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Authors: Etter, Andrés, and Villa, L. Alberto

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Andrés Etter and L. Alberto Villa

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Andean ecosystems are among the most diverse and threatened ecosystems in the world. Only very general data on the extent and impacts of the transformation processes that have affected ecosystems in Colombia are available

to date. This study analyzes the transformation of forests in part of the Eastern Colombian Andes, using the landscape ecological approach, with remote sensing, field-work, and GIS. There are two levels of analysis: a regional level (1:500,000) covering 4.1 million ha and a subregional level (1:50,000) covering 225,000 ha. The former covers the central portion of the East-Andean Cordillera, where the remaining forest and páramo areas were quantified and their spatial distribution analyzed. The subregional analysis level is located in the Middle Chicamocha Watershed. The effects of human activities on the ecosystems were analyzed, taking current farming systems into consideration. The historical human impact in the region has been intense, especially in the drier parts of the study area. At the regional level, only 22% of the original forests remain, of which 28.7% are located in the national parks. In the subregional study area, only 7.6% remain, mainly at altitudes of more than 3000 m. Of five identified forest types, the two with considerable covered areas were the High-Andean Polylepis Forests (33.6%) and the High-Andean mixed forests (35.1%). The original land cover of the sub-Andean dry forests has been almost totally replaced by seminatural shrublands, pastures, crops, and severely degraded areas. The largest fragments are Andean mixed forests and the Andean oak forests, with sizes up to 866 and 1182 ha. Of 19 identified farming systems at the subregional level, only 5 include substantial proportions of their original forest covers.

Keywords: Landscape change; biodiversity; landscape ecology; farming systems; forest remnants; tropical mountains; Eastern Andes; Colombia.

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Introduction

The ecosystems of the Andes are currently considered high-priority conservation areas. The reasons for this include their high levels of biodiversity and endemism (Andrade 1993; Gentry 1993; Dinerstein et al 1995), their great value in terms of environmental services such

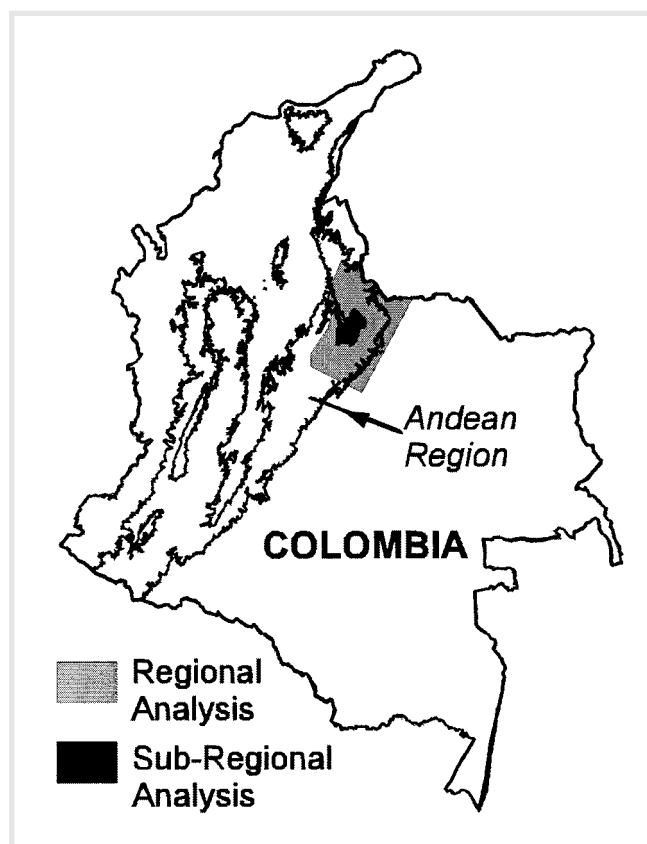
as hydrologic regulation and soil conservation, and especially their accelerated rates of destruction (Etter 1998). Andean ecosystems are thought to host over 40,000 plant species (Gentry 1995), contributing significantly to Colombian and global biological diversity. Depending on the altitude belt, only 18–25% of the original Colombian Andean forest ecosystems remain (Etter 1998). These ecosystems are being threatened by colonization and planting of illegal crops (Cavelier and Etter 1995).

Human occupation of the Colombian Andes dates back to at least 13,000 BP (Van der Hammen 1974, 1992). Etter and Van Wyngaarden (2000) developed a general analysis of ecosystem transformation relating rural population density to transformation at the national level over the last 500 years. This study shows the long and extensive impact of human activities, especially in the Andean region. In Colombia, the spatial distribution of natural remnants is uneven (Etter 1998). The inner side of the main Andean mountain ranges has historically been subject to greater impacts since they have been more intensely and permanently occupied.

When the Spaniards arrived, the study area in the Chicamocha region was already occupied by well-established chiefdoms, with high population densities, at altitudes ranging from 1000 to 3000 m (Langebaeck 1987). Man has thus played a highly significant role in the historical configuration of the actual landscapes. The transformation of the original ecosystems by different farming systems caused substantial changes in the landscape at the structural and functional levels. According to IDEADE (1992), several types of evidence support this. One is alteration of the spatial patterns of vegetation and geometrization of the territory, expressed in the reduction and fragmentation of the natural ecosystems (forests, thickets, and páramo areas) or in their total replacement by anthropogenic vegetation (crops, pastures). A second is alteration of hydrological cycles and associated processes, resulting in present water shortages in many areas, reported by the population. Another is reduction of the productive capacity of the soils. There is also loss of biodiversity, especially with regard to animals. Finally, there is even apparent alteration of the local/regional climate, most probably also related to extra-regional factors.

