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Colombia Sub-global Assessment Report

Ecological Function Assessment in the Colombian Andean Coffee-growing Region

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1. Introduction

The Colombian coffee-region millennium ecosystem assessment is an ecological function assessment of the coffee-growing region of Colombia. This assessment is one of 33 sub-global assessments linked to the Millennium Ecosystem Asessment (MA), a four year global effort to provide decision-makers with information on the consequences of ecosystem change for huma well being (MA, 2003). The objectives of the Colombian coffee-region assessment were to provide useful environmental information to institutions and decision-makers in the coffee-producing regions of Colombia.and also analyze information between ecosystem services, direct and indirect drivers of change, and human wellbeing. This report presents a summary of the current condition and trends of several ecosystem services, and identifies some consequences of ecosystem changes and their impact on the wellbeing of human populations in these areas. This pilot assessment is in its first stages and has been a completely self-funded assessment so far. Complete trends, scenarios and response options will be developed in the next two years if a full assessment is finally aproved and sufficient funding is secured.

1.1 Assessment area

The coffee-growing region of Colombia is located on the three Andean mountain ranges between 1,000 and 2,000 meters above sea level. It encompasses an area of more than 3.6 million hectares (*sensu lato)* that extends along the entire Andean region, between 1° and 12° latitude north (from the Sierra Nevada de Santa Marta in the north to the department of Nariño in the south). Coffee is grown in 605 municipalities in the country (56% of the national total), and the industry involves 420,000 households and more than half a million agricultural productive units or farms. Around 870,000 hectares are currently devoted to coffee production and the average coffee-farm size is near 2 ha.

We have focused the analysis in Colombia´s main coffee region that is located in the central part of the country and includes the mountainous regions of Antioquia, Caldas, Risaralda, Quindio, and Valle. This region runs along the Cauca River Valley, between the Central and Western mountain ranges. Ecosystem services are assessed at multiple scales (Figure 1); a) at the national level, examining two spatial extents: country level and the main coffee producing region (Figure 1a); b) at a regional level, individually analysing each one of the 5 departments and (Figure 2), c) at a local level, examining one of the coffee production municipalities (El Cairo) and a local window of 2,500 ha within it (Figure 3).

Figure 1 Coffee committees in the coffee region

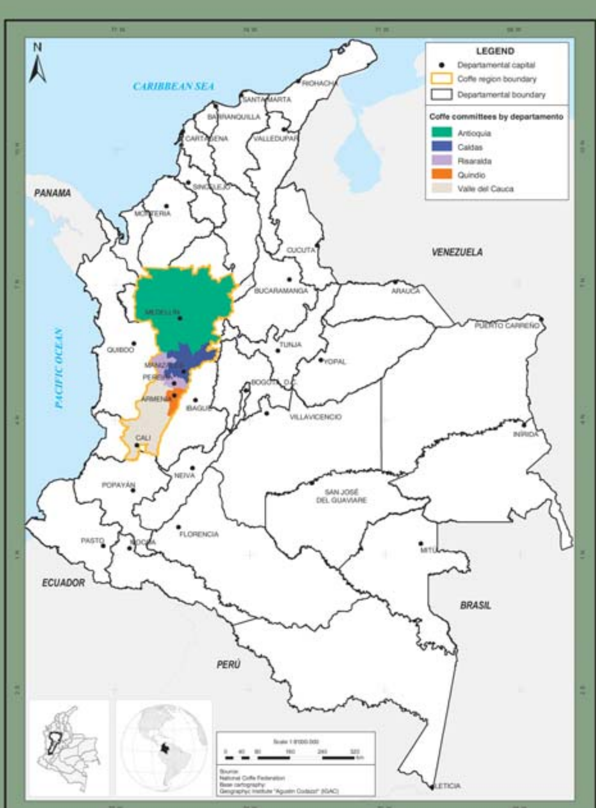
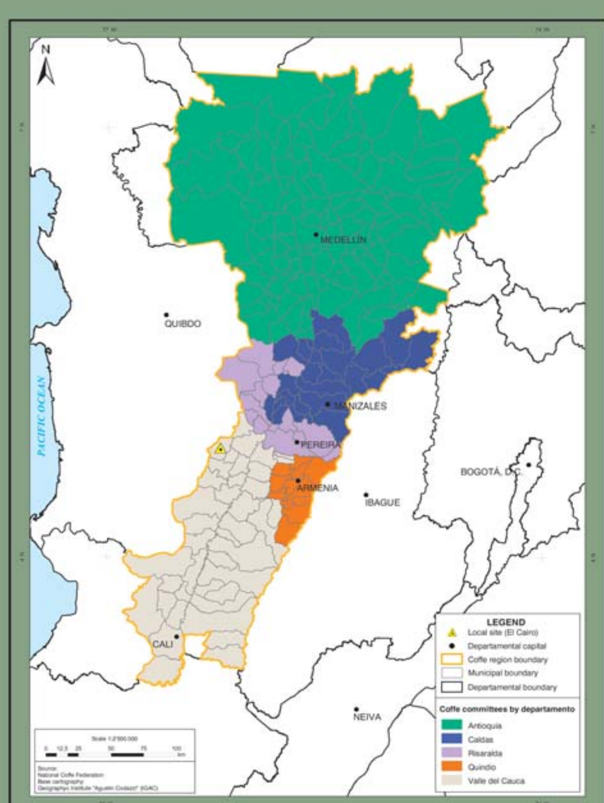
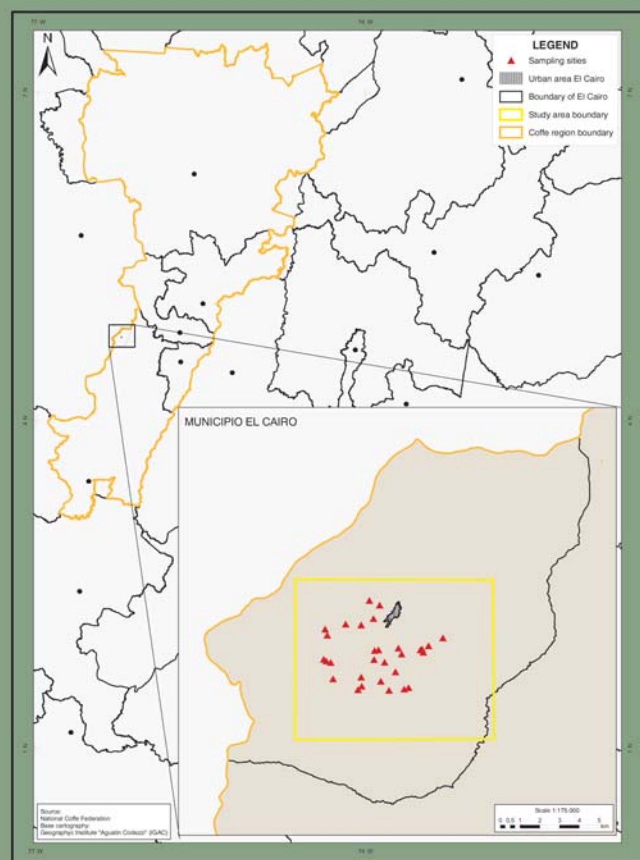


Figure 2. Study area at the regional scale for the assessment



User needs at multiple decision-making levels were evaluated through an analysis of the Government Development Plan, the ministry National Biodiversity Policy and Technical Proposal, and the Coffee Region development plan, and through interviews with departmental and municipal coffee committees and local communities.

Figure 3. Local Scale: municipality of El Cairo and local window with sampling points



1.2 Need

Ecosystem goods and services significantly contribute to the wellbeing of the human population in coffee-growing regions and to their economic productivity. For example, abundant rainfall regimes have provided this region with an ample supply of water, which has helped to sustain dense human population levels and abundant agricultural production. Fertile volcanic soils have also allowed a rich agricultural production (See Table 1), world famous for the quality of the coffee produced there.

