Mountains, biodiversity and conservation

A. Chaverri-Polini

Adelaida Chaverri-Polini is with the School of Environmental Sciences, National University, Costa Rica.

Factors leading to high levels of species diversity and biological diversity in the mountains of Latin America.

Mountains have always presented the human race with a great challenge - they have had to be climbed, cultivated and tamed. They have also been the subject of numerous books about heroic deeds, wars, adventures, real and imagined, and of mystical and romantic poetry, as well as favourite places for prayer and adoration. From the scientific viewpoint, mountains are large, interesting laboratories of knowledge where species and communities, which have adapted in various ways to their environment, are to be found; they are places where one can observe and understand the evolution of species and the efficient distribution of organisms between similar environments from one mountain "island" to another, separated from each other by thousands of kilometres. Mountains have also borne witness to the many different ways their inhabitants have lived in harmony with them, adapting to their environment, using and manipulating the gifts of the earth and, often, striving to keep the environment as healthy as possible.

In this article, we shall consider mountains as upthrusts or swellings of the earth's cortex, rising to altitudes of more than 2 000 m, which are due to various factors (tectonic, volcanic). This altitude is chosen arbitrarily as, according to a number of phytogeographers, it represents the line dividing the altitudinal zones (temperate and cold, or lowland and highland, etc.). Alternatively, we could have taken other altitudes, corresponding to different latitudes.

Geographically, this article focuses on Latin America, from Mexico to Tierra del Fuego, with particular emphasis on the neotropics. The major mountain systems of Latin America are the Sierra Madre (Western and Eastern) in Mexico, which crosses most of the country, the Sierra de los Cuchumatanes in Guatemala, the central and Talamanca volcanic ranges in Costa Rica, which also extend into Panama, and the Andes in South America, stretching from Colombia to the western part of Tierra del Fuego. Not only is this the largest mountain range in the American continent, it is also the largest in the world, extending through Venezuela, Colombia, Ecuador, Peru, Bolivia, Chile and Argentina, with foothills in the various countries, forming eastern, central and western ranges in some of them.

This article refers mainly to the environmental and biotic conditions in mountains and provides explanations concerning the high degree of speciation (the formation of new species), diversity and endemism, giving some interesting examples of richness in the latter two. Soil use in mountain areas is then discussed and, finally, conservation measures are proposed and some examples given.

THE PHYSICAL ENVIRONMENT IN MOUNTAIN AREAS

The mountains of Latin America were shaped by local climatic and edaphic factors and by important past events, such as the Pleistocene glaciations, which affected their geology and climate. They occur in temperate or cold areas, which may be a growth-limiting factor, and the occurrence of sudden fluctuations in temperature may also further restrict the growth of fauna and flora. Mean annual temperatures range between 12° and 16°C in the low montane and 6° and 12°C in the high montane. Humidity, on the other hand, is extremely variable, with some areas very humid and wet (in Central America, Ecuador and most of Colombia) and others dry and arid (in

Mexico and, especially, Peru, Bolivia and Argentina). Annual average rainfall may range from 4 000 mm (occasionally 5 000 mm) to 700 (or 600) mm.

Soil types also show wide variations. In mountains with medium or high humidity (e.g. in Central America, Ecuador and Colombia) soils are acidic, with acidity increasing with altitude and rainfall. Aluminium content also rises with these increases and cation (calcium, potassium, magnesium, etc.) content falls. Furthermore, soils in dry, arid areas (e.g. in Peru and Bolivia) are excessively saline.

The most significant environmental factor determining the altitudinal zoning of plant species is probably mean annual temperature and not seasonal temperature differences, water availability or humidity. The chemical characteristics of the mountain soils of Central and South America, combined with temperate and low soil and atmospheric temperatures, are factors which limit overall plant growth, with the result that plants and associated wildlife have had to develop ways of adapting in order to survive.