In many parts of the study area, these problems pose severe limitations to the sustainability of present farming systems (Etter et al 1995). Although there have been vast transformations, several relict areas of original forest vegetation can still be found, upon which reconstruction and ecosystem restoration can be based. Recently, local communities and institutions have begun to study the causes of environmental problems and have undertaken environmental restoration and conservation activities. The present article is a partial output of a project initiated in 1990 known as Integrat-

FIGURE 1 Location map showing the regional and subregional study areas.



ed Forestry Development in the Middle Watershed of the Chicamocha River (Boyacá-Colombia). It deals specifically with three aspects of the present situation of the forests in the Eastern Cordillera of the Colombian Andes:

- The degree of deforestation and altitudinal ranges of forest remnants.
- The relation of forest remnants to actual farming systems.
- Fragmentation characteristics.

Study area

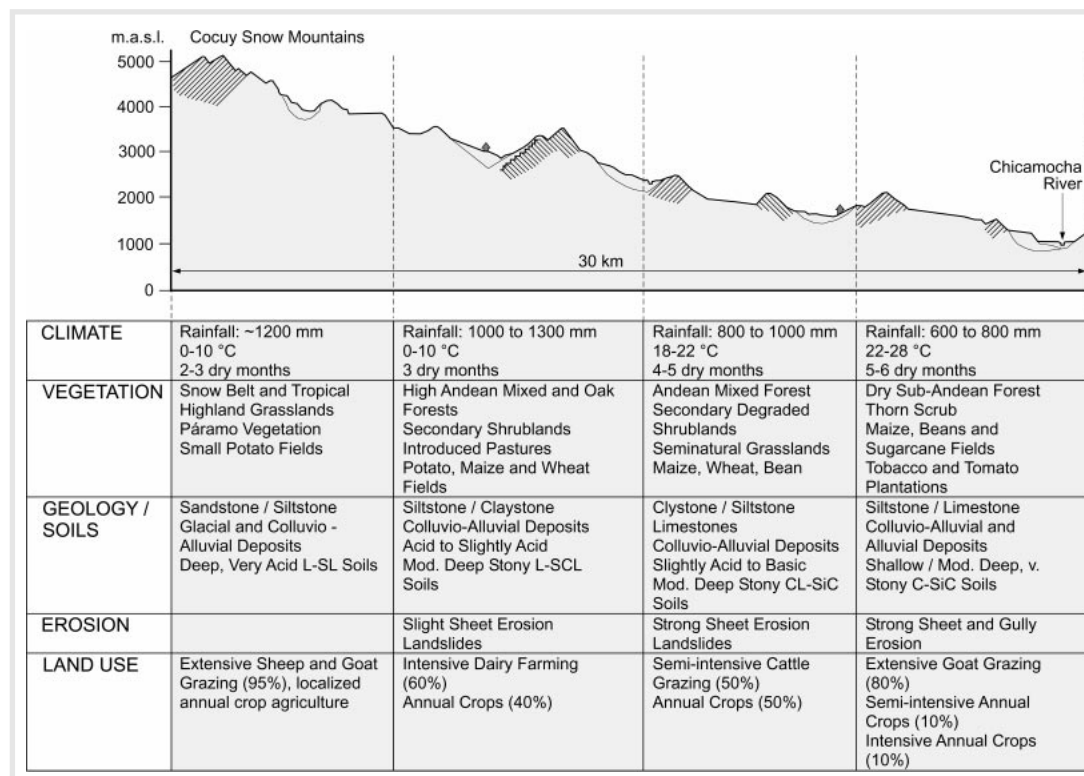
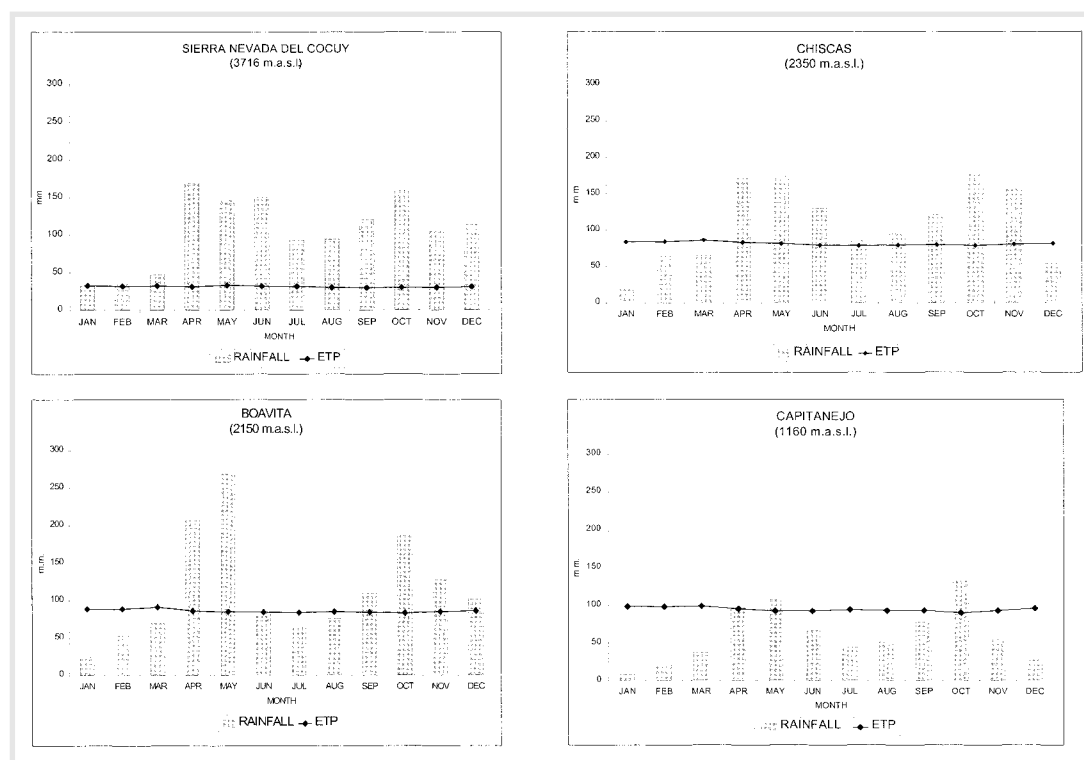
The study area is located in the Eastern Andes of Colombia between 6° and 7° N, where two levels of analysis were carried out: regional (1:500,000) and sub-regional (1:50,000) (Figure 1). The regional level covers the central part of the Eastern Andean Range, including the slopes that face the Eastern Plains (*Llanos Orientales*), and the central part comprising the upper and middle watersheds of the Chicamocha and Fonce-Suárez rivers in the states of Boyacá and Santander, covering approximately 4,100,000 ha. Four national parks are located in this area—the El Cocuy

