 1.3 Map of average annual rainfall (1998–2010) derived from rain radar data and ground measurements projected on a digital elevation model of the region around Loja (see also Rollenbeck and Bendix 2011)

VdN-situations (Veranillo del Niño) with a maximum incidence in November (Emck 2007; Bendix et al. 2008a). During this drier period convective showers induced by the valley-breeze system are also frequent in the afternoons of the San Francisco Valley. With regard to the vertical cloud moisture gradient in the valley, a clear increase of cloud frequency and thus, cloud water deposition is observed above 2,600 m (Rollenbeck et al. 2010). During the early morning hours around sunrise, however, cloud frequency increases almost linearly upwards from the valley bottom, starting with higher values also in its lowermost range (Bendix et al. 2008b). Radiation fog (visibility < 1 km) at the valley bottom is scarce (Fig. 1.3) and relates to nocturnal radiation losses during dry periods, while at higher altitudes particularly in austral winter cloud fog and cloud water deposition is extremely prominent, due to the cap clouds touching the upper slopes (cloud fog).

A novel finding is the occurrence of two daily maxima of precipitation in the Rio San Francisco Valley. Apart from the afternoon showers during drier periods the other maximum can be attributed to cap clouds in austral winter. These early morning rains are also related to highland–lowland interactions and mesoscale atmospheric dynamics. The confluence of nocturnal katabatic flows from the escarpment—caused by the specific concave shaping of the eastern Andes in the East of the research area—produces local cold fronts in the warm-moist Amazon air during the night. In combination with an Andean-parallel low level jet (LLJ) above 1,500 m a.s.l. they cause strong atmospheric instability leading to the formation of mesoscale convective systems (MCS) over the eastern foothills. In their mature phase around sunrise (MSC_{ms} in Fig. 1.4), these systems are forced towards the eastern escarpment by the easterlies, fostering rainfall over the valley itself (details in Bendix et al. 2009; Trachte et al. 2010).