MOUNTAIN PLANT COMMUNITIES

It is difficult to classify Latin American mountain plant communities. While this difficulty is partly due to their high degree of heterogeneity, the task is further complicated by the wide variety of biogeographical and plant classification systems used in each country or region. The Holdridge life zones, the Grubb system and other systems proposed by international organizations such as UNESCO (1973) or IUCN (Udvardy, 1975) are examples. Other classification systems have also been developed by Latin American ecologists, biologists and biogeographers - Cabrera in Argentina, Ribera and Unzueta in Bolivia, Pisano in Chile, Rangel in Colombia, Gómez in Costa Rica, Acosta Solís and Cañadas in Ecuador, Cabrera in Peru and Huber, Alarcón and Monasterio in Venezuela are some of the most prominent in recent years. Although each of them has carried out an in-depth analysis of each country's vegetation, a regional effort is now needed to assemble similar criteria and plant categories for Latin America as a whole (see Huber and Riina, 1997).

ADAPTATION, SPECIATION AND ENDEMISM IN MOUNTAINS

Mountain biota (plants and animals) survive under the environmental conditions of their habitat because of their adaptability (e.g. pubescence, coriacaceous leaves, daily leaf movements, use of warmer burrows) which allows them to establish themselves and reproduce. It is precisely this ability to adapt to the specific characteristics of a given microsite which has shaped one of the theories which partly explains the endemism found in the mountains through speciation. Endemism is also explained by past climatic and geological changes when plant populations, which formerly lived together in a given area, separated into "island" communities, often thousands of kilometres apart. This separation allowed single-species populations to develop through geological time and to survive by adaptation to the environment, eventually to differentiate and even form new species. Thus, the mountains were able to act as substrates for speciation and endemism.

How, then, can we explain the high degree of richness and diversity found in the mountains? Explanations point mainly to three major factors: the effect of climatic and geological history on biotic development, the various environmental impacts on the biota adaptation mechanisms and the continuous dispersion of fauna and flora.

- Climatic changes during the Pleistocene Epoch, the time when a number of glacial periods occurred and when climates were very cold and wet, interrupted by warm, dry periods, allowed the formation of refuges, which not only served as shelters for a rich diversity of species, but as sources for dispersion to neighbouring areas as warming of the climate allowed species to propagate.

• The existence of migratory routes for species from the north to the south and vice versa during the Pliocene Epoch is another factor contributing to the region's rich diversity, reflected in its mountains.

• Altitudinal differences in the mountains have also made for very varied climates, promoting the diversification of groups of species, adaptable to different environments.

• The wide diversity of climates combined with local differences owing to geomorphological, edaphic and plant cover features have given rise to a range of microclimates which have become habitats for different species which adapt to them, making them their specific niches.

• Animals (especially birds and mammals) play a vital role in the dispersal of plant species on which they feed or with which they come into bodily contact (e.g. plants with achenes).

MOUNTAINS AND VASCULAR PLANT DIVERSITY

As has already been mentioned, mountains are places with a high degree of diversity and endemism. This characteristic was observed throughout the area studied, in trees and in bryophytes, in botanical families and in species. Diversity would appear to bear little relation to rainfall or to latitude in the neotropics (Gentry, 1995; Rangel, 1995). Below are some case studies covering the neotropics in general, a number of mountain ranges in a single country, a plant family and its related species commonly occurring in the Andean area, and a Caribbean island.

Studies (Gentry, 1995) conducted on 0.1-ha plots in 37 Andean locations and in 17 locations in Central America and Mexico, at altitudes between 800 and 3 050 m above sea level, show that as altitude increases, the diversity of plant species of diameter at breast height (dbh) greater than or equal to 2.5 cm decreases. The sample areas (Table 1) were located in Mexico, Central America (Nicaragua and Costa Rica), the northern Andes (Colombia and Ecuador), the central Andes (Peru and Bolivia) and the southern Andes (Argentina). The Andes showed the richest diversity, followed by the Central American mountains (insignificant difference) and, finally, Mexico (significant difference) with the poorest diversity. Even though it forms part of the Andes, the Sierra Nevada de Santa Marta in Colombia showed less diversity than expected, possibly owing to its geographic isolation or to anthropogenic factors dating back to pre-Columbian times (Gentry, 1995).