National Park, the Alto Río Fonce-Guanentá Vegetation and Fauna Sanctuary, the Tamá National Park, and the Pisba National Park, all containing parts of the largest forest remnants of the region (see Figure 5). The subregional level of analysis is located within the above-mentioned area, including the middle basin of the Chicamocha River in the northeast of Boyacá State. The area is approximately 225,000 ha in size, comprising 17 municipalities, and covers an altitude gradient from 1000 to 5300 m.

The marked altitudinal gradients, varied geology, morphology of the watershed, and the history of human occupation in the study area provide a complex geographic setting combined with a great diversity of natural and transformed ecosystems. Figure 2 shows a schematic profile summarizing the biophysical conditions and the land uses at the subregional level.

Regionally, the climate of the study area ranges from humid conditions on the external eastern flank of the *cordillera* to subhumid to slightly dry areas on the internal flanks. At the subregional level, the climate is bimodal, having pronounced dry and wet seasons, with rainfall ranging from 600 to 1300 mm/y (Figure 3). Combined with the strong relief and the deforestation process, this makes the area very prone to land degradation problems such as soil erosion and water shortage. The climate is essentially determined by the status of the Chicamocha Valley, as the largest transverse intra-Andean valley in Colombia. Valleys of this type have intense wind circulation along their axis due to the interaction of low, warm areas with high, cold ones (White et al 1984). This interaction forms an arid nucleus in their middle portion that coincides with the subregional study area in this particular case. This is especially evident in the zones below 2000 m that are more exposed to strong wind action. The water deficit decreases with altitude, from 9 to 3 dry months. The soils of the area tend to be chemically fertile due to the local geology, mostly finely textured, with high levels of stoniness. About 50% of the area is affected by some kind of erosion, especially in the lower zones. Depending on altitudinal belts and substrate conditions, several types of natural vegetation are found, including *páramo* grassland, forest, scrub and thicket-shrubland (IDEADE 1992).

At present, around 80% of the Chicamocha landscapes that lie below 3500 m are highly transformed ecosystems, where the great diversity of biophysical conditions is also reflected in land use. Nineteen types of farming systems have been identified in the Middle Chicamocha Watershed, ranging from extensive highland sheep and cattle grazing to intensive dairy farming, intensive mixed cropping, extensive mixed cropping and grazing, and intensive high-input agriculture. The different farm types show a close relation to land units or associations of land units (IDEADE 1992).

FIGURE 2 Schematic cross-section of the Middle Chicamocha Watershed (subregional level).**FIGURE 3** Rainfall amount and evapotranspiration in four areas situated in the Middle Chicamocha Watershed.

Methods

The conceptual guidelines of landscape ecology were applied (Forman and Godron 1986; Etter 1993; Zonn-eveld 1995; Farina 1998) in order to undertake an integrated analysis of the landscape including the biophysical setting, the actual land use, and the effects of anthropogenic landscape transformation. The general procedure included mapping, fieldwork, and GIS applications, as shown in Figure 4.

Mapping and databases

Mapping was based on remote sensing products that were subject to visual interpretation of land cover and geomorphology in order to delineate land units. Black and white aerial photographs (1985–1990, scales approximately 1:20,000 to 1:30,000) and Landsat satellite images in black and white and “false color” prints (1987 and 1992, scales 1:500,000 and 1:100,000) were

used. Topographic maps at scales of 1:500,000 and 1:50,000 from the National Geographic Institute were drawn on for the cartographic base.