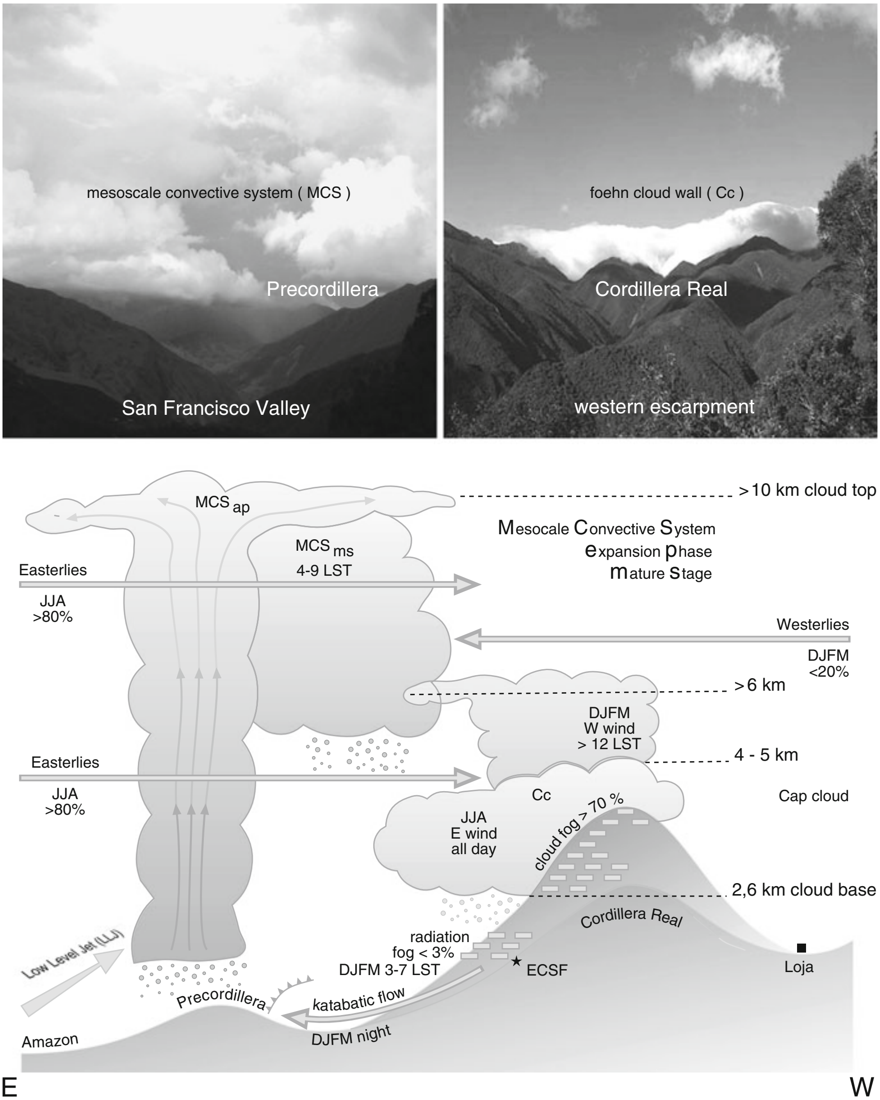

Fig. 1.4 Summary of cloud and rain formation processes affecting the study area. *Note*: The graph contains climate features of various seasons. JJA = austral winter (June–July–August), DJFM = austral summer (December–January–February–March). *ECSF* Estación Científica San Francisco, *LST* local standard time, *MCS* mesocale convective system. Photos: Michael Richter (*left*) and Paul Emck (*right*)

The great number of rainy and cloudy days results in low amplitudes of the persisting high relative humidity during the peak season of rainfall in austral winter (JJA). In contrast, in October–November pronounced fluctuations occur during VdNs, when abrupt drops of 80 % can happen within few hours. The most dramatic case was recorded at night (!) of 17/18 October 1998, when the summit area was stressed by a sudden decrease from relative humidity (rH) >95 % down to <15 %, initiated by an enhanced downswing of air masses towards a strong low at the eastern foothills of the Andes.

Extraordinarily high values of global irradiance of up to 1,832 W m^{-2} were measured in the paramó above the tree line during such irregular meteorological events. Incidence of "superirradiance" of over 170 % of the potential "clear sky" irradiance occur predominantly under easterly weather conditions (EWC) when global radiation is enhanced by reflections and diffractions of transparent clouds screening the sun disk and through lensing effects by water droplets (Emck and Richter 2008). Ultraviolet radiation with its mutagenic potential must be considered to reach record levels as well, which might enhance the genetic dynamic of the organisms.

1.4.2 Landforms, Erosion and Mass Movement

Typically, landform characteristics in high mountains result from past as well as recent geomorphological processes. Among the latter, gelifluction and/or glaciation traces of the ice ages are obvious in the Cordillera Real, but not down in the valley. Glacial cirques and moraines are absent as are obvious signs of frost debris remnants. Both phenomena are, however, present in the upper regions of the neighbouring Rio Sabanilla Valley. Hence, apart from the quasi-continuous uplift since the Tertiary, land-forming processes are to a large extent restricted to fluvial erosion and slope denudation (Fig. 1.5).

Deeply incised V-shaped valleys are a typical landform in the entire eastern range of the wet tropical Andes. Side crests and offsets are mostly staggered and graded on concordant levels showing relics of formerly interrelated and meanwhile dissected rock terraces. They are considered residuals of ancient valley floors which developed during phases of slow uplift of the Andes. Narrowly delimited flat sections on side crests are generally fixed on hard parent rock such as quartz, which builds resistant strata between the phyllites or fine sand stones. In the RBSF terrain prominent terrace levels are at 2,200 m a.s.l. and around 2,580 m a.s.l. (pale yellow areas in Fig. 1.6, left). The steep appearance of the research area becomes apparent by the fact that around 55 % of its surface belongs to the inclination class between 25 and 40°, and slopes >40° are represented by almost 20 %.

Due to such inclinations under a perhumid climate and an on-going lowering of the erosion base level, slope stability is weak and landslides are a frequent natural phenomenon. The most striking morphological processes of the San Francisco Valley are numerous translation slides in the rainforest area (Fig. 1.6, right), which are a characteristic feature of destructive mass movements in the Rio San Francisco Valley (see Chap. 12). Vanacker et al. (2003) stated that under forests, slope steepness affects slope stability. Additionally, in case of the forested research area slide activity results from the destabilisation of thick, water-soaked organic and humus layers and in particular of the weight of dense tree stands (Richter 2009,