However, biodiversity and its associated ecosystem services have traditionally been undervalued and are often ignored in regional decision-making processes. Furthermore, the existing conceptual and empirical knowledge on regional ecosystem functions is inadequate for the analysis of dynamic linkages between biodiversity, sustainable agricultural production, and human population livelihood. Knowledge and appreciation of the supporting and regulating services that ecosystems provide to agricultural systems in the Andean regions are inadequate.

An ecosystem is a functional unit with homogenous biophysical and anthropogenic conditions in a given territory. It includes the ecological processes and geophysical elements that interact at a given scale. People are an integral part of it. Ecosystem goods and services are the benefits that people obtain from ecosystems. Millenium Assessment has classified services as:

- Provisioning (food, water, fiber, fuel, and other biological products). Goods such as non-timber forest products, food, genetic resources are provided by ecosystems.
- Regulating - pollution control, microclimate regulation, water cycle regulation.
- Cultural - aesthetic, recreational, religious, and
- Supporting - biodiversity.

All these goods and services can be greatly affected by changes in ecosystems. Such is the case in the Colombian Andes where traditional agriculture has transformed mountain ecosystems into rural landscapes. In most of this region, some elements of the agricultural landscapes are the only alternative for conservation of biodiversity, as very few fragments of the natural ecosystems remain. These rural landscapes are also the habitat of wild relatives of commercially important species and where traditional production systems and knowledge are maintained. Furthermore, these landscapes provide water, food, fiber, timber, and medicine plants to the population in those areas. Research studies conducted by Humboldt Institute and Cenicafé in the last four years have documented the importance of forest remnants, shade-coffee farms, and forested streams to the preservation of regional biodiversity.

Natural resource management in these rural landscapes is hindered by conflicts between local and national administrations, partly due to lack of coordination among the entities in charge of resource administration and regulation. An improvement in the quality and amount of information on the environmental conditions in coffee regions will benefit the natural resource management process. However, social and political mechanisms are also needed to address

Table 1 Core indicators analysed for the Colombian coffee sub global assessment

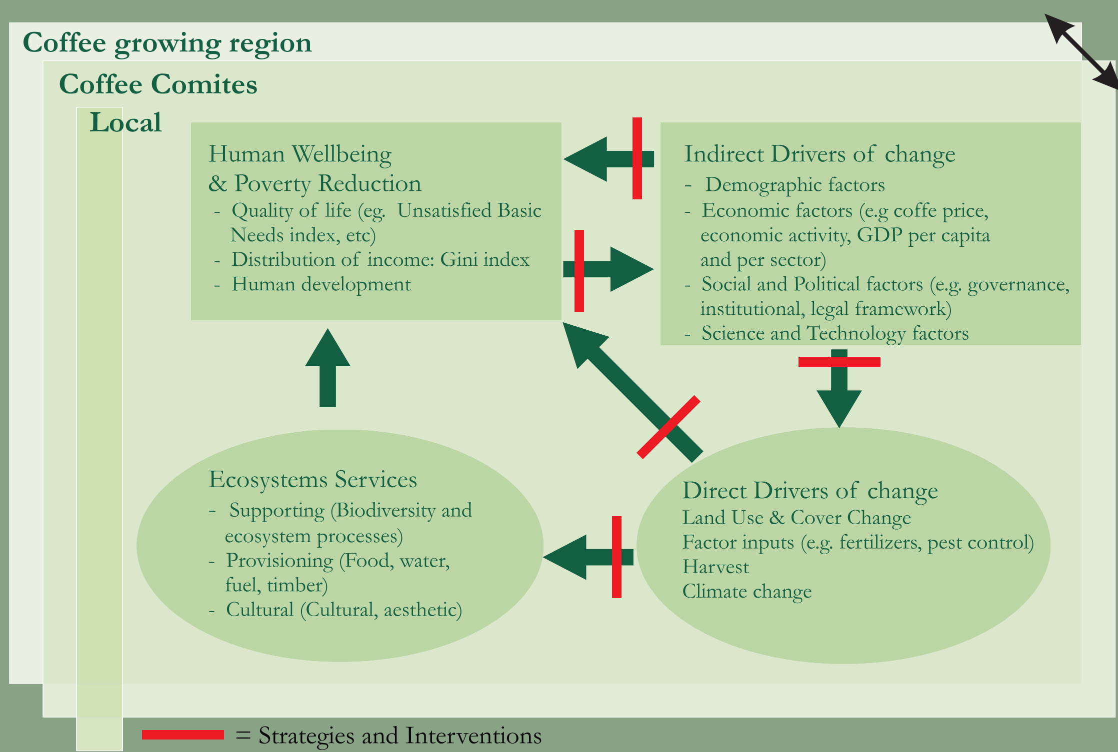
	CATEGORY	TYPE
Ecosystem services	**SUPPORTING**	BIODIVERSITY:
		Area and distribution of ecosystems (80's - 2001)Ecosystem diversity (80´s - 2001)
		Area under shade coffee
		SOIL:
		Erosion
	Provisioning	FOOD
		Coffee production
		Agricultural and cattle production
		WATER:
		Water deficit index
	Cultural	ECO-TOURISM
		Number of visitors to ecotourism farms per year
		Number of visitors to national parks or natural reserves
Direct Drivers	Land Cover Change	Forest cover change (80's - 2001)
		Natural/transformed cover change (80's - 2001)
	Phytosanitary factors	Area affected by coffee rust (*Hemileia vastatrix*)
		Area affected by coffee-berry borer (*Hyphotenemus hampei*)
Indirect Drivers	Demographic factors	Number of inhabitants
		Population density
		Population growth
	Economic factors	Percentage of area in coffee production
		Number of coffee production units
		Annual coffee production
		Economic activity index
		Gross domestic product (national and per sector)
	Social and political factors	Number of environmental institutions and associations
Human well being	Population quality of life	Quality of life of the population
		Education
	Economic Security	Economic activity per capita
		Distribution of income and land tenure (GINI Indeces)
		Non-satisfied basic needs index
		Population below poverty line

these issues and to formulate and implement incentive schemes and sanctions. Mechanisms are also needed to monitor and enforce agreements and environmental management processes. The ecosystem assessment in coffee-growing regions analyzed and identified some of the environmental, economic and institutional factors that influence environmental planning and policy making in coffee growing ecosystems.

1.3 Adaptation of the MA Conceptual Framework

The MA conceptual framework places human well-being as the central focus for assessment and recognises that it has multiple constituents (MA, 2003). Ecosystem services are the benefits people obtain from ecosystems, which the MA describes as provisioning, regulating, supporting and cultural services. Changes in these services affect human well-being and the growing demand being placed on ecosystems tends to affect rural populations and poorer people most directly. This pilot assessment has adopted the MA conceptual framework by identifying the relationships between drivers of ecosystem change, ecosystem services and human well-being specific to the Colombian situation (Figure 4). Factors that have been taken into consideration include coffee related factors, levels of mortality due to violence, and others that might have an important effect on the well-being of local populations (see Table 1 for the complete list).

Figure 4 Conceptual framework for this sub-global assessment (adapted from ME Conceptual Framework)



1.4 Undertaking the assessment

1.4.1 Coordinating Institutions

The ecosystem assessment of the Colombian coffee-growing region was coordinated by two institutions: the Alexander von Humboldt Biological Resource Research Institute and Cenicafé, the research branch of the National Federation of Coffee Growers of Colombia (Federación Nacional de Cafeteros de Colombia).