At the subregional level, fieldwork was carried out (1991–1995) to characterize the land units by means of a stratified sampling of aspects related to relief, lithology, soil, hydrology, geomorphic processes, vegetation (physiognomy, structure, composition), and land use. A typology of farming systems was defined according to the approaches established by Fresco (1986), Hart (1989), and Etter (1994). To characterize the farming systems, variables such as altitude, agroecosystems, technology, tenure, and size of the properties were analyzed. Census data (National Geographic Institute and National Statistics Department) on production, population, and *cadastre* were used. Based on analysis of the collected data, maps of landscape ecological units and farming systems were prepared at a scale of 1:50,000.

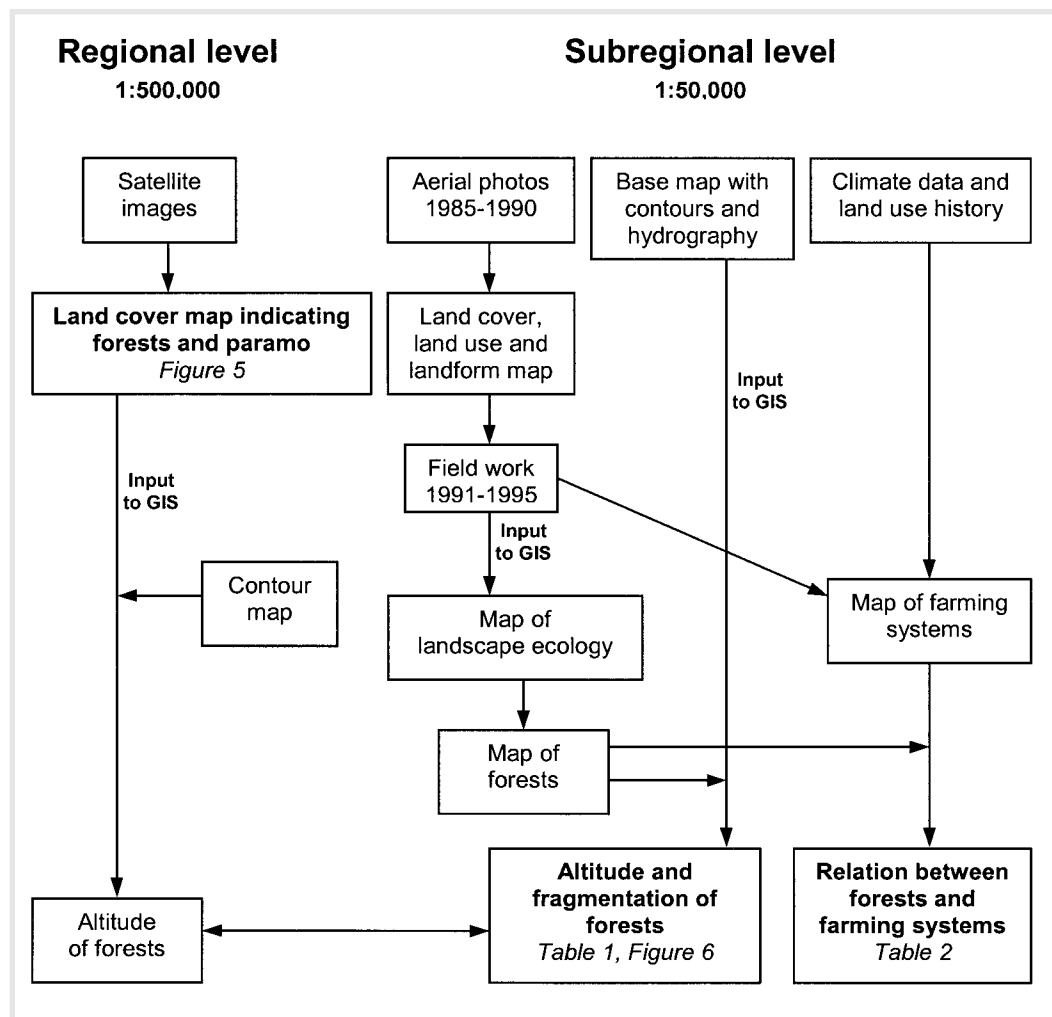


FIGURE 4 Methodological procedure.

GIS analyses

GIS ILWIS 2.2 (ITC 1999) software was used to perform selective data retrieval, map overlay operations, area calculations, and fragment analysis. At the regional level, an overlay of the forest cover map with the 1000-m interval altitude map was performed to obtain the altitudinal proportions of forest cover.

For the subregional level, data on forest cover, 500 m contours (altitude map), and land use/farming systems were retrieved in raster format from the general landscape ecology maps and data base (IDEADE 1992) in order to carry out map overlay operations. Analyses were done in relation to the actual situation of forest remnants with respect to

- (1) Total present forest area, fragment size, and number of fragments per forest type.
- (2) Comparison of present with original forest cover by forest type.
- (3) Altitudinal distribution, according to 1000 m belts.
- (4) Forest types and area of forest cover per farming system.