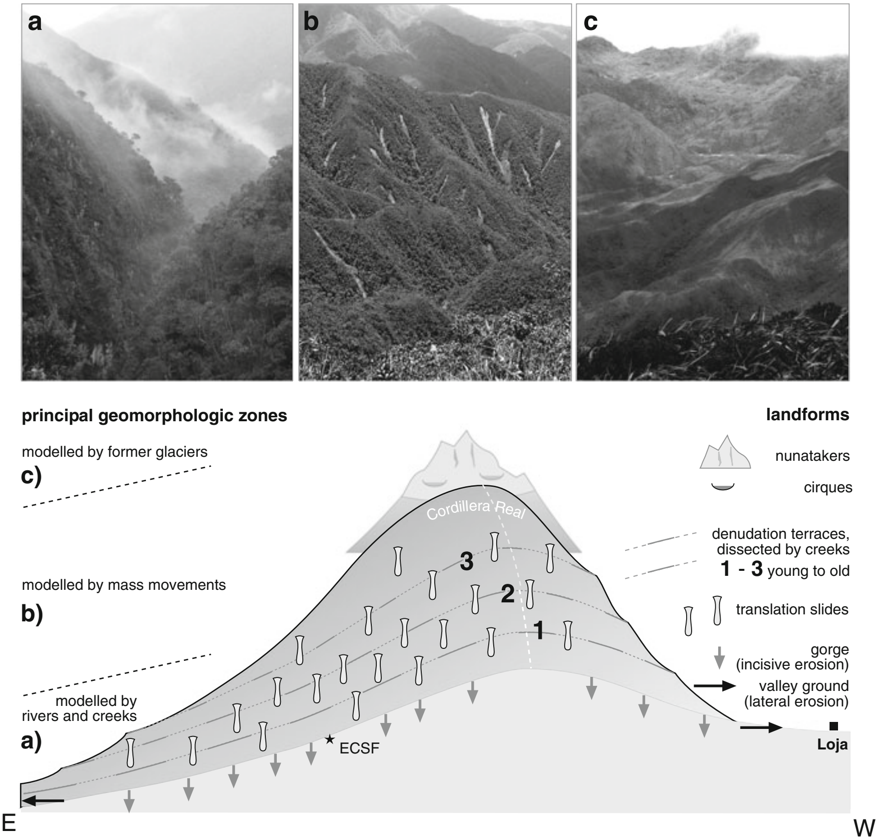

Fig. 1.5 Geomorphologic zonation and landform distribution in the RSF Valley including the summit region few kilometres further south in the Cordillera Real. (**a**) V-shaped RSF Valley near the research station at 1,800 m a.s.l., (**b**) slide section around 2,500 m a.s.l. in the RBSF, (**c**) view towards Lagunas de los Compadres, 3,100–3,550 m a.s.l. Photos: Michael Richter

see also Chap. 12). After deforestation, however, slumps, debris and mud flows on pasture land become rare. Such areas are devoid of the thick organic layer and the humic topsoil is very compact due to trampling by the cattle. If any, bulk density and soil wetness gain some importance as the above ground weight of the vegetation is negligible and the compact root systems of the grasses reach deep.

The importance of landslides for ecological processes in the research area is obvious from the numbers in Table 1.1.

Denudation rates by sheet erosion and splash are present throughout, although of scarce visibility. At around 2,000 m a.s.l., continuous measurements on soil erosion test plots on 40 ± 5° inclined slopes show denudation rates between 200 and 1,100 kg ha^{-1} a^{-1} in the rainforests of RBSF, depending on the density of the understory, while the values on active or abandoned pastures vary between 200 and 300 kg ha^{-1} a^{-1}. Interestingly, these results of removal by sheet erosion resemble

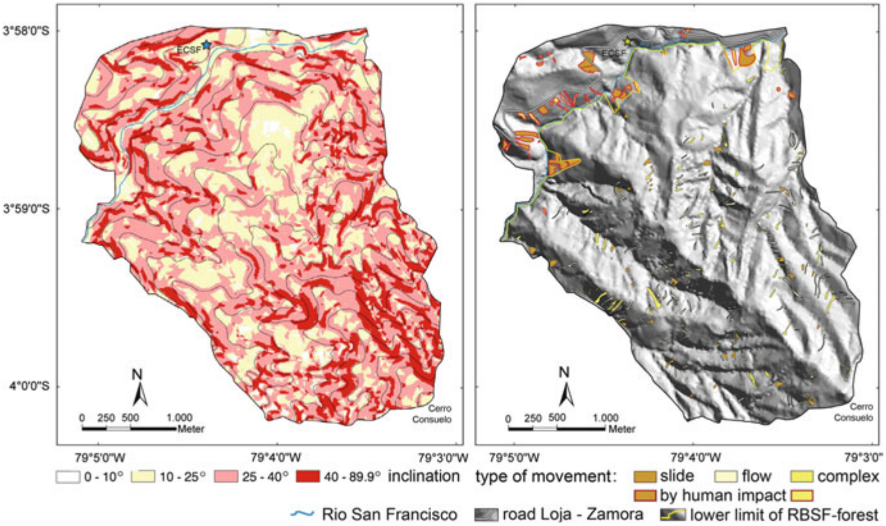

Fig. 1.6 Inclination (*left*) and landslides (*right*; each slide clearly visible in 1998 is indicated, after Münchow et al. 2012) mapped in RBSF including parts of Llashipa

