# 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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conditions that favoured this biodiversity hotspot during the twentieth century may disappear entirely during the twenty-first century. Consequently, the extraordinarily high biodiversity of this region appears as strongly endangered (Myers et al. 2000; Brummitt and Lughadha 2003; Southgate and Whitaker 1992; Harden 1993; Myers 1988, 1993; Bendix et al. 2010). Scientific research is therefore essential for developing and fostering conservation strategies.

In this chapter current knowledge of the recent development of the three major ecosystem threats of land use dynamics, climate change and nitrogen deposition (Sala et al. 2000) will be discussed for the study area of southern Ecuador.

## 2.2 Land Use Dynamics

Andean environments have undergone modifications by human activities for at least 7000 years (Bruhns 1994; Jokisch and Lair 2002; Sarmiento and Frolich 2002), but the intensity of land use has accelerated considerably during the past century (Ellenberg 1979; Luteyn 1992; Peters et al. 2010). This especially holds true for Ecuador, which exhibits the highest deforestation rate in South America (FAO 2005; Mosandl et al. 2008). Figure 2.1 shows the decisive role of road construction for land reclamation in this country. In 1938 only few roads existed within the coastal plain and the Andes of Ecuador, while the eastern regions of the country were still untouched. At least 75 % of the western part of the country was forested at that time, and as of 1969 primary forest covered still ca. 63 % (Dodson and Gentry 1991). Only a few new roads were constructed in western and central Ecuador during the interim, while the eastern part of the country remained almost unexploited. During the period up to the year 2000 various factors initiated a rapid expansion of road construction, which also encroached the eastern lowlands (Fig. 2.1). The population increased from less than 4 to more than 10 million people during the same period, and land reform programmes effectively promoted inner colonisation of government-owned forested lands. Large sums were invested in road construction to provide communication between and transport to new cities and transfer sites (Dodson and Gentry 1991). Petroleum became the most important export commodity, and the cultivation of cash crops contributed to the derogation of natural environments. Today an extensive network of primary and secondary roads has opened up most of western and central Ecuador, while parts of the Oriente have been converted into protected areas and safeguarded to certain extents.

Facilitated access has had a devastating effect on the mountain rainforest of the Rio San Francisco (RSF) valley. Between 1960 and 1980 approximately 0.25 % of the south Ecuadorian Andean forests were cut by slash-and-burn annually (Keating 1997; Marquette 2006). While most of the north-facing slopes of the Reserva Biológica San Francisco (RBSF, see Fig. 1.1, map 3) are still covered by primary mountain rainforest today, much of the forest on the south-facing slopes has been converted into pastures. The construction of the road from Loja to Zamora led to a rapid establishment of settlements in the region subsequent to 1957 (Pohle et al. 2009),