The original forest cover for each forest type at the subregional level was established on the basis of the relationship between the types of remaining natural vegetation and landform, lithology, soil conditions, and the altitudinal vegetation distribution limits (IDEADE 1992). The upper boundary for high Andean forest was established at 3700 m, according to Van der Hammen (1974, 1992).

Results

Regional level

At the regional level, the larger forest areas are located mainly in the vicinity of the more humid and inaccessible altitudinal zones—the eastern slope of the mountain range, the peaks of internal mountain ranges, and the high basin of the Fonce River—coinciding to a large extent with the national parks (Figure 5). The smaller fragments are located in the Middle Chicamocha Watershed and the Cundinamarca and Boyacá

Plateau, usually above 2800–3000 m. The total remaining forest area is 899,000 ha, equivalent to 22% of the area and approximately 25.4% of the original forests, while the *páramo* grasslands occupy 570,000 ha (13%). The national parks in the area include 257,649 ha, or 28.7% of the forest remnants.

In terms of the region as a whole, forests are concentrated mainly in the 1000–2000 m (36%) and 2000–3000 m (32%) altitudinal belts. Within each altitudinal belt, these forests also show the largest proportion of conserved areas, with 31 and 22%, respectively.

Subregional level

The existing remnants of the different forest types in the Middle Chicamocha Watershed are shown in Figure 6. Five forest types were identified in the area: the high-Andean *Polylepis* forest (HAPF), high-Andean mixed forest (HAMF) (*Weinmania-Valea-Clethra-Ericaceae*), Andean mixed forest (AMF) (*Weinmania-Hedyosmum-Melastomataceae*), Andean oak forest (AOF) (*Quercus*), and sub-Andean dry forest (SADF).

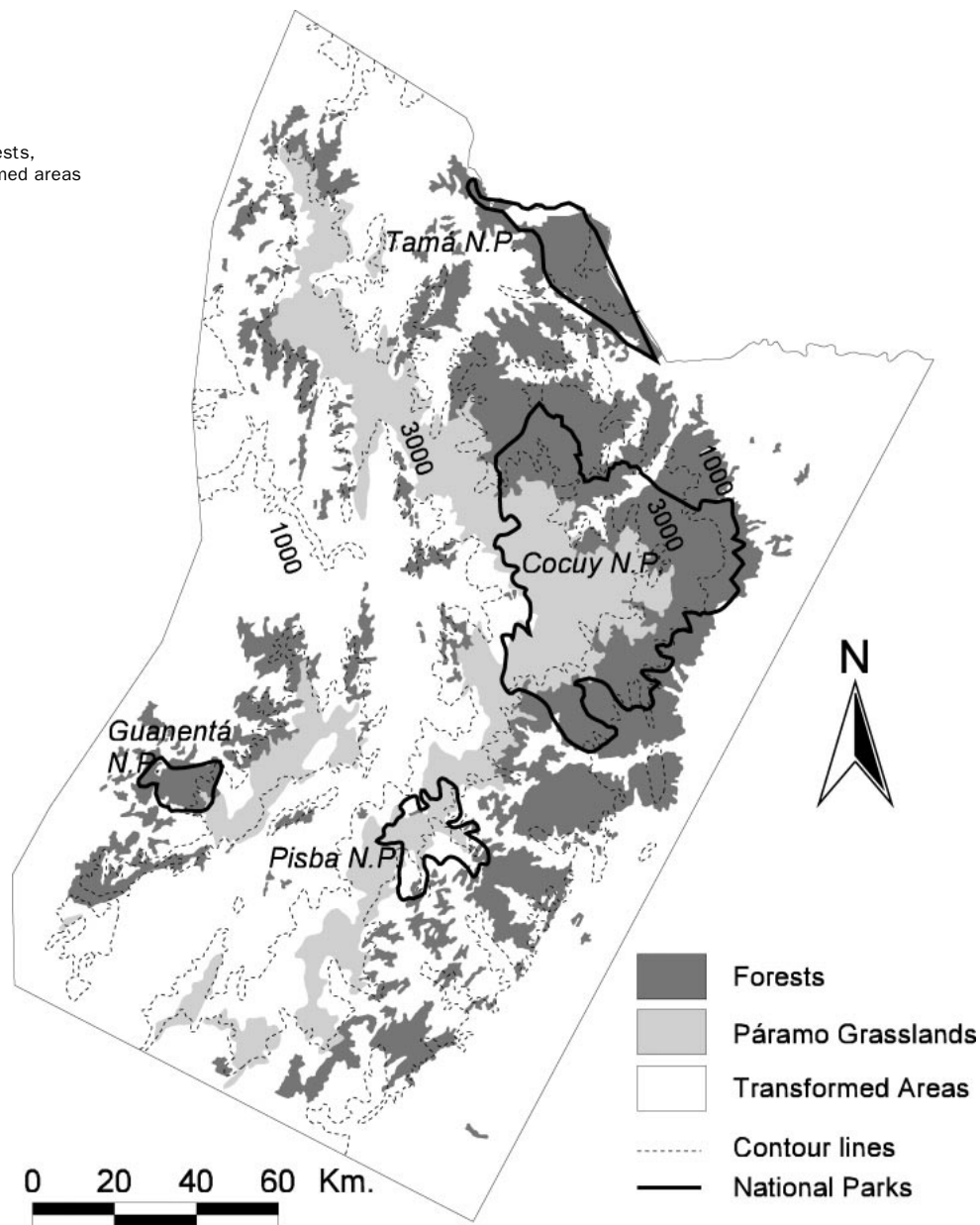
The original forest cover was 165,300 ha, or 73% of the study area. The present total forest cover is 17,113 ha, which is equivalent to only 7.6% of the study area and around 10.4% of the total original forest area. Distribution of the forest remnants by altitudinal belts, at 1000-m intervals, shows that most (66%) of the forested areas are located in the range of 3000–4000 m. Of the altitudinal belts originally covered by forests, the belt at 1000–2000 m has the lowest conserved proportion (<5%), while the 2000–3000 m and 3000–4000 m belts have the greatest proportion of conserved areas, with 36 and 38%, respectively.