Table 1.1 Landslides in the research area (relating to all incidents between 1963 and 2000; Münchow et al. 2012)

	Natural forest	Roadside and pasture land s.l.
Number of landslides	691	138
Landslide density (km^2)	12	14
Mean landslide size (m^2)	558	1,070
Proportion of slided terrain surface (%)	3.41	7.73

Note: By far, most of the mass movements in pasture and abandoned land are caused by roadside slides

the transport amounts produced by splash, which vary between 250 and 850 kg ha^{-1} a^{-1} in forest stands and around 80–150 kg ha^{-1} a^{-1} on pastures. The natural denudation rates caused by sheet wash and splash depend considerably on the structure of the mountain rainforest, on the soil structure and on the quantity of rainfall. At 1,000 m a.s.l., splash and sheet erosion rates in the rainforests of Bombuscaro are up to three times higher compared to RBSF, as rain intensities and tree size in the lower site are much higher and such are the energies of the droplets (Hagedorn 2001).

1.4.3 Causes for the Outstanding Biodiversity

Available reports of recent botanical expeditions and own observations document a high probability to discover unknown plant species in the so-called Amotape-Huancabamba floristic zone (Weigend 2002). With respect to the uplift of the

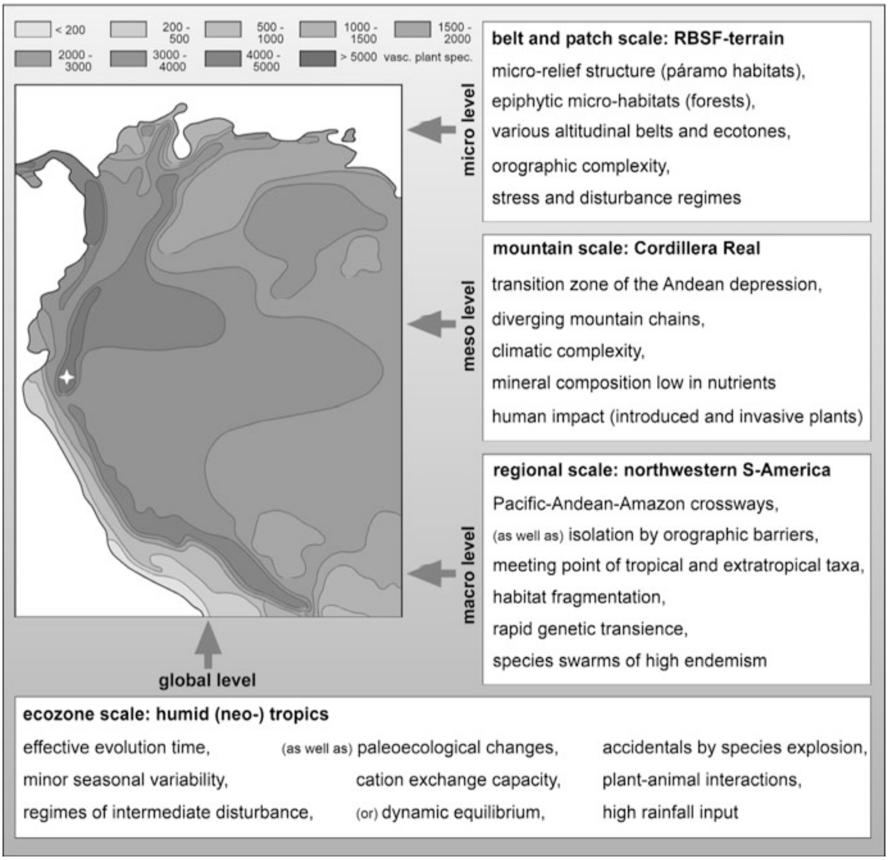

Fig. 1.7 Scale dependent factors contributing to plant diversity in the study area in southern Ecuador (Richter et al. 2009). Four levels from global to microscale are expressed in separate *boxes*. The map of vascular plant species (vasc. Plant spec.) richness is based on a world map by Barthlott et al. (2007). *Star* indicates the position of the RBSF research area

mountain system, this zone represents a geologically young part of the tropical Andes and since the uplift is apparently the crucial event for speciation, a high dynamics of the biological diversity can be expected. On the family level, far above average endemism has been shown for Orchidaceae (55 % of the occurring species), Bromeliaceae (50 %), Asteraceae (37 %) and Piperaceae (37 %). The ample supply of digestible plant organs, flowers and fruits provides a broad spectrum of food for generalists as well as for specified consumers and in turn affects faunal diversity.