The Alexander von Humboldt Biological Resources Research Institute was created in 1993 (National Law 99) as one of the five entities that provide scientific and technical support to the Ministry of the Environment. It is a non-profit organization, with a General Assembly that includes the Ministry of the Environment, the national science organization (Colciencias), public and private universities, regional environmental authorities (CAR) and non-governmental organizations. Its mission is to promote, coordinate, and carry out research that contributes to the conservation and sustainable use of biological diversity in Colombia. With support from the GEF–World Bank and the government of the Netherlands, the Humboldt Institute designed and in 2001 began the implementation of a six-year long project titled «Conservation and Sustainable Use of Biodiversity in the Colombian Andes». Amongst other objectives, this project will identify conservation opportunities in rural landscapes, and develop and promote sustainable use and management tools for biodiversity conservation in those areas. The coffee-producing region is one of the rural landscapes where the Andes project is presently in operation.

The National Federation of coffee growers, an organization that was founded in 1927, is entirely owned and controlled by Colombia's coffee farmers (it includes more than 500,000 farmers). Farmers associated to the Federation obtain benefits such as a price guarantee, set up as a buffer against unpredictable international market prices for coffee. Since its creation, the Federation has been concerned with the sustainability of coffee production. It has provided financial resources for restoration of watersheds, acquisition of land for water protection, and the conservation of areas of riparian forest. The Federation has also provided local communities with basic infrastructure, such as electricity, water supply services, schools, and roads, which has resulted in improved living conditions in these areas.

Cenicafé is the research department of the Coffee Federation. Its objective is the production and transfer of scientific and technological knowledge according to coffee-growers' needs. For more than six decades, Cenicafé has conducted research to promote sustainability in the coffee

production, to reduce production costs (harvest and post-harvest), to preserve natural resources and also to improve the quality of Colombian coffee. It has also developed soil conservation programs, integrated pest control systems, and pollution reduction technologies related to coffee production in Colombia.

1.4.2 Assessment Process

The assessment was initiated by constructing a database with available information on selected study areas. We collected maps, satellite images, data from population and agricultural censuses, studies on quality of life of the populations in the study areas, as well as all demographic and economic indicators previously developed. We informed stakeholders at different levels of this assessment through site visits and with a letter explaining the project. Initial outreach provided us with the opportunity to gather data at different levels. This assessment also involved stakeholders and gained access to information located in the private sector at the National Federation of Coffee Growers of Colombia, departmental and municipal coffee committees, as well as local councils.

Remote sensing data from satellite imagery for the period 1985-2001 (Landsat MSS, TM, ETM) were used to generate ecosystem maps for the whole coffee region at a resolution of 1:100.000. Major ecosystem types were determined by a combination of supervised classification and manual interpretation of satellite images supplemented with secondary information and finally ground-truthing. The work was developed from a previous study on the Andes (Rodriguez et al. 2004). The areas classified as transformed by human activities were defined using spectral characteristics of deforested sites, and this category includes areas transformed by agriculture. Standard methods of analysing the accuracy of the assessment were used, based on contingency tables. For the municipality of El Cairo a more detailed interpretation was carried out (1:50,000) and we had access to information collected by Cenicafe in the 2,500ha window located within this municipality. This information included responses to a questionnaire relating to local issues highlighted by user groups in El Cairo (the interviews were conducted by Cenicafe, Botero et al, 2003).

In this report we present the results of a spatial and temporal comparative study of several social, economic, demographic and environmental variables at different scales. As previously mentioned, we examined data at multiple scales at the national level, examining two spatial extents: country level (Colombia) and the main coffee producing region, which includes all 5 coffee departments (or committees according to the variable analysed) as a whole unit; b) the regional level analysing each one of the 5 departments individually (or coffee commitees) and, c) the local level, examining one of the coffee production municipalities (El Cairo) and a local window of 2,500 ha within it. The methodological details and mathematical expressions of most of the indicators used can be found at http://www.humboldt.org.co.

2.1 Drivers of change

Ecosystem goods and services significantly contribute to the wellbeing of the human population in coffee-growing regions and to their economic productivity. However, understanding the factors that cause changes in ecosystems and how those drivers generate serious impacts that can cause environmental, economic and social imbalances in the long term is essential in the Colombian Andes, where traditional agriculture has transformed mountain ecosystems into rural landscapes. In the coffee-growing region it is relatively easy to identify indirect drivers that can have an effect, not directly on ecosystems and ecosystem services, but on those factors that directly influence ecosystem processes (so called direct drivers). Indirect drivers in the region include the economic activities of the Colombian population, and the behaviour of the population itself becomes one of the main drivers of change in natural and seminatural land cover, and is responsible for the greater use of pesticides and fertilizers, the introduction of new species, etc.

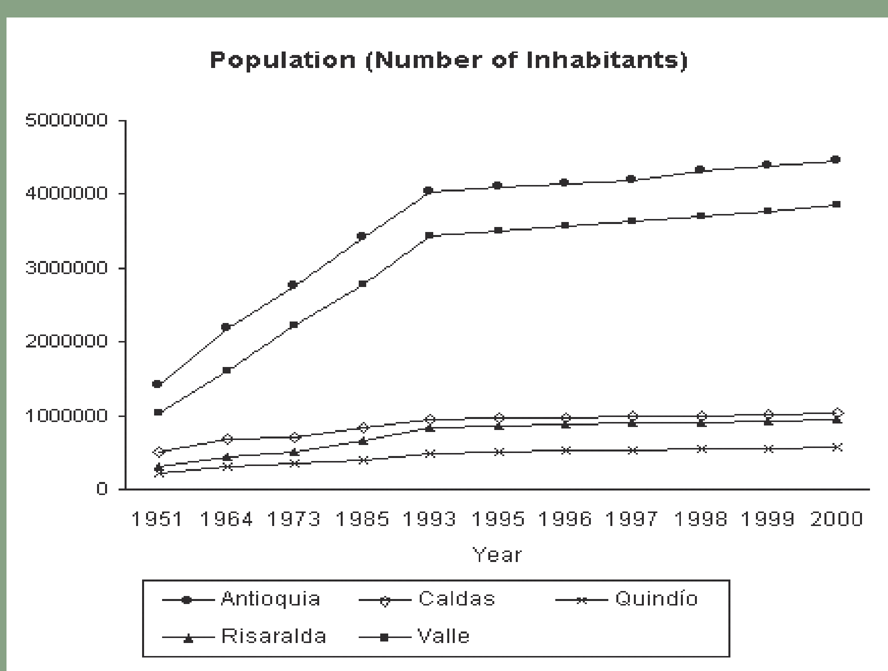
2.1.1 Indirect drivers

Demographic: total population and population density

Indicators of demographic structure were derived from the only five existing population censuses at the municipal level (years 1951, 1964, 1973, 1985 and 1993). We also used estimated population projections from the Departamento Administrativo Nacional de Estadística (DANE). We analysed information from the five coffee departmental committees (Figure 2): Antioquia, Caldas, Quindio, Risaralda y Valle. From Figure 6 it can be appreciated that there is a clear difference in population dynamics after 1951 between Antioquia and Valle and the other committees.

El Cairo, our local window, has a projected population for 1999 of 9,035 inhabitants corresponding to 0.22% of the departmental total. A total of 3,309 (36.6%) inhabitants live in the urban areas and the rest (5,726 or 63,4%) in rural areas (EOT, 2000). In fact, this municipality has had a

Figure 5. Population (number of inhabitants)



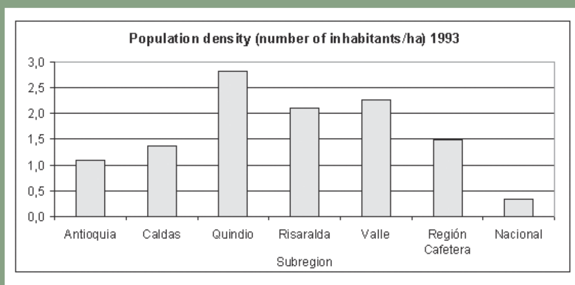
Source: DANE (1998). Fundación Social, (1998). DNP-UDS-DIOGS, (SISD) v.2, (2002). Year 2000 projection DANE

negative population growth since 1964, with a 47% decrease in population until 1999.
The population density (Figure 6) of the coffee region is much higher (1.5 inh/ha) than the national average (0.3 inhabitants/ha). Our local municipality, El Cairo has a population density similar to the national average.