The botanical families with the highest degree of diversity in the high mountains of Latin America are: Asteraceae, Myrsinaceae, Poaceae, Polypodiaceae, Orchidaceae, Leguminosae, Melastomataceae, Ericaceae and Cyperaceae (Moraes and Beck, 1992; Rangel, 1995: Kappelle, 1996; Chaverri and Cleef, 1997). For instance, studies on community diversity and description in four transects in Colombia - Sierra Nevada de Santa Marta (Buritaca-La Cumbre), Parque de los Nevados, Puracé (Valle del Magdalena-Volcán del Puracé) and Tatamá - with an altitudinal gradient between 350/500 m and 4 500 m above sea level (Rangel, 1995) showed that the families with the largest number of species were: Asteraceae, Polypodiaceae, Orchidaceae and Melastomataceae. Some genera such as *Miconia, Piper, Anthurium* and *Solanum* showed a considerable degree of ecological plasticity and a high representation of species. Diversity was attributed to a combination of topographic and physiographic factors; in other words, the higher the mountain the greater the likelihood of topographic accidents, wider life zones, diversity of habitats and effect of climatic changes, implying greater floristic diversity (Rangel, 1995).

TABLE 1. **Diversity of plant families and species in the mountains of Latin America, based on 0.1-ha samples (partial list)**

Location	Altitude (*m*)	Number of families	Number of species	Number of tree species with dbh = 2.5 cm
Sierra Juárez, Oaxaca, Mexico	2 250	26	44	37
Benito Juárez, Chiapas, Mexico	2 100	21	~30	29
P.N. Braulio Carrillo, Costa Rica	2 775	17	24	19
P.N. Braulio Carrillo, Costa Rica	2 225	34	66	52
Neusa, Cunamarca, Colombia	3 050	19	~35	~24
Alto de Sapa, Antioquia, Colombia	2 670	28	~63	49
Finca Meerenberg, Huila, Colombia	2 290	43	107	88
Pasochoa, Pichincha, Ecuador	3 010	19	~35	~21
El Pargo, Cajamarca, Peru	3 000	20	~36	~29
Cutervo, Cajamarca, Peru	2 330	42	~96	76
Sacramento, La Paz, Bolivia	2 450	33	91	72

Note: ~ signifies approximately.
Source: Gentry, 1995.

Endemism was high for Asteraceae in Talamanca and the Andes, with *Senecio, Pentacalia, Baccharis, Diplostephium* and *Mikania* being the most common genera. This family is well represented in terms of genus and species in all types of vegetation - paramo (see Table 2), puna and forest - with Bolivia accounting for most of the current diversity. The geological history of the Andes has played a major role in the distribution and evolution of the Asteraceae, most of which originated in a single region, adapting from lower-altitude local ancestors. There are two groups of tribes classified as native to this region: one, with distribution centres in the Andes, found almost exclusively in the Western Hemisphere (Heliantheae s.l., Eupatorieae, Mustisieae, Liabeae and Barnadesieae); and the other, common in the Andes and with some specialized features, but also found in the Eastern and Western Hemispheres (Senecio, Asteraceae and Vernonieae) (Funk *et al.,* 1995).

Another interesting family, especially in the Andes, is that of the woody bamboos. None of the genera is exclusive to the area, but about 90 percent of the species are endemic. Of the seven genera present, four, *Aulonemia, Chusquea* (with 50 percent of the species represented), *Neurolepis* and *Riphidocladum* have their centres of dispersion in the Andes, especially in Colombia (dark, 1995). Roughly 1 500 ferns and associated species were observed in the Andean region, compared with some 280 in the Amazon basin in Brazil (Henderson, Churchill and Luteyn, 1991).