Of the remaining forests, HAMF is the most extensive, with 8063 ha, as well as the most diverse according to our field surveys. The SADF, originally found in the altitudinal belts between 1000 and 2400 m, has been almost completely replaced by pastureland, cropping areas, and degraded thickets. Only 300 ha remain, equivalent to 0.4% of the original area. Considerable conserved areas of HAPF and HAMF remain, with 33.6 and 35.1%, respectively (Table 1).

TABLE 1 Characteristics of forest types and their fragmentation in the Middle Chicamocha Watershed.

Name	Altitudinal range (m)	Total area (ha)	Number of fragments	Average size of fragments (ha)	Min (ha)	Max (ha)	Original size of forest cover (ha)	Present size (%)
High Andean <i>Polylepis</i> forest	3500–4300	1109	27	41.1	15	175	3300	33.6
High Andean mixed forest	2500–3800	8063	125	64.5	14	135	23000	35.1
Andean mixed forest	2500–3200	4633	21	220.6	3	1182	47000	9.9
Andean oak forest	2500–3200	3007	24	125.3	12	866	18000	16.7
Sub-Andean dry forest	1100–2400	300	5	65.0	10	160	74000	0.4

FIGURE 5 Map of forests, páramo, and transformed areas at the regional level.



Considering that the original ecosystems were characterized by extensive and compact forest cover and taking into account the low area figures for most of the remnants, the study area has a high degree of fragmentation (Table 1). The average size of the fragments depicted at this level of analysis is in the order of 70 ha. There are considerable unfragmented remnant areas of AMF and AOF, with fragments of up to 1182 and 866 ha, respectively. Although HAME covers the largest total area, there are also many small fragments (<50 ha). As can be observed in Figure 6, the AMF and AOF together form the largest and most interconnected forest mosaics of the area. In general, forest remnants are located toward the higher, more inaccessible and humid parts of the mountain peaks or in the more rugged areas and on steeper slopes.

The transformation process involving natural vegetation has occurred mainly on the valley bottoms, extending toward the peaks. The observed transformation levels and fragmentation patterns are closely related to the type of farming system involved and to location in the landscape. Nineteen different types of farming systems were identified in the study area, of which only 5 have forest cover greater than 10% (Table 2). Most of the forest remnants at present are associated with farming systems A6 (34.5%) and A2 (26.6%), that is, dairy and pastoral farming systems in the cold regions above 2200 m. Farming systems A2–A6 and A12 have tended to encourage the presence of natural vegetation in the form of hedgerows and forest patches (Figure 7). The forest types included are mainly HAME, AMF, and AOF.