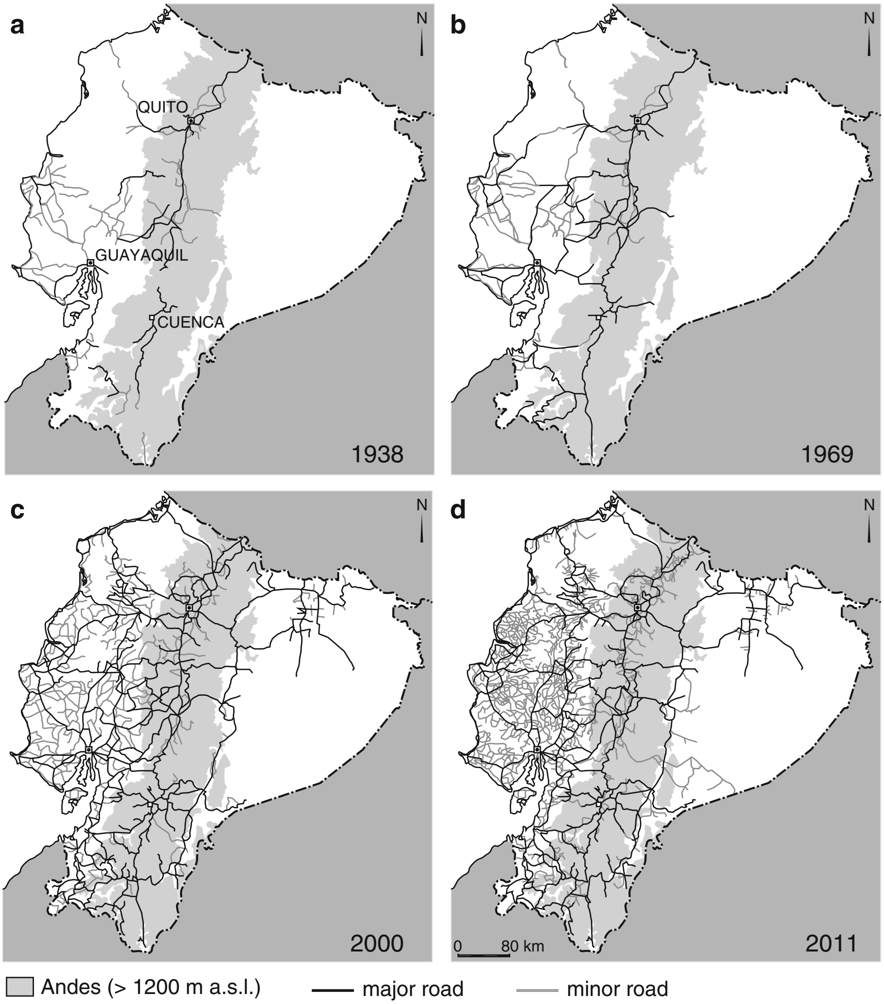


**Fig. 2.1** Road networks of Ecuador in 1938, 1969, 2000 and 2011. The maps are based on the following sources: the American Geographical Society of New York (**a**), the Head Office of Geodesy and Cartography, German Democratic Republic, Berlin (**b**), the Instituto Geográfico Militar, Quito, Ecuador (**c**) and own inquiries (**d**), respectively

and pastoral land use increased rapidly between 1962 and 1989. With the foundation of the Podocarpus National Park (PNP) in 1982 (Pohle and Gerique 2008) and the RBSF in 1997, major parts of the Cordillera Real were declared as protected areas. Land use was intensified on the northern slopes of the RSF valley and on unprotected areas near Sabanilla (Fig. 2.2).

In order to quantify land use changes within the wider area between the two cities of Loja and Zamora (cf. model domain, Fig. 1.1), two orthorectified Landsat TM/ETM+ scenes from 1987 and 2001 were pre-processed and classified.