TABLE 2. **Selected common plant communities in Latin American mountains**

Type of vegetation	**Description**	**Countries where found**
Paramo	Highland vegetation, not more than 2 m high, characterized by Gramineae, Cyperaceae, Asteraceae, Rosaceae, Ericaceae and/or "frailejones"	Costa Rica, Panama, Colombia, Venezuela, Ecuador, Peru
Puna	High Andean vegetation, dominated by herbaceous species, Gramineae, Cyperaceae and some shrubs; climate cold and relatively dry	Peru, Bolivia, Argentina, Chile
Alpine grasslands (zacatonal)	-	Mexico, Guatemala
Peat bog	Azonal vegetation in flooded, poorly drained areas, characterized by Cyperaceae, Juncaceae, Ericaceae, *Sphagnum* and/or cushions of *Distichia* and *Plantago*	Costa Rica, Colombia, Peru, Bolivia, Chile, Argentina
Marshland (bofedal)	Azonal vegetation in flooded areas such as peat bogs, characterized by cushion plants; genera: *Plantago* and *Distichia;* Cyperaceae	Bolivia
Arrayan belt	Ecotonal vegetation, between the paramo and the montane or Andean forest, characterized by ericacious shrubs	Costa Rica, Colombia
Montane dwarf forest (Queñoa)	Low-growing tree vegetation, at the highest possible altitude in the Andes (4 000 m), contorted trunks, epiphytes in abundance; genus *Polylepis*	Bolivia, Peru, Colombia
Montane fringe forest	Dense, evergreen, low-growing forest, in very wet climates, with epiphytes in abundance, chacterized by *Weinmannia, Podocarpus, Polylepis,* Ericaceae and Araliaceae	Ecuador, Peru, Bolivia
Andean fringe forest (chaparral)	Highland vegetation, between the paramo and the Andean forest, characterized by leathery-leaved, heavily thorned dwarf shrubs	Ecuador
Yungas	Low-growing, xeromorphic shrub vegetation with latifoliate leaves, along rivers and gorges	Bolivia, Argentina, Peru
Cloud forest	Tree vegetation, at various altitudes, cloudy and wet throughout the year; with Lauraceae, Myrtaceae, Melastomataceae, Ericaceae and epiphytes in abundance	El Salvador, Costa Rica, Colombia, Venezuela, Bolivia, Puerto Rico (at lower altitudes)
Montane forests	Very varied vegetation differing from country to country	All countries
Montane shade-loving	Highland forest, medium-growth habit, epiphytes in abundance in wet areas, characterized by	Venezuela

forests	Podocarpaceae, Araliaceae, *Alnus, Brunellia* and *Weinmannia*	
Coniferous forest	Intermediate-altitude forest with a predominance of *Pinus, Juniper, Abies* and *Cupressus*	Mexico, Guatemala, Honduras, El Salvador, Nicaragua
Pine and oak forest	Intermediate-altitude forest, with a predominance of *Quercus, Pinus* and other genera	Mexico, Guatemala, Honduras (at lower altitudes)
Oak forest	Forest with a predominance of trees of the genus *Quercus,* as well as *Clethra, Ilex, Styrax,* Lauraceae, Araliaceae, with epiphytes in abundance	Mexico, Costa Rica, Panama, Colombia

Source: Huber and Riina, 1997; Chaverri and Herrera, 1996; Chaverri and Cleef, 1997; Almeida-Leñero, 1997.

The mountains are also home to many cloud forests, which may be found at altitudes of between 500 and 3 500 m, but are much more common between 1 200 and 2 500 m (Doumenge *et al.,* 1995). Although rich in diversity, the cloud forests mainly show a high degree of endemism. In the Monteverde Cloud Forest Biological Reserve in Costa Rica, there is a rich diversity of Lauraceae and a number of families (e.g. Sapotaceae, Podocarpaceae and Lauraceae) exhibit a high level of endemism. Indeed, it is one of the areas in the country where endemism is highest. Puerto Rico's Caribbean National Forest and Luquillo Experimental Forest are located in another cloud forest at a lower altitude of little more than 1 000 m. (This forest is included in this article because of its special insular feature.) Subjected to frequent rainfall brought by the trade winds, from which it draws much humidity, this is a small area of cloud forests located on the mountain peaks of a Caribbean island. Endemism is high and the ecosystem is considered to be endangered. The area's geographical isolation brings with it genetic isolation, and this has led to speciation (it contains a large number of endemic plant and animal species). Some 32 percent of the plants on the Pico del Oueste are endemic to Puerto Rico, with 40 percent found only in the West Indies. The area contains 62 of the 141 tree species endemic to Puerto Rico and 23 of these are found only in this area, in primary forest stands (Lugo, 1994).