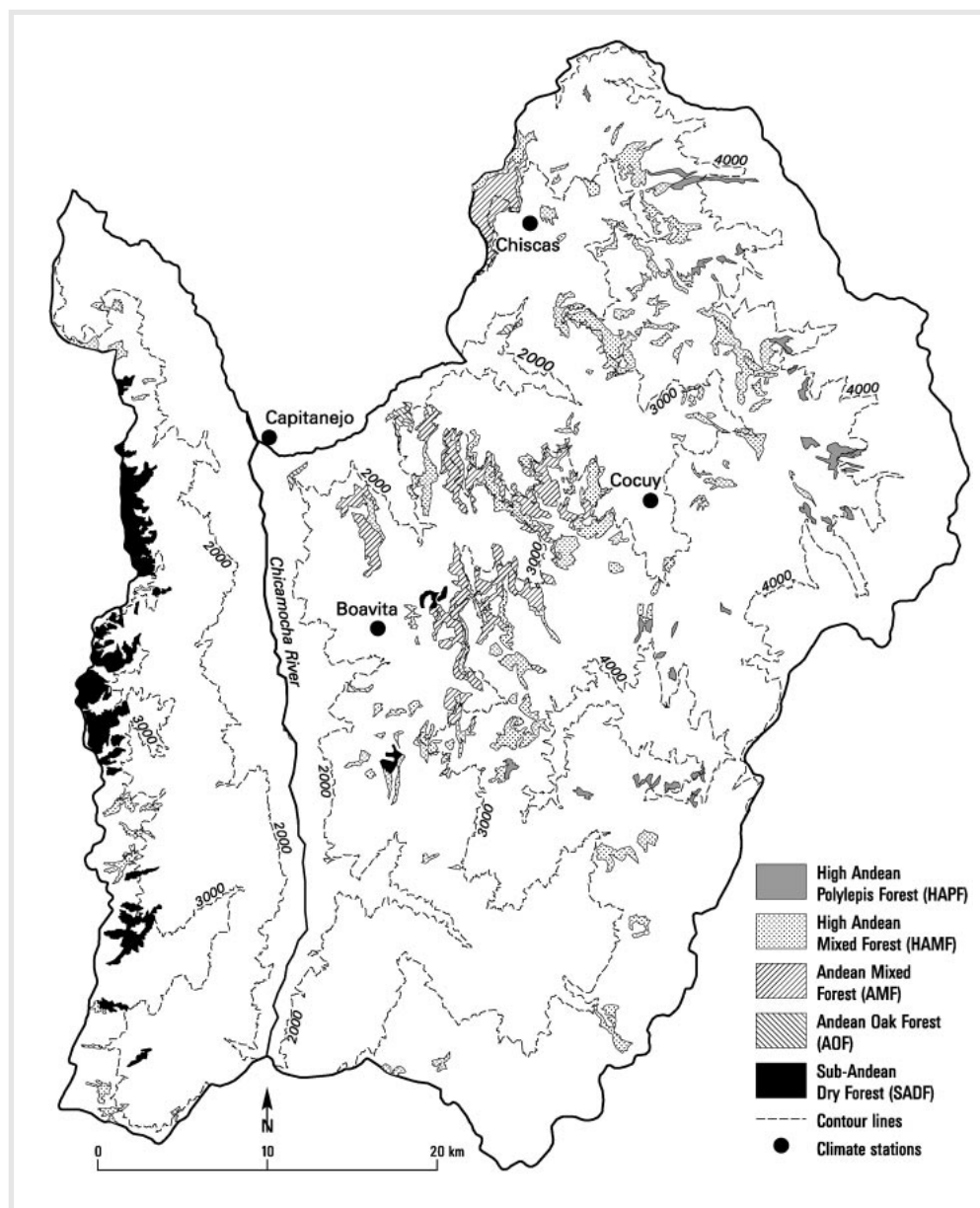


FIGURE 6 Map of forest types in the Middle Chicamocha Watershed (subregional level).

Discussion

The figures for forest remnants in the Middle Chicamocha Watershed are low for all altitudinal belts considered, especially for the subregional level, compared with those given by Etter and van Wyngaarden (2000). This means that, at the national level, the area is one of those most heavily impacted by human transformation. This is understandable considering that human occupation has lasted longer and been more permanent in this area than in other parts of the Colombian Andes (IDEADE 1992).

In comparing the altitudinal distribution of the forest remnants analyzed in this study, two patterns emerge. At the regional level, forests are concentrated in the altitudinal belts between 1000 and 3000 m, while at the sub-

regional level, they are in the 2000–4000-m range (Table 1). This can be explained by different historic patterns of settlement, but it is also due to differences in climate and accessibility (IDEADE 1992). The lack of forest cover above 4000 m is explained in both cases by the fact that this is the upper limit of the timberline.

At the regional level, forests are more fragmented and isolated in areas toward the inner side of the mountain range. These areas are more stable at present, however, since the border between forests and transformed areas has remained constant in recent decades (IDEADE 1992). In contrast, the more natural areas on the eastern slopes of the mountain range are undergoing an active colonization process, mainly from the lower altitudes upward (personal observation). Part of the most compact

FIGURE 7 View of a Chicamoca landscape from a height of 3500 m. The farming systems in the foreground belong to categories A5 and A6. (Note the forest remnants and hedgerows at this altitude.) In the lower areas visible in the background, the farming systems belong to categories A10, A11 and A14; these areas are almost devoid of forest cover. (Photo by A. Etter)



forested areas here is associated with the existing national parks in the region, which in turn are the less accessible areas. However, there is also evidence of encroachment by new colonists in these areas, who can be expected to reclaim substantial portions of the forests in the future, especially in the lower areas of Cocuy National Park.

The forest situation is critical at the subregional level, especially below 2000 m. In this region, however, some core areas with high hedgerow densities could become the basis for local restoration of the ecosystem through interconnection of local patchiness to form a network. In the dry zone below 1500 m, almost no examples of the original sub-Andean dry forest are left (Table 1). In this belt, Langebaek (1987) and Pérez (1993) reported an intense human occupation process and human settlements since pre-Hispanic times, mainly related to the cultivation of cotton, corn, and coca. During the Spanish colonial period, this part of the region also had a large and concentrated population density associated with cattle raising and cultivation of sugarcane and tree crops; these activities still exist in some areas (A12, Table 2). Between 1950 and 1960, the introduction of intensified tobacco cultivation accompanied

by goat grazing (A18, A19) had a heavy impact in the area, even on very steep slopes. Nonetheless, large areas of degraded dry forests and thorny thickets (*Cercidium*, *Prosopis*, *Thecoma*, *Cereus*) still exist and are used for extensive goat grazing. In principle, these areas have a high potential for recovery under isolated conditions created by fencing. This, together with the present trend to abandon land in such areas, will probably promote their recovery in the near future (Etter et al 1995).