Economics: economic activity indicator, national gross domestic product

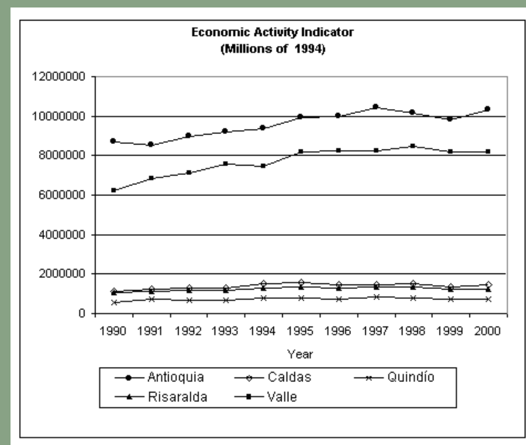
The economic activity indicator shows trends that are similar to the population indicators. The same tendency was observed in all cases: steady increases up to 1999 when the economic recession affected the coffee sector in Colombia (Figure 7). When analysing the economic activity per capita (Figure 8), this confirms the tendency reflected in both population and total economic activity. The whole region, but in particular Antioquia and Valle, have higher economic activity than the national average. Again, El Cairo is well below both the national and regional level.

Figure 6. Population density (number of inhabitants/ha)



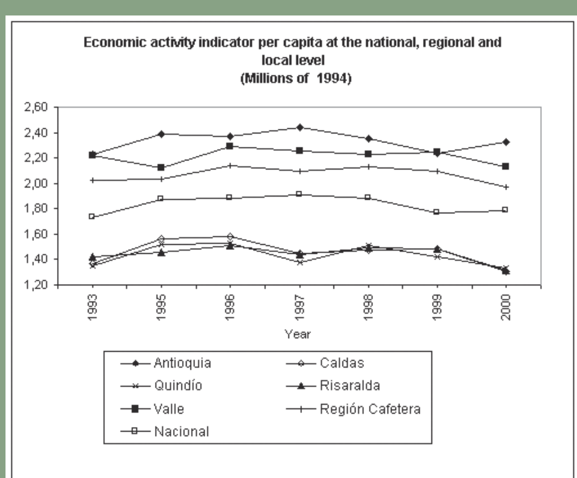
Source: DANE (1998). Fundación Social, (1998). DNP-UDS-DIOGS, (SISD) v.2, (2002). Year 2000 projection DANE

Figure 7 Economic Activity Indicator (Millions of 1994)



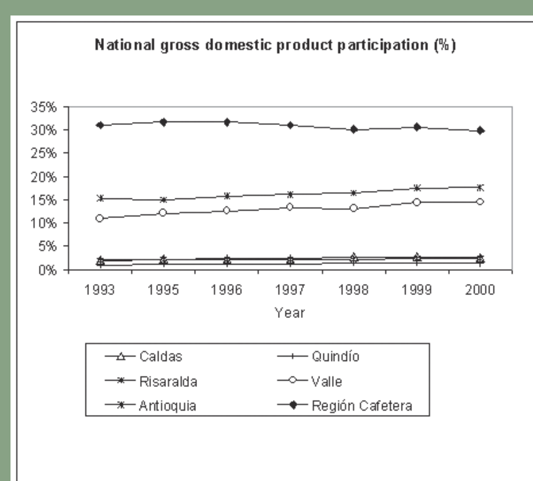
Source: DANE (2004), Humboldt Institute calculation

Figure 8. Economic activity indicator per capita at the national, regional and local level



Source: DANE (2004) – Nacional Accounts Direction

Figure 9. National gross domestic product participation (%)



Source: DANE (2004) – Nacional Accounts Direction

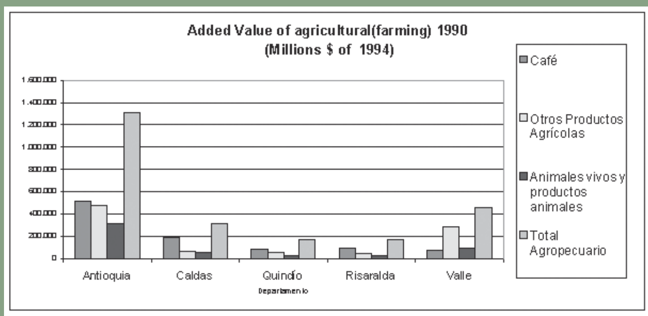
This region has an important and quite stable contribution to the national gross domestic product, 30-32% between 1993 and 2000. Again, Antioquia and Valle stand out with 15-18% and 11-14% (Figure 9). Figures 10 and 11 show the values of gross domestic product per sector in 1990 and 2000. Again Antioquia and Valle present higher values, however the composition of the GDP changes in Antioquia from coffee as the major sector in 1990 to other agricultural products in 2000. Similar trends are observed in Quindio but in el Valle coffee production increased towards 2000.

Political: environmental NGOs and other associations

The number of environmental NGOs in the region is approximately 32 in Antioquia, 57 in Quindio, 83 in Risaralda, 111 in Caldas and 192 in Valle (FNC, 1997). In El Cairo, there is a municipal Coffee Committee associated with the National Federation of Coffee Growers of Colombia. This association provides technical assistance to the coffee growers within the municipality. There are also 4 other non-coffee related agricultural organisations. El Cairo also has one ecology group and one registered environmental NGO as well as several other non-environmental associations (red cross, civil defense, third age, etc.).

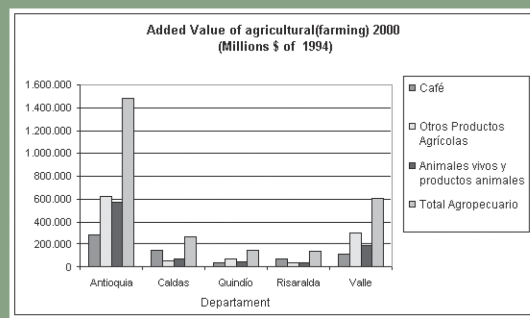
At the more local level, i.e the 2,500 ha window analysed in El Cairo, interviews covering an area of 975 ha were undertaken. A total number of 81 farmers, located between 1000 and 2000 meters above sea level, were interviewed. Most of the interviewees were associated to some kind of organization. 91,4% of the coffee growers interviewed belong to a coffee committee. From these, 21% participate in the coffee committee and are also involved in at least one more

Figure 10. Gross domestic product per sector (agriculture) in 1990



Source: Departamento Administrativo Nacional de Estadística de Colombia (DANE) – Nacional Accounts Direction

Figure 11. Gross domestic product per sector (agriculture) in 2000



Source: Departamento Administrativo Nacional de Estadística de Colombia (DANE) – Nacional Accounts Direction

organisation such as the Technical Assistance Municipal Unit, «Umata» (Unidad municipal de asistencia técnica), the Regional Environmental Authority or an NGO. Another 13,6% of them are affilliated to the coffee committee plus 2 or more additional organisations (Botero et al. 2003).