The wet paramos of Central America

Paramos are highland areas, lying within the tropical zone, between 11° north and 8° south latitude at altitudes between 3 000 and 4 500 m above sea level, with cold mean annual temperatures, sudden daily changes in temperature and mean annual precipitation in excess of 700 nun. The latter feature is a major factor differentiating puna vegetation (drier environment), commonly found in the high plateaus of Peru and Bolivia, from the alpine grasslands of Guatemala and Mexico. The vegetation is low growing (2 to 3 m high), with small, leathery leaves and growth is slow. Its life forms are characteristic: pachycaul-rosettes, cushion plants with bryophytes and lichens in abundance and a predominance of a dwarf bamboo species of the genus *Swallenochloa,* common in the very wet and rainy paramos of both Central and South America.

Paramo vegetation is common in the Andean countries of Venezuela, Colombia and Ecuador. In Central America, it is found in small pockets on the summits of the highest mountains in Costa Rica and Panama (in the border area). Costa Rica accounts for the largest paramo area in Central America (about 90 percent, mainly in Chirripó National Park), where the families with the largest number of species are: Asteraceae, Poaceae, Cyperaceae, Rosaceae, Scrophulariaceae and Apiaceae. Two typical tropical Andean species are not found in the Central American paramos: the pachycaul-rosettes (*Espeletia* and the other genera of Espeletiinae), called "frailejones", and the characteristic cushions of *Distichia* sp., of the Juncaceae.

In Guatemala, the high montane vegetation in the Tajumulco, Tacaná and Acatenango volcanoes, at altitudes above the tree line (about 3 800 m), is considered to be alpine grassland (zacatonal), physiognomically very similar to that found in Mexico's central region, although its flora is different and less diverse.

Source: Chaverri and Cleef, 1997.

The *tepuis* are other areas of high endemism. For instance, at altitudes of between 200 and 2 800 m, the vegetation in the Duida-Marahuaka National Park in Venezuela is diverse, consisting of forests, shrubland, grassland and savannah, in addition to pioneer vegetation on sandstone rock faces; in submontane and montane *tepui* forests floristic diversity and endemism are exceptional (Dezzeo and Huber, 1995).

Also striking are the rich diversity and endemism in the Talamanca range (Kappelle, 1996) on the eastern slopes of the Bolivian Andes around Lake Titicaca, in the yungas of La Paz in Bolivia (Moraes and Beck, 1992), and in the montane forests of the Eastern and Coastal Cordilleras and the northwestern Andes in Venezuela, Colombia, Ecuador and Peru.

MOUNTAINS AND NON-VASCULAR PLANT DIVERSITY

As already mentioned above, the diversity of vascular plant species decreases as the altitude increases. With non-vascular plants, the question of diversity is very different, for example, in Colombia and Peru (Gradstein, 1995) and Bolivia (Moraes and Beck, 1992).

It is estimated that the Andes contain between 800 and 900 species of *Hepatica* and Anthocerotae within 135 genera and 42 families. Diversity is greater in Colombia and Peru at altitudes between 1 200 and 3 700 m than in French Guyana and Guyana at altitudes between 150 and 300 m (Gradstein, 1995). As regards the mosses represented in the Andes, some 900 species have been collected in the Andean zone, compared with some 200 to 250 in the Amazon basin.

The rich diversity of non-vascular plants in high mountains could be related to climatic, edaphic and floristic factors. Perhaps the most important constant factor is atmospheric humidity. Another important factor may be the presence of humus-rich organic soils (low temperatures and constant humidity), typical of mountain areas, which promote the growth of land species. Greater light intensity in and around the soil, owing to a more open canopy, would also encourage plants to develop in the undergrowth.

Finally, the fact that the distribution limits (in altitudinal terms) of many taxa lie within this belt slightly increases plant diversity (Gradstein, 1995; Wolf, 1993).