According to IDEADE (1992), 15,013 ha (87%) of the 17,113 ha of high Andean and Andean forest remnants are well-conserved forests and 2100 ha (13%) are fragments subjected to the impacts of cattle and wood extraction. The better conserved areas are associated with farming systems located above 2200 m that concentrate on intensive and semi-intensive dairy farming (A2–A6), introduced after Spanish settlement in the 16th and 17th centuries. Most of the forested areas with greater connectivity and extension are associated with these activities. Moreover, new agricultural areas are currently replacing forests at a reduced rate (IDEADE 1992). This situation could be explained by the stability of the larger properties, where rotation cycles involving

TABLE 2 Farming systems and their relation to forest fragments in the Chicamocha Watershed.

Code	Farming system	Farm size (ha)	Total area (ha)	Forest area (ha)	Percent of total forest area	Percent of forest per farming system
A1	Extensive grazing (>3600 m)	50–250	68,885	2136	12.2	3.1
A2	Semi-intensive sheep and goat grazing (3000–3600 m)	10–50	32,001	4656	26.6	14.5
A3	Extensive sheep and cattle grazing and annual crops (3000–3600 m)	10–50	4579	2017	11.5	44.0
A4	Semi-intensive dairy farming and annual crops (3000–3600 m)	3–10	5079	1105	6.3	21.8
A5	Semi-intensive agriculture and grazing, and fuelwood extraction (2500–3000 m)	10–50	1710	326	1.9	19.1
A6	Intensive dairy farming (2200–3000 m)	3–10	36,407	6031	34.5	16.6
A7	Intensive mixed cropping (>3500 m)	1–3	1195	0	0.0	0.0
A8	Intensive cattle grazing and annual crops (2500–3000 m)	3–10	7880	21	0.1	0.3
A9	Extensive sheep and goat grazing (2000–2500 m)	10–50	18,911	175	1.0	0.9
A10	Intensive fodder agriculture (2000–2500 m)	3–10	981	0	0.0	0.0
A11	Semi-intensive agriculture and goat grazing (1000–2000 m)	3–10	678	0	0.0	0.0
A12	Extensive grazing and semi-intensive agriculture (2000–2500 m)	3–10	20,565	862	4.9	4.2
A13	Intensive annual crops (1800–2300 m)	3–10	6133	51	0.3	0.8
A14	Intensive agriculture and grazing (1800–2300 m)	10–50	136	0	0.0	0.0
A15	Perennial crops and cattle grazing (1500–2200 m)	3–10	220	0	0.0	0.0
A16	Intensive annual crops (1200–2000 m)	3–10	4170	2	0.0	0.0
A17	Semi-intensive annual crops and cattle grazing (1500–2000 m)	3–10	2473	54	0.3	2.2
A18	Extensive goat grazing (1200–1800 m)	10–50	13,554	51	0.3	0.4
A19	Intensive tobacco culture (1000–1800 m)	1–3	100	10	0.1	10.0

grazing and agriculture are 10 years or longer. This contrasts with smaller farms in other systems, where the area and the intensity of activities related to agriculture are both greater and rotation cycles are much shorter. Nevertheless, grazing as well as fuelwood and timber extraction affect both the margins and the interior of forest areas found in less hilly places; they lead to spatial processes such as perforation and contraction (Forman 1995), which alter the structure of the forest remnants and their regenerative potential.

Despite the spatial relationship between remaining forest areas and farming systems where cattle grazing activities prevail, it would be hard to conclude that cattle raising and other types of pastoralism (goats and sheep) have historically contributed to the conservation of forest ecosystems. The animal population increase during the 19th and 20th centuries (IDEADE 1992) and

the consequent opening of new grazing lands in the Middle Chicamocha Watershed have certainly been determinant impact factors in the dynamics and the magnitude of forest transformation. This pattern is similar to those in other parts of Latin America and Europe where the impact of grazing has been analyzed (Abella 1993; Molinillo 1993; Rabey 1993).

Few remaining fragments of forest in the study area are relatively large (50, 100, and up to 1182 ha); but they are seldom related to hydrologic corridors, which tend to be devoid of natural vegetation (IDEADE 1992). The persistence of forests in the area is generally due less to the planned activities of farmers than to where these forests are located in the landscape (IDEADE 1992; Baptiste 1994). Recently, however, because of water shortages and loss of hydrologic regulation, many of the region's inhabitants have started to worry about conserving areas

of natural vegetation. It can be argued that the forest areas that survived the landscape transformation processes did so more as a result of chance or biophysical limitations than as the result of conscious actions on the part of their owners. In this sense, the situation can be explained by the concepts of passive management or beneficial negligence, introduced by Hobbs et al (1993).

Faced with this situation, local communities and municipalities have been developing a land use planning and restoration process since 1993, implemented

by the Project for Integrated Rural Landcover Development in the Middle Chicamocha. Management activities integrate production and conservation of natural and cultural vegetation, based on the potential created by the existence of forest remnants in the different altitudinal belts. The major difficulties confronted at the outset were related to community work, especially the lack of solidarity, community organization, and understanding of the need to integrate conservation and production processes (Etter et al 1995).

AUTHORS

Andrés Etter, L. Alberto Villa

Department of Territorial Processes and Human Settlements, Faculty of Environmental and Rural Studies, Javeriana University, Cra. 7 Nr. 42-27, p6, Bogotá, Colombia.

aetter@javeriana.edu.co and lvilla@javeriana.edu.co

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