2.1.2. Direct drivers

Land cover change

In 1987 (Figure 12), transformed ecosystems covered almost 50% of the total study area and 33% of the landscape corresponded to natural ecosystems. Natural ecosystems covered only 26% of the area in the year 2000 (Figure 13) and surprisingly there is a considerable increase of semi-natural ecosystems, mainly pastures. Forest area had a particular high reduction (25%), followed by paramos (19% loss). Ecosystems with a restricted geographic distribution, mainly due to local climate and soil conditions (e.g. xerophytic vegetation), were more severely transformed with a loss of 49% in 13 years. Table 2 summarises the land cover area in both years and Figure 14 illustrates the land cover change and ecosystem loss (in red) between the year 1987 and 2000.

Figure 12. Land cover in 1987

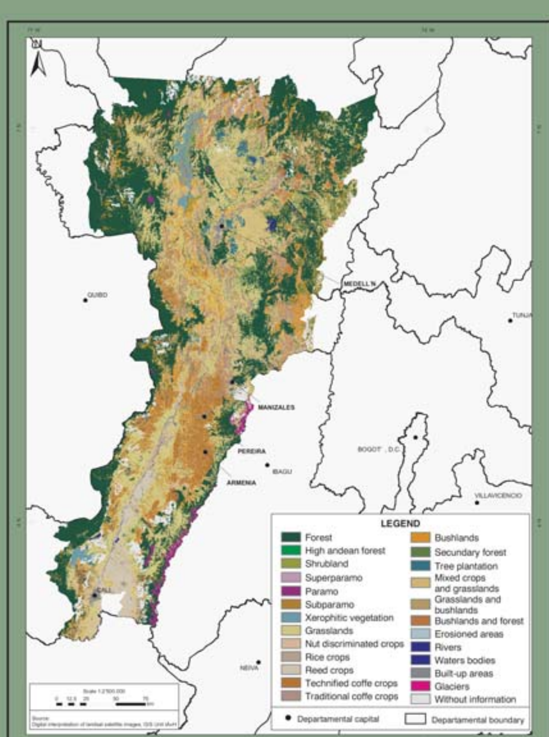


Figure 13 Land cover in 2000

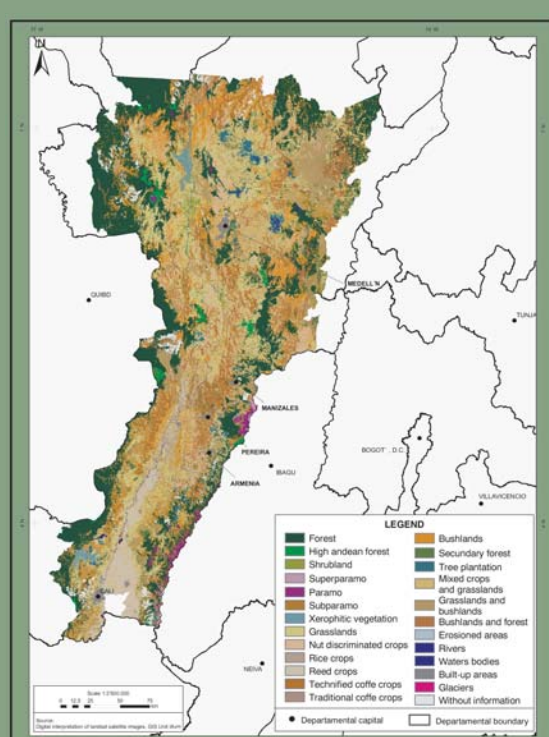
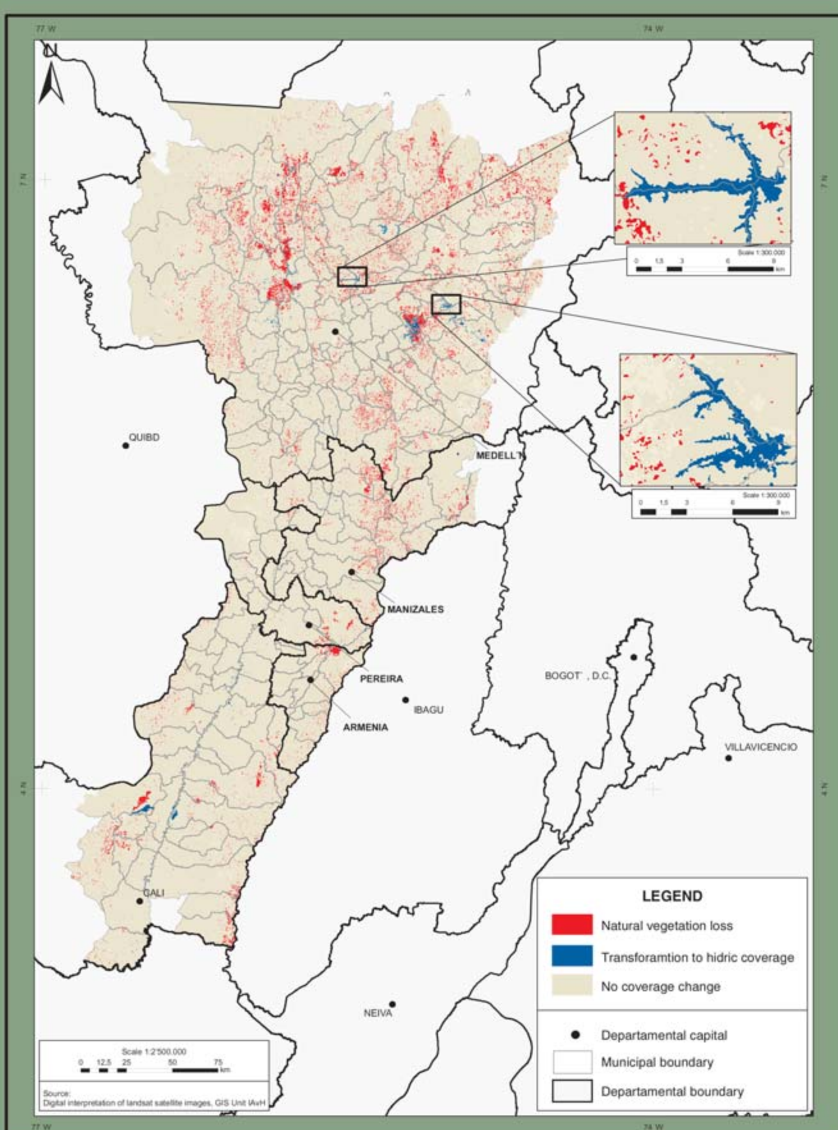


Table 2 Ecosystem cover in 1987 and 2000

ECOSYSTEM TYPE	YEAR 1987	%	YEAR 2000	%
Natural ecosystem	2.085.825	33,44	1.625.642	26,06
Semi-natural ecosystem	731.551	11,73	1.173.900	18,82
Antropic	3.123.884	50,08	3.240.609	51,95
Other	85.297	1,37	86.312	1,38
Information not available	211.244	3,39	111.338	1,78
Total	6.237.803	100	6.237.803	100

Figure 14. Land cover change between 1987 and 2000



Regarding agroecosystems, pastures (managed, non-managed and miscellaneus) are the predominant type. In 1987, pastures covered 30,25% of the study are and increased to 34,43% in 2000. This type of land cover is generally associated with small secondary vegetation fragments. Pastures are also associated with crops (25.05 % of the study area), where coffee systems are predominant.

Traditional shaded or technified coffee production systems are distributed in a belt between 900 and 2.000 meters above sea level. Coffee is found growing in three basic systems: unshaded, crop-associated, and shaded coffee. Crp-associated coffee is usually found with plantain, corn, beans and yucca, and the shaded variety is associated with native tree species. Land cover data indicates a significant reduction in shaded coffee, which has largely been transformed to other crops and pastures. This seems to be due in part to policies that promoted other types of coffee systems and conversion to pastures and other crops such as sugar cane and plantain. The drop of the international coffee price at the end of the 1980's (from above 2US$/lb to 0.6US$/lb in a year) also had a significant impact on the transformation occurred. This was appreciated with the results that showed an increase in seminatural ecosystem cover (up to 37.7%)

Table 3 and 4 summarise regional land cover. The department that shows the highest loss of natural ecosystems is Antioquia, followed by Valle del Cauca. Quindío had very little change (Table 3). The smaller departments of Caldas, Quindío and Risaralda, despite having only the 13,53% of the total natural ecosystems of the study area, have the best preserved forests in the coffee belt (the national park Los Nevados is located here).