SOIL USE IN MOUNTAIN AREAS

Climate and soil conditions may make uplands more susceptible than lowlands to human-caused changes. The slower pace of recovery of natural regenerative processes, owing to colder temperatures, the greater potential for erosion, owing to steeper gradients and generally less fertile soils, are some of the reasons why the natural environment and soil fertility in the mountains are in danger. In addition to this, the isolation of the plant populations is a factor which tends both to help and to hinder speciation, given that human action reduces and further fragments the habitats occupied by the species.

Human activity in the mountains covers a very wide range, from the cultivation of various crops (especially potatoes, maize and coffee) and the grazing of cattle, sheep and goats, to tree cropping using introduced species (such as *Alnus* spp., cypresses, pines and eucalyptus) and, of course, deforestation by felling and burning, to make room for the above-mentioned uses, and selective harvesting of some species (such as bryophytes or tree ferns for cottage industries or for ornamental uses). Other activities include mining and tourism.

As has already been noted, habitat fragmentation is posing a threat to plant and wildlife species. An example of this trend is the reduction of the habitat of the volcano rabbit (*Romerolagus diazi*), an endemic and endangered species in Central Mexico's Pelado, Tláloc, Popocatépetl and Iztacchíhuatl volcanoes, at altitudes of 2 600 to 5 450 metres. Human-caused fragmentation, owing to road building, agriculture and intensive burning and overgrazing, significantly reduces the various habitats the wildlife need to survive (Velázquez, 1993). Further reduction of the areas where the fauna and flora effectively live is due to environmental degradation along the fringes of the fragmented areas.

Furthermore, tree felling at altitudes close to the maximum tree line causes this line to retreat. This was observed between 2 700 and 3 100 m on the Cerro de la Muerte in Costa Rica's Talamanca range (author's observation) and between 3 400 and 3 800 m in Los Nevados National Park on the western slopes of the Central Range in Colombia (Kok, Verweij and Beukema, 1995).

Deforestation in the montane forests has also reached significant levels in some countries. In the Colombian Central Andes, at between 500 and 2 000 m, deforestation has taken place to give way to coffee plantations, one of the mainstays of the economy (Cavelier and Etter, 1995). A large proportion of the primary forests on the eastern slopes of the Cordillera Oriental and on the western slopes of the Cordillera Occidental of the Colombian Andes have been felled to make room for illegal opium cultivation (*Papaver somniferum*) for opium, morphine and heroin production. In 1992 alone, it was estimated that some 20 000 ha were planted, 17 000 ha of which had formerly been under low-montane primary forests. It has been calculated that 50 000 ha have been felled, opened up or abandoned in Colombia for the introduction of this crop (Cavelier and Etter, 1995).

CONSERVATION OF MOUNTAIN ECOSYSTEMS

This wide variety of richly diverse and endemic upland plant communities should be protected. The conservation planners' idea of preserving a sample of each community or life zone within a national park or reserve system is an important first step in the right direction. Moving beyond frontiers, the conservation of cross-border areas and the international effort to protect shared ecosystems are measures, used increasingly in recent years, which have played a significant part in drawing attention to certain conservation areas. The establishment of biosphere reserves and ecological corridors (e.g. the Corredor Biológico Mesoamericano) are also laudable conservation efforts which deserve recognition and protection by the international community.

In addition, high-mountain forest management will have to include appropriate ecological and sylvicultural techniques in order to ensure the sustainable use of forest resources and prevent land-use changes. Such measures should include: protection for all forest species; preservation of wildlife habitats, such as standing dead trees or fallen tree trunks; the provision of training for forest workers; increasing the minimum diameter for cutting, as small diameter limits result in more intensive felling than is ideal for upland forests, especially in areas where it is essential to protect watersheds and the water resource; and planning, in order to ensure that roads and logging tracks are kept to a minimum (preferably less than 15 percent of the total area involved) (Chaverri and Herrera, 1996).