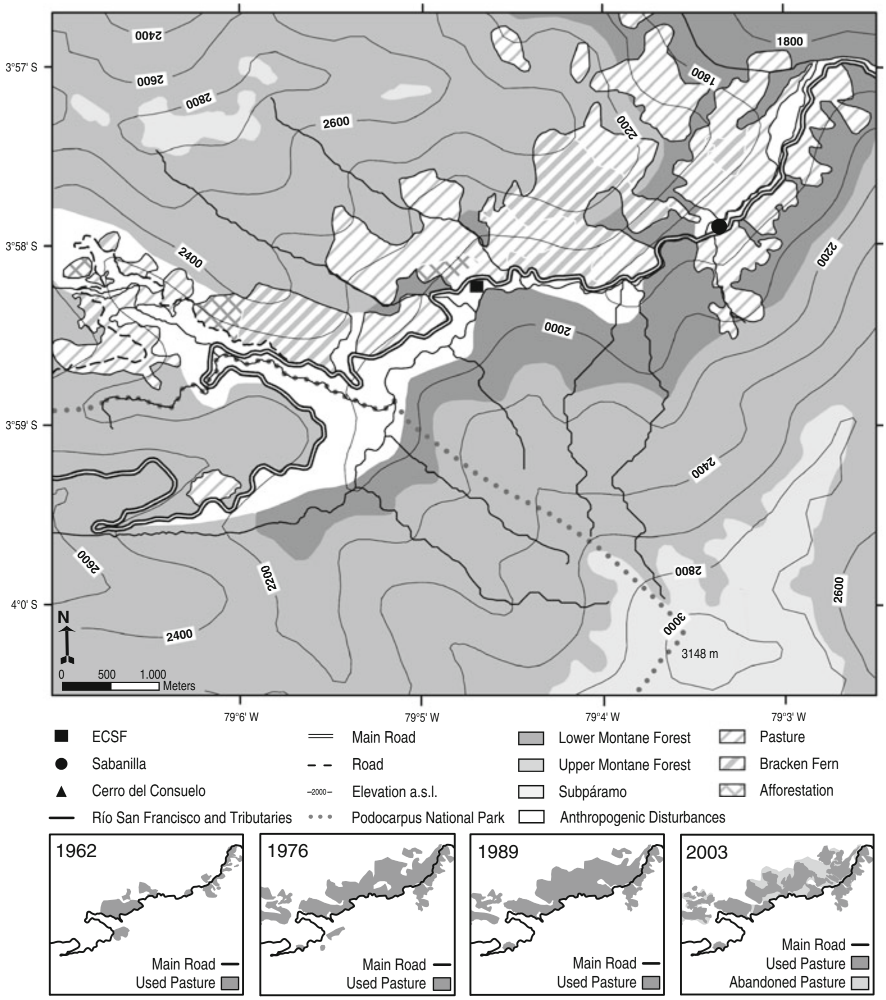


**Fig. 2.2** Principal plant formations in the study area of the upper Rio San Francisco valley. The *large upper map* dates from July 2009. The *four smaller maps* illustrate the land use forms in the vicinity of the road between Loja and Zamora over a 40-year period. *ECSF* research station Estación Científica San Francisco

A post-classification change detection analysis revealed the changes that took place within an area of 4,800 km$^2$ during the 14-year period. Analysis was conducted by a pixel per pixel comparison based on univariate image differencing (post-classification intercomparison technique; Singh 1989), whereby cloud-covered areas in both scenes were excluded from the analysis (for more details on the classification technique see Göttlicher et al. 2009). The results (Fig. 2.3) demonstrate that the greater part of the region is still covered by forests, of which large parts can be found within the protected area of the PNP. Grassland is frequently encountered,

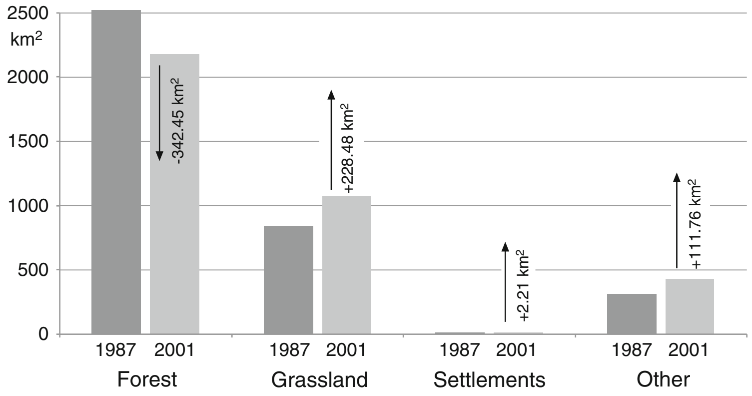


**Fig. 2.3** Land use changes between 1987 and 2001 within the 4,800 km$^2$ study region encompassing Loja and Zamora. The *black arrows* indicate the quantitative changes in km$^2$. Details as to the methods are provided in the text

particularly in the valleys. Urbanised areas occur especially in and around Loja and Zamora. Forests suffered the greatest quantitative losses (Fig. 2.3). A total of 424.6 km$^2$ were cleared between 1987 and 2001, and even after taking the reforestation of 82.1 km$^2$ into consideration, the net loss of forest was 342.45 km$^2$. The expansion of urban land amounted to 2.2 km$^2$ and became especially apparent in the growth of Loja. The detected deforestation rate of 13.61 % for the study area corresponds to an annual deforestation rate of 0.97 %. Goerner et al. (2007) reported a deforestation rate of 0.9 % per year for the same study area.