It is very important to point out that around 50% of the study area corresponds to antropic land uses, evidence of the high pressure that forest ecosystems have endured in these regions.

Table 3 Regional level: Ecosystem cover (ha) in the coffe departments in 1987

Ecosystem type	Antioquia (ha)	%	Caldas (ha)	%	Risaralda (ha)	%	Quindío (ha)	%	Valle (ha)	%	Total (ha)
Natural ecosystem	1.470.479	70,51	108.435	5,20	124.772	5,98	49.030	2,35	332.724	15,95	2.085.442
Semi-natural ecosystem	491.046	67,13	82.646	11,30	52.579	7,19	18.100	2,47	87.145	11,91	731.519
Managed ecosystem	1.595.484	51,08	400.526	12,82	158.932	5,09	122.380	3,92	846.048	27,09	3.123.371
Other	46.256	54,24	5.993	7,03	4.714	5,53	3.301	3,87	25.015	29,33	85.281
Information not available	20.988	9,89	67.975	32,04	13.128	6,19	718	0,34	109.377	51,55	212.188
Total	3.624.255	58,10	665.577	10,67	354.127	5,68	193.531	3,10	1.400.311	22,45	6.237.803

Table 4 Regional level: Ecosystem cover (ha) in the coffe departments in 2000

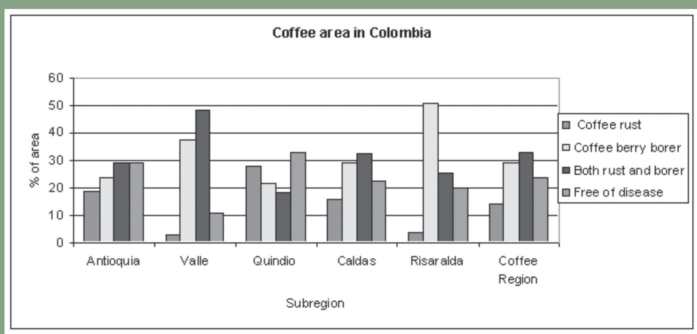
Ecosystem type	Antioquia (ha)	%	Caldas (ha)	%	Risaralda (ha)	%	Quindío (ha)	%	Valle (ha)	%	Total (ha)
Natural ecosystem	1.029.252	63,45	101.904	6,28	110.587	6,82	52.143	3,21	328.374	20,24	1.622.263
Semi-natural ecosystem	826.631	70,42	53.970	4,6	31.216	2,66	22.001	1,87	240.008	20,45	1.173.828
Managed ecosystem	1.716.423	53,39	454.689	14,14	188.911	5,88	109.478	3,41	745.141	23,18	3.214.644
Other	31.947	37,02	6.860	7,95	5.810	6,73	4.080	4,73	37.588	43,56	86.287
Information not available	20.000	14,21	48.152	34,2	17.602	12,5	5.827	4,14	49.197	34,95	140.779
Total	3.624.255	58,1	665.577	10,67	354.127	5,68	193.531	3,1	1.400.311	22,45	6.237.803

Phytosanitary aspects

About 14.29% of coffee in the region is infected by coffee rust, 29.39% by coffee-berry borer and 32.59% by both. 23.77% of the area is free of these diseases (FNC, 1997). Figure 15.

In El Cairo 92,1% of the farms have coffee rust or both coffee rust and borer and only 7,3% of the farms are disease free. These high figures have economic consequences in terms of both the production cost for farmers that decide to use chemical, mechanical or biological controls and in the economic losses for those that do not use any disease control mechanism (FNC, 1997).

Figure 15 Phytosanitary aspects per department



2.2 Ecosystem services

2.2.1 Ecosystems

As mentioned in the land use change section, this is a region highly transformed with natural ecosystems covering only 26% of the study area in the year 2000 (Figure 13). In the region studied in this assessment, there are 7 protected areas (932,296 ha) that belong to the national protected areas system in Colombia. Of these areas, only 28% (260,718ha)of their territory area are in fact embedded in the study area (they represent only 4.2%).

At the local level, in the municipality of El Cairo, 33% (7,329 ha) of the total area (22,200ha) are still under natural forest cover, although this is highly fragmented in the lower areas. The rest is under coffee (mainly shade coffee) and other agricultural systems, as well consisting of pastures and secondary vegetation. Regarding species inventories conducted in El Cairo, several ant and bird species of importance were detected. For instance amongst the 74 morpho species found in the area, *Tatuidris tatusia* was found for the first time in the southwest of Colombia. This is a species considered to be a living fossil of the Agroecomyrmecini tribe and was collected in shade coffee areas and also secondary forests. Regarding bird species, several threatened species were found such as *Grallaria guatimalensis,* usually a forest species that was found in the shade coffee plots (Botero et al. 2003). Regarding plant species, several endangered and threatened species of wax palms, orchids, and native forest endangered species were found.

2.2.2 Coffee production

Coffee fields in the region cover an area of 419,740 ha. Antioquia has the most extensive area of coffee, with 125,212 ha under coffee production (30% of the region, see Figure 16) (FNC, 1997). Coffee production in this region is principally managed by small-scale community-based growers and most properties are smaller than 3 ha. The exception is Quindio, where over 50% of the coffee production properties are bigger than 3 ha (Figure 17, Table 5).

Figure 16. Coffee area (ha) per department

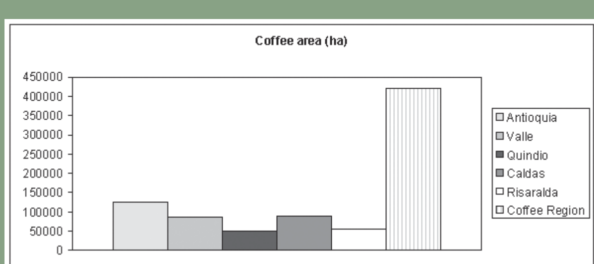
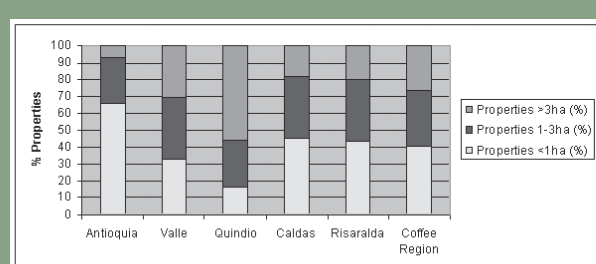


Figure 17. Distribution of coffee property size per department



As mentioned before, coffee is cultivated in Colombia under two main production systems: traditional shaded systems (67,000ha) versus «modern» systems that use a new coffee variety called caturra (300,067ha), more tolerant to direct sunlight. Other systems (crop associated coffee) have an extension of approximately 52,000ha. Rice & Ward (1997) estimated that sun coffee production made up about 40% of coffee production in Colombia, Middle America and the Caribbean. Our results suggest that 46% of coffee production in the Colombia uses the sun resistant caturra variety (Table 6).