Efforts worldwide in forest ecosystem management have included the establishment of criteria and indicators for sustainable forest management (as proposed by the

International Tropical Timber Organization in 1990 and the so-called processes - Helsinki in 1993, Montreal in 1993, Tarapoto for the Amazon countries in 1995 and Nairobi for the dry zone of Africa in 1995). In 1996 and 1997 the Central American Forest and Protected Area Council and FAO took the first steps towards adopting such a system which included montane forests (CCAD/FAO/CCAB-AP, 1997); this was drafted and accepted by experts in Honduras in 1997 (the Lepaterique process).

Conservation measures, treated with much suspicion to begin with in the 1960s and 1970s, have to be understood, adopted and adapted by the people in and around the conservation areas, by the inhabitants of the countries involved and by the international community in general. In this era of globalization, when governments' roles are increasingly restricted, most of the responsibility for conservation lies with civil society which has already picked up the gauntlet and taken appropriate action. The establishment of private nature reserves and of a network (NGO) cooperating in their management and protection (e.g. in Costa Rica) is but one example. However, conservation measures must, in some cases and in some way, be profitable if they are to receive firmer backing by neighbourhood and national groups. Ecotourism (unfortunately, poorly understood and implemented at times), forest conservation incentives (e.g. the forest protection certificate scheme in Costa Rica) and the carbon-fixing system are some of the ways to make conservation a little more profitable.

In 1996, the Costa Rican private sector received US$45 million from the Norwegian private sector for the forestry component of jointly implemented projects. The funds were channelled by the Fondo Nacional de Financiamiento Forestal (FONAFIFO) to pay for environmental services by small and medium-sized private farmers (reforestation, forest management or voluntary protection of primary forests at any altitude). This was the first time that certifiable tradable offsets (CTOs) were issued for carbon fixing (Proyecto estado de la nación, 1997).

Finally, environmental education has a key role to play in efforts to raise awareness of the problem, in sustainable resource management and in the protection of areas that are representative of different plant communities. Fortunately, all the Latin American countries have promoted official and unofficial environmental education programmes. The requirement now is for periodic assessments to measure achievements and to check whether objectives are being met.

Globalization should not only be economically driven; it should also include the conservation and sustainable management of vegetation in montane areas and other altitudinal zones throughout the world.

Bibliography

Almeida-Leñero, L. 1997. Vegetación, fitogeografía y paleoecología del zacatonal alpino y bosque montanos de la región central de México. Amsterdam University, the Netherlands. (Ph.D. thesis)

Cavelier, J. & Etter, A. 1995. Deforestation of montane forests in Colombia as a result of illegal plantations of opium. *In* S.P. Churchill, H. Balslev, E. Forero & J.L. Luteyn, eds. *Biodiversity and conservation of neotropical montane forests. Proceedings,* p. 541-550. New York, USA, New York Botanical Garden.

CCAD/FAO/CCAB-AP. 1997. Criterios e indicadores para la ordenación forestal sostenible en Centroamérica. Report of Expert Meeting, 20-24 January 1997, Tegucigalpa, Honduras. Consejo Centroamericano de Ambiente y Desarrollo/FAO, Rome. 34 pp.

Chaverri, A. & Cleef, A.M. 1997. Las comunidades vegetacionales en los páramos de los macizos del Chirripó y Buenavista, cordillera de Talamanca, Costa Rica. *Revista Forestal Centroamericana,* 17: 44-49.

Chaverri, A. & Herrera, B. 1996. Criterios e indicadores para el manejo forestal sostenible de los bosques de altura en Centroamérica. Consultant's report. San José, FAO, Comisión Centroamericana de Ambiente y Desarrollo (CCAD) y Consejo Centroamericano de Bosques y Areas Protegidas (CCAB-AP). 60 pp.

Clark, L.G. 1995. Diversity and distribution of the Andean woody bamboos. *In* S.P. Churchill, H. Balslev, E. Forero & J.L. Luteyn, eds. *Biodiversity and conservation of neotropical montane forests. Proceedings*, p. 501-512. New York, USA, New York Botanical Garden.

Dezzeo, N. & Huber, O. 1995. Tipos de bosque sobre el cerro Duida, Guayana Venezolana. *In* S.P. Churchill, H. Balslev, E. Forero & J.L. Luteyn, eds. *Biodiversity and conservation of neotropical montane forests. Proceedings,* p. 149-158. New York, USA, New York Botanical Garden.