## 2.3 Climate Change and Its Effects

Using a regional climate model based on the prospective IPCC (Intergovernmental Panel on Climate Change) climate scenarios A2 and B2 (Meehl et al. 2007), grid cell maps presented by Urrutia and Vuille (2009) show that several regions of the tropical Andes may sustain dramatic temperature and precipitation changes as a result of currently progressing climate change. For the grid cell of southern Ecuador a slight increase in rainfall (+8 %) and cloud cover (+4 %) is expected, together with a marked increase of air temperature of +3°K relative to the average of 1980–1999 (Meehl et al. 2007). Climate change may thus severely affect a floristic region which harbours one of the global diversity hotspots for vascular plant species (Barthlott et al. 2007; Richter et al. 2009). Unfortunately, long-term series of meteorological measurements for SE-Ecuador are available to an only very limited extent. Only the INAMHI (Instituto Nacional de Meterología e Hidrología) station "Loja" (2,160 m a.s.l.) that is located in the inter-Andean basin west of the main Cordillera has provided continuous data since 1964. The main station of the Oriente in Zamora (970 m a.s.l.) was closed in the1990s. In the San Francisco Valley itself,

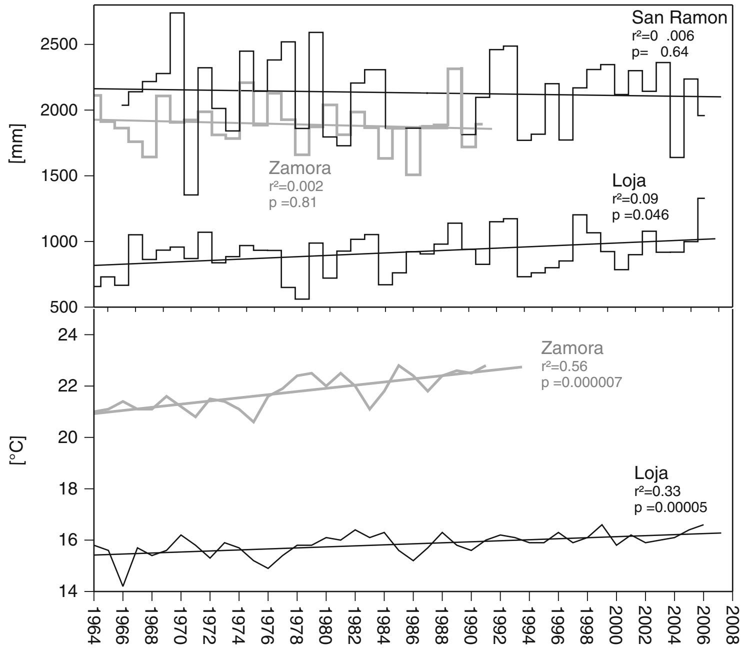


**Fig. 2.4** Climate trends in the study area in southern Ecuador over a 40-year period. *Top*: annual rainfall [mm]. *Bottom*: average annual air temperature [°C] at selected locations. Data taken from the INAMHI (Instituto Nacional de Meterología e Hidrología) and EERSSA (Empresa eléctrica regional del Sur S.A.) climate stations

the regional electricity company EERSSA (Empresa Electrica Regional de Sur S.A.) has operated a rain gauge since 1966 at a location close to ECSF's main meteorological research station (1,950 m a.s.l.) that has been recording meteorological data since 1998. The insufficient supply of data is a general problem with regard to the fact that the regional climate of SE-Ecuador is locally highly variable and exhibits pronounced seasonal changes. Along a W–E distance of only 40 km it ranges from semiarid conditions and a relative dry season in MJJ at Catamayo in the west of the main Cordillera to a perhumid climate east of the main Cordillera (at the Cerro met station of the research programme, see Fig. 1.2), with peak rainfall occurring in the same period (Richter 2003; Emck 2007; Bendix et al. 2008a). However, some general climatic trends can be observed in spite of the poor data basis (Fig. 2.4). Both the western inter-Andean basin of Loja and the eastern Andean escarpment at Zamora reveal a significant warming trend. The air temperature at the station "Loja" about 30 km to the west of the ECSF meteorological station evidences a warming of ~0.6 °C over the 45 years of 1961–2008 (0.13 °C per decade). The station "Zamora" (San Ramon) situated in the eastern Andean foothills was characterised by an even stronger warming trend up to 1990.