The soils in the municipality of El Cairo have average to low fertility. The potential land use is thus shaded coffee (60-80 trees/ha) because this variety minimises soil erosion and coffee is cultivated mainly between 1350 and 1750 meters above sea level. Most coffee is cultivated under the shade of plantain and guamo and the Colombian variety of coffee predominates, followed by Caturra and older traditional systems that use Tipica and Borbon coffee varieties (FNC, 1990). In the local window analysis conducted in this municiplaity, traditional and technified

Table 5 Coffee property size (ha, between 1000 and 2000 m) and area for each coffee variety (traditional and caturra/colombia)

Departament	Properties			Properties with coffee		Area per coffee variety				
	Size (ha)	Number	% of total per region	Number	% of total per region	Traditional (ha)	% of traditional per region	Caturra/ Colom. (ha)	% of caturra per region	Total traditional and caturra (ha)
Antioquia	< 1ha	92.184	66,47	82.675	65,75	3.421,2	25,98	26069,4	23,27	29.490,6
	1 a 3	36.841	26,56	33.867	26,93	4.909,3	37,28	34.669,2	30,94	39.578,5
	3.1 a 5	5.328	3,84	5.023	3,99	1.854,6	14,08	12.717,2	11,35	14.571,8
	> 5	4.333	3,12	4.184	3,33	2.985	22,66	38.587	34,44	41.572
Caldas	< 1ha	25.537	46,67	23.129	45,42	2.407,0	14,62	7.242,8	9,66	9.649,8
	1 a 3	19.820	36,22	18.703	36,73	5.780,1	35,10	19.428,6	25,92	25.208,7
	3.1 a 5	4.913	8,98	4.749	9,33	3.140,0	19,07	11.265,2	15,03	14.405,2
	> 5	4.446	8,13	4.338	8,52	5.142	31,22	37.016	49,39	42.158
Quindío	< 1ha	1.298	16,32	1.280	16,24	208,7	2,10	469,2	1,13	677,9
	1 a 3	2.258	28,40	2.228	28,26	1.176,2	11,84	2.677,8	6,45	3.854,0
	3.1 a 5	1.237	15,56	1.229	15,59	1.219,3	12,27	3.363,4	8,10	4.582,7
	> 5	3.159	39,73	3.146	39,91	7.333	73,79	35.037	84,33	42.370
Risaralda	< 1ha	12.716	44,33	11.905	43,43	1.130,6	10,05	3.770,2	7,42	4.900,8
	1 a 3	9.640	33,60	9.254	33,76	3.075,0	27,35	9.938,6	19,56	13.013,6
	3.1 a 5	2.870	10,00	2.820	10,29	2.096,2	18,64	7.170,8	14,11	9.267,0
	> 5	3.462	12,07	3.434	12,53	4.943	43,96	29.928	58,90	34.871
Valle	< 1ha	9910	33,21	9540	32,87	1737,00	6,24	2891,80	4,68	4628,80
	1 a 3	10927	36,62	10624	36,61	6422,70	23,08	10921,70	17,69	17344,40
	3.1 a 5	3831	12,84	3753	12,93	4991,80	17,94	8409,70	13,62	13401,50
	> 5	5.170	17,33	5.103	17,58	14.680	52,75	39.515	64,00	54.195

Table 6 Area for each coffee variety Típica, Caturra and Colombia (FNC, 1997)

Localidad	TIPICA		CATURRA		COLOMBIA		TOTAL	
	Área (Hectáreas)	%	Área (Hectáreas)	%	Área (Hectáreas)	%	Área (Hectáreas)	%
Antioquia	13170	16,74	62054,1	32,1	49988,3	33,83	125212,4	29,83
Caldas	16468,7	20,94	39006,5	20,18	35946,3	24,32	91421,5	21,78
Quindío	9937,3	12,63	23411,1	12,11	18135,90	12,27	51484,3	12,27
Risaralda	11244,6	14,3	27765	14,36	23042,4	15,59	62052	14,78
Valle del Cauca	27831,3	35,39	41074,2	21,25	20664	13,98	89569,5	21,34
Total departamento	78651,9	100	193310,9	100	147776,9	100	419739,7	100
El Cairo	2464,8	3,13	1744,2	0,90	679,5	0,46	4888,5	1,16

coffee were both present: 599.6 ha are under traditional coffee systems (with an average age of 20 years old) and 24.8ha are under technified coffee systems (with 0,6 years old as average age) (Botero et al, 2003). 26.7% of the properties under coffee production in the area located in this window operate under a conservation coffee program funded by Conservation International(Table 7). 20.1% of the average coffee farm area is used for cattle ranching. Other production systems found are pig, fish and chicken farms and banana crops (Botero et al. 2003). Maize, corn, beans and yucca were also found as alternative products. Only 7 out of 81 farms had forest fragments covering a very small area of 7.5ha. In 47 out of 81 farms there are some guadua (bamboo) trees (11.7 ha) (Botero et al. 2003). Table 8 summarises the distribution and extension of farm size and productive systems in El Cairo.

Table 7 Conservation farms in 2500 ha local window (Botero et al, 2003)

VEREDA	ÁREA (ha)
Costa Seca	4
El brillante	6,5
El Edén	53,5
La Laguna	32
La Palmera	19
Nápoles	5,52
San Jose del Cairo	106,73

Table 8 Coffee farms properties in El Cairo. National Coffee census, SICA (FNC, 1997)

Ranch size (ha)	Number of ranchs	Percentage	Area Ander coffe/ranch	Ranch area (ha)					
				Forests	Associated crops	Pastures	Caturra variety coffee	Typical variety coffee	Total crops
Menos de 1	154	15%	94%	0	0	2,2	34,1	32,5	79,7
1 a 3	219	22%	80%	1	0,5	52,3	128,8	180	432,2
3.1 a 5	156	16%	76%	0	0,2	82,8	141,3	278,1	624,7
Más de 5	467	47%	60%	8,6	8,1	2835,1	1440	1974,2	8801,8
Total	996	100	72%	9,6	8,8	2972,4	1744,2	2464,8	9938,4

2.3 Human wellbeing

2.3.1 Population quality of life and % of households with unsatisfied basic needs

There are similar trends in both the indicators of quality of life and percentage of households with unsatisfied basic needs. These indicators have values of 72-78% and 18-25%, both values are quite close to the national average, but again the regional values indicate better quality of life than the Colombian mean (71% quality of life index, 31% unsatisfied basic needs) (Figure 18). Urban and rural areas also present regional differences but clearly indicate that rural areas are those with lower quality of life (Figure 19).

Figure 18 Quality of life (ICV) and unsatisfied basic needs (NBI)

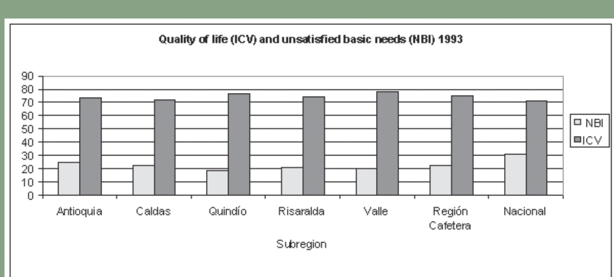
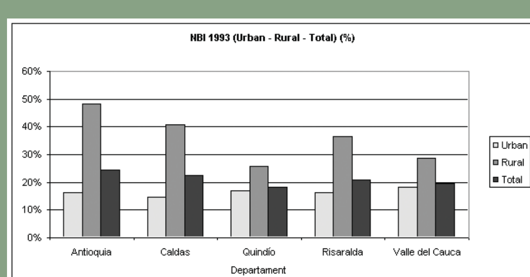


Figure 19 Unsatisfied basic needs (NBI)



Yet again, in el Cairo, the results are different from those at the regional level, and show values of 56% quality of life index and 39% of households with unsatisfied basic needs (Figure 18). 1997 coffee census data (FNC, 1997) indicated a 55.31% value in the latter index.

In el Cairo, there are 2098 households, 718 (34.2%) of which are urban and 1380 (65.8%) rural. (EOT, 2000). 12.50% of the population does not go to school. The poverty index is of 34.17% and the misery index goes up to 10.52% (FNC, 1997).