Several factors may be considered as driving forces for the development of the high diversity of vascular plants (see the box “ecozone scale” in Fig. 1.7). Examples are the long effective evolution time in combination with a low seasonal variability, the reasonably fair cation exchange capacities of strongly weathered tropical subsoils, high rainfall and the multiplicity of plant–animal interactions (for details see Richter et al. 2009). On a regional and mountain scale, corridors for species migration but also barrier effects from the orographic heterogeneity between ridges and valleys give rise to a variety of microclimates producing a multitude of ecological niches. In addition habitat fragmentation triggered by the high relief energy is of importance. On the plot scale slight terrain differences in particular in the páramo ecosystems or bark peculiarities favouring a variety of epiphytic populations in the RBSF forests are decisive variables for the coexistence of ecological microniches.

Disturbances take place at all scales. On the plot scale, gaps originate by falling branches or tree veterans, while landslides produce vertically oriented gaps of several hundred metres length, each triggering the onset of a succession sequence and thus contributes to the maintenance of the biological diversity of the hotspot. Big disturbances are man-made agricultural areas, mostly pastures, a significant portion of which are not sustainably managed and thus are abandoned after some years of cattle farming (see Chap. 17). After clearing the natural forest by slash and burn, pasture grasses, predominantly exotic species are planted, because grasses are rare (except bamboo) in the mountain forest. The non-natural species composition of the pastures is not resistant to the invasion by fast growing and propagating weeds, as e.g. the Southern Bracken Fern (*Pteridium arachnoideum* and *Pt. caudatum*) or shrubs like *Ageratina dendroides*, *Baccharis latifolia, Brachyotum spec.* and *Monochaetum lineatum* which are accompanied by a specific fauna. They contribute to collateral non-native elements, most of them of ubiquitous occurrence in the tropics and commonly considered as undeserved organisms. Species numbers of most of the native taxonomic groups decline upon human impact (e.g. Rubiaceae, Lauraceae, Araceae among vascular plants and Geometridae among moths) while others increase considerably (e.g. Asteraceae, Poaceae, Melastomataceae and Arctiidae, respectively; Peters et al. 2010; Brehm et al. 2005). Biodiversity is replaced by high abundances of a few species. These changes are accompanied by an expansion of the daily temperature ranges, a decrease in relative humidity, resulting from the conversion of a dense humid forest into open pastures, i.e. into brightly illuminated, drier and warmer environments (Fries et al. 2009, 2012).

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Chapter 2
Environmental Changes Affecting the Andes of Ecuador

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2.1 Introduction

It is indisputable since the announcement of the Millennium Ecosystem Assessment (2005) that global environmental change, especially land use and climate change, are threatening biodiversity. Although it is widely supposed that climate change will lead to the extinction of many species in the future (Colwell et al. 2008; Williams et al. 2007), human land use is currently the most important threat to biodiversity (Pimm and Raven 2000; Köster et al. 2009; de Koning et al. 1998; Southgate and Whitaker 1994; Bebbington 1993). Sala et al. (2000) have pointed out in this regard that global terrestrial biodiversity will be most severely affected by expanding agriculture by the year 2100, with climate change and nitrogen deposition being the next most important factors. Tropical forests have recently undergone great changes, due mainly to land use activities that annihilate ecological niche diversity and lead to the extinction of species (Sala et al. 2000). In this context it must be emphasised that the tropical Andes contain about one-sixth of all known plant species in a space of <1 % of the world's terrestrial area (Mittermeier et al. 1997).

The area of our research—southern Ecuador—comprises dry and humid mountain biomes as well as lowland tropical rainforests. A great variety of ecosystems are found in this area, ranging from high altitude habitats harbouring only a few species to complex, extremely species-rich habitats on the eastern escarpment of the Andes (Richter et al. 2009). Williams et al. (2007) argued that the climate

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