The climate data in conjunction with model calculations thus point to a clear warming trend in the study area. The ecological importance of such a thermal shift is obvious. Assuming a stationary average annual lapse rate of $-0.61$ °C 100 $m^{-1}$

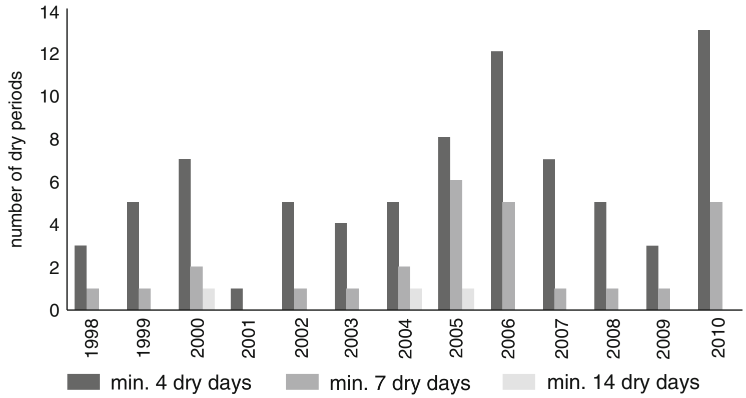


**Fig. 2.5** Number of periods at the ECSF meteorological station during which no rain fell and that were continuously dry for at least 4, 7 or 14 days

(Bendix et al. 2008b) until 2100, the increase of temperature must result in an altitudinal shift of ecothermal belts in the study area (Bendix et al. 2010). An increase in temperature of 3 °C during the course of the twenty-first century would result in climatic conditions currently prevailing at a particular altitude being found at significantly lower altitudes. For example, the average air temperature of 15.5 °C now recorded by the ECSF meteorological station at an altitude of 1,860 m a.s.l. would be found at an altitude of 2,300 m a.s.l. at the end of the current century. This would lead to an upslope migration of thermophilous species, for which, however, suitable habitat corridors to higher areas are a prerequisite (Colwell et al. 2008). The numerous valleys of the Precordillerean and Amazon forelands might represent such corridors in the case of the Cordillera Real. Many lowland rain forest species have outposts in western Amazonia (Miles et al. 2004), from where they would be able to spread into the valleys and Precordillerean ranges. Drought- and heat-tolerant species are accordingly most likely to migrate into new terrains, and taxonomic input of invasive species from anthropogenic habitats can play a significant role in re-shuffling communities. Sources of invasive species are pastures, abandoned former cultivated land, roadsides and exotic tree plantations close to the RBSF and further downstream in the valley.

The situation of rainfall is more complex (Fig. 2.4). There has been a weak but significant trend towards an increase in rainfall in Loja over the observation period of 1964–2006. The slight decrease in rainfall in the eastern Andean foothills at Zamora is, however, not significant. The station San Ramon between Loja and Zamora also features an almost unnoticeable negative trend over the observation period. The areas west of the main Cordillera are subject to a slight increase in the amount of rainfall, while the humid eastern regions received a little less. The ECSF climate station has documented an obviously accelerating decrease in precipitation during the last 10 years of observations and particularly after 2005 (for more details see Chap. 19). This negative trend can mainly be attributed to an increase in the number of dry days and a more frequent occurrence of longer lasting dry phases in 2005, 2006 and 2010 (Fig. 2.5). However, it should be kept in mind that the high