Doumenge, C., Gilmour, D., Ruiz Pérez, M. & Blockhus, J. 1995. Tropical montane cloud forests: conservation status and management issues. *In* L.S. Hamilton, J.O. Juvik & F.N. Scatena, eds. *Tropical montane cloud forests,* p. 24-37. New York, USA, Springer-Verlag.

Funk, V.A., Robinson, H., McKee, G.S. & Pruski, J.F. 1995. Neotropical montane Compositae with an emphasis on the Andes. *In* S.P. Churchill, H. Balslev, E. Forero & J.L. Luteyn, eds. *Biodiversity and conservation of neotropical montane forests. Proceedings,* p. 451-471. New York, USA, New York Botanical Garden.

Gentry, A.H. 1995. Patterns of diversity and floristic composition in neotropical montane forests. *In* S.P. Churchill, H. Balslev, E. Forero & J.L. Luteyn, eds. *Biodiversity and conservation of neotropical montane forests. Proceedings,* p. 103-126. New York, USA, New York Botanical Garden.

Gradstein, S.R. 1995. Diversity of Hepaticae and Anthoceratoe in montane forests of the tropical Andes. *In* S.P. Churchill, H. Balslev, E. Forero & J.L. Luteyn, eds. *Biodiversity and conservation of neotropical montane forests. Proceedings,* p. 321 - 334. New York, USA, New York Botanical Garden.

Henderson. A., Churchill, S.P. & Luteyn, J.L. 1991. Neotropical plant diversity. *Nature,* 351: 21-22.

Huber, O. & Riina, R., eds. 1997. *Glosario fitoecológico de las Américas. Vol. 1.* Caracas, UNESCO. 500 pp.

Kappelle, M. 1996. Los bosques de robles (*Quercus*) en la Cordillera de Talamanca, Costa Rica. INBio, Amsterdam University, Heredia. 319 pp.

Kok, K., Verweij, P.A. & Beukema, H. 1995. Effects of cutting and grazing on Andean treeline vegetation. *In* S.P. Churchill, H. Balslev, E. Forero & J.L. Luteyn, eds. *Biodiversity and conservation of neotropical montane forests. Proceedings,* p. 527-539. New York, USA, New York Botanical Garden.

Lugo, A.E. 1994. Preservation of primary forests in the Luquillo Mountains. *Conservation Biology,* 8(4): 1122-1131.

Moraes, M. & Beck, S. 1992. Diversidad florística de Bolivia. *In* M. Marconi, ed. *Conservación de la diversidad biológica en Bolivia,* p. 73-111. La Paz, Centro de datos para la conservación - Bolivia, USAID/Bolivia.

Rangel-Ch., J.O. 1995. La diversidad florística en el espacio andino de Colombia. *In* S.P. Churchill, H. Balslev, E. Forero & J.L. Luteyn, eds. *Biodiversity and conservation* *of neotropical montane forests. Proceedings,* p. 187-205. New York, USA, New York Botanical Garden.

Proyecto estado de la nación. 1997. *Estado de la nación en desarrollo humano sostenible: un análisis amplio y objetivo de Costa Rica a partir de los indicadores más actuales.* San José, Proyecto estado de la nación. 306 pp.

Udvardy, M.D.F. 1975. A classification of biogeographical provinces of the world. IUCN Occasional Paper No. 18. Gland, Switzerland, IUCN. 48 pp.

UNESCO. 1973. Clasificación internacional y cartografía de la vegetación. UNESCO Ecology and Conservation Series. Geneva, Switzerland. 92 pp.

Velázquez, A. 1993. Man-made and ecological fragmentation: case study of the volcano rabbit (*Romerolagus diazi*). Z. *Säugertierkunde,* 58: 54-61.

Wolf, J.H.W. 1993. Ecology of epiphytes and epiphyte communities in tropical montane forests of Colombia. Amsterdam University, the Netherlands. (Ph.D. thesis)