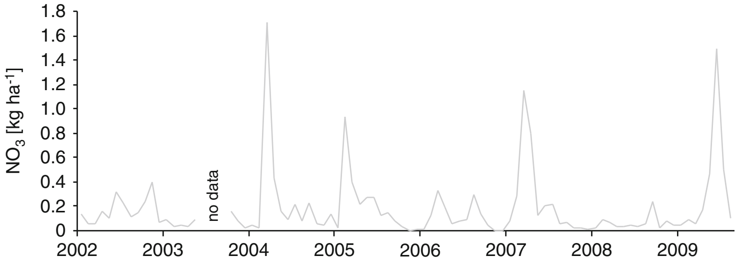


**Fig. 2.6** $NO_3$ depositions at the meteorological station ECSF between 2002 and 2009

variability of annual precipitation and the limited length of the data series do not yet permit a distinct trend analysis.

## 2.4 Atmospheric Nutrient Deposition

The spatial distribution and temporal dynamics of precipitation and wind also regulate the deposition of water-dissolved matter into mountain ecosystems. These depositions can contain relatively high concentrations of plant nutrients (particularly N, S, P, and K) and acids (Boy et al. 2008), that are transported over long distances in the atmosphere. Especially Amazonia and even northern Africa are source regions for the nutrients that are transported to the mountain forests of Ecuador. Several authors showed that biomass burning (as, e.g. takes place in the Amazon) has a fertilising effect on ecosystems that thereby receive an input of N and P (Da Rocha et al. 2005; Fabian et al. 2005; Boy et al. 2008). To identify processes involved in these mineral depositions, rain water samples are being analysed for principal cations and anions, pH-value and electrical conductivity. The sampled water generally has very low concentrations of ions, and conductivity rarely exceeds values of 20 μS $cm^{-1}$. The values are generally lower during the rainy season due to dilution effects (Rollenbeck et al. 2006). The results shown in Fig. 2.6 suggest seasonal differences in element concentrations present in rainfall, probably resulting from biomass burning in Amazonia. For example, depositions of nitrate ($NO_3$) were higher during “fire episodes” in 2004 and 2007 than during “no fire” periods, and these peaks of nutritional input could in the long run affect the floristic composition of the mountain forests (Rollenbeck 2010). A thorough analysis of nutrient inputs into the mountain forest and its temporal development is presented in Chaps. 11 and 21.

## 2.5 Aspects of Future Threats

The expansion of agricultural land use in conjunction with an augmentation of population pressure is a major threat to the biodiversity hotspot on the eastern escarpment of the Ecuadorian Andes and in the adjacent lowlands of the Oriente.

They may well result in irretrievable losses of natural forests. Further fragmentation of already rare animal and plant population refuges will proceed along with the expansion of the road network. The imminence of this threat to plant and animal life is highly topical, since substantial mineral deposits have been detected in the Andes and their immediate forelands, even though they have not yet been exploited on a large scale. Especially in the south-eastern part of the country, in the surroundings of the Cordillera del Condor, gold and copper beds are assumed to exist. The Zamora-Loja connection road passing the RBSF will suffer from a dramatic rise of traffic volume if these resources are exploited. Increasing traffic and industrial activities in regions as remote as the booming megacities of Brazil will contribute to increasing inputs of aerosols and airborne pollutants. Not all of these are harmful, though, and some might even contribute to plant nutrient deposition. Acid fallouts, however, will exacerbate an acidification that is already burdening a majority of the natural ecosystems. According to Urrutia and Vuille (2009), warming is predicted to be moderate in western Ecuador, while the eastern part will suffer from increasing heat. Changes in precipitation are expected to be spatially much less cohesive, with manifold increases and decreases in rainfall throughout the Andes (refer to Chap. 19). More important yet are changes expected for the austral summer, when weakened mid- and upper tropospheric easterlies and strengthened westerlies may result in longer and more frequent dry spells. These will extend from October to January and could promote the migration of thermophilous organisms towards higher reaches. More serious appears, however, an increase of fire incidence.

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