Regarding land tenure, property is mainly owned by individuals (85.2% only one owner). Family property was found in 9.9% of the farmers interviewed and farms owned by societies represent only 3.7% of the properties in el Cairo (Botero et al, 2003).

Regarding accessibility to electricity, 86.85% of households have access to electricity and only 1.94% have phone lines. Only 0.93% of rural households have access to some kind of sewer system although 25.97% have aqueducts. 11.38% of rural households do not have any kind of basic services (FNC, 1997).

2.3.2 Poverty line

We also analyzed the percentage of people below the poverty line and its evolution between 1996 and 2000. There is an increasing trend of people below the poverty line from 1997 onwards in all departments (Figure 20). The current rate of unemployment in the rural population of El Cairo is 31% according to interviews conducted by the NGO Corposerraniagua.

2.3.3 Mortality rates per cause of death

Three different mortality factors were analyzed: digestive chronic disease, acute breathing problems and violence. There is an exceedingly high number of violent deaths in Antioquia (31%) followed by Valle. In fact 4 out of 5 departments have a higher value of violent deaths than the national average. The other two indicators have a more steady behaviour over the region. For all three mortality factors, El Cairo stands out for being different; this municipality has lower values than national and regional averages.

2.3.4 Education: Illiteracy rate, levels of education

The illiteracy rate oscillates between 5 and 8% in the region, below national level that has an average of 10%. Male illiteracy rates are generally higher than female rates. El Cairo shows a 14% illiteracy rate, well above both regional and national levels (Figure 21). Another figure from the national coffee census indicates a 22.95% illiteracy rate in El Cairo (FNC, 1997). This municipality has 38 rural schools and 3 urban schools. According to the coffee census, 21.5% of the rural population has no educational level, 71.6% primary, 6.5% secondary and 0.05% of the population has a higher-level or university education.

Figure 20. Percentage of people below the poverty line

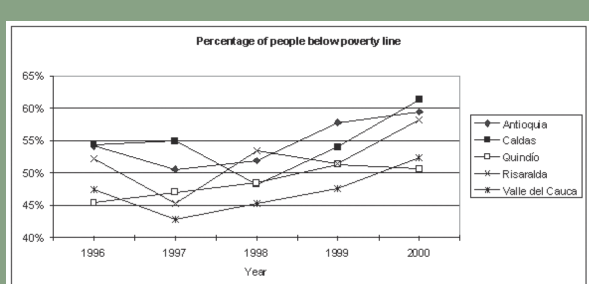
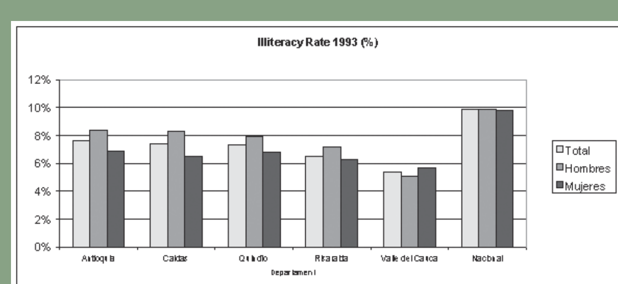


Figure 21 Illiteracy rates



2.4 Correlation analysis with and without spatial autocorrelation considerations

2.4.1 Methodological aspects

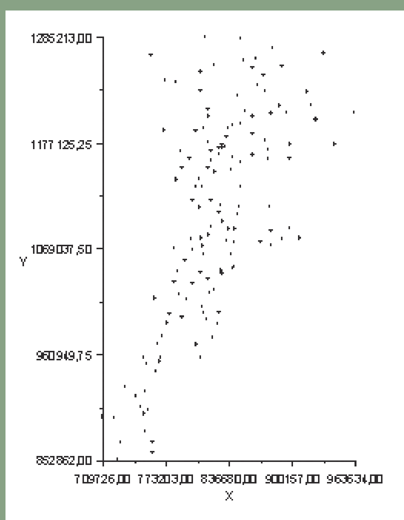
Maps of deforestation were produced for each of the pilot areas (Figure 14). In order to facilitate reporting, ecosystem classes were aggregated into a) biomes amd b) three major ecosystem types (natural, semi-natural and transformed). Any kind of landscape dominated by land uses associated with agriculture, pasture or urban sites were assigned the category of transformed ecosystems.

The smallest spatial unit for which most socio-economic and demographic data is available is the *municipio*, a purely administrative boundary. In order to analyze the impact of human pressures on natural ecosystems and the possible determinants of ecosystem change we undertook correlation analysis using the Pearson correlation coefficient with and without considering spatial autocorrelation

We analyzed the correlation amongst 60 environmental, demographic and socio-economic variables in 139 municipalities, some of which were analysed in different moments in time (see list in Appendix). Municipalities were considered as spatial units when taking into account the spatial autocorrelation in the analysis and the geographical coordinates of the urban area were considered the gravitational center (Figure 22 and Appendix 2 explains the methodological aspects of this analysis).

2.4.2 Results

Figure 22. Gravity centers of the urban areas



Pearson correlation (without spatial autocorrelation)

The unsatisfied basic needs index (NBI, 1993) has a statistically significant and positive correlation (direct) with natural and seminatural cover for both years analysed (1987, 2000). Conmplementary to this result, the quality of life index for 1993 (ICV, 1993) presented an inverse negative and also significant correlation with the same variables. These results might indicate that the areas better preserved coincide with higher values of unsatisfied basic needs and lower levels of quality of life, and higher poverty areas. This is confirmed by the positive correlations found between natural and seminatural cover and misery and poverty indicators.

On the other hand, and not surprisingly, transformed areas coincide with areas of high population density (5% significance for 1993 and 2000). Furthermore transformed areas also show significant correlation with the number of agricultural production units (*unidades de produccion agropecuaria* or UPAS), number of small holdings and number of farms per municipality. In addition the result is also significantly correlated with the violence index (1995). Clearly, population pressure and economic activity are influencing the transformation of natural cover to transformed ecosystems in the area.

Another interesting result shows that the natural cover has a direct and significant correlation with the number of displaced people. This might be due to the fact that those areas are generally identified as zones of lower quality of life with a general absence of public forces, which has led in some areas to the establishment of outlaw groups. The misery indicator is also correlated with the number of displaced people - the poorer the area, the higher the displaced population.

Looking at education variables, better-preserved areas are associated with lower levels of education. This is confirmed by the inverse correlation found between levels of secondary and higher education with natural and seminatural ecosystem cover. Education indicators have also a clear positive correlation with the economic activity index and an inverse correlation with poverty and misery indicators.

The results also show direct correlation between the percentage change of economic activity (1993-2000) and percentage change in natural cover between 1987 and 2000. Yet again this confirms the evidence of the pressure that economic activities have on natural ecosystems.
Slope was significantly correlated to areas with higher values of natural and seminatural ecosystem cover, indicating that the better preserved areas are located in less accessible areas with lower soil productivity potentially due to the steep slopes.

Another significant and positive correlation was found between population, economic activity and water scarcity index. This might be indicative of the pressure that urban areas and their activity levels have on ecosytem services such as water availability.

The economic activity index is significantly and directly correlated with the GINI coefficient. This indicate that the richer the municipality, the higher the inequity. GINI shows an inverse correlation with the quality of life, probably indicating that the higher inequity, the lower quality of life for the population. This GINI index also shows a direct correlation with the water scarcity index.
The results of all the analysis that does not take into account spatial autocorrelation have been published in Colombia as Rincon et al (2004).

Pearson correlation (with spatial autocorrelation)

Figures 22 and 23 illustrate the spatial autocorrelation analysis of two variables: economic activity per capita (Figura 22) and percentage of natural cover in 1987 (Figure 24).

Figure 23.Spatial distribution of the variable economic activity per capita (year 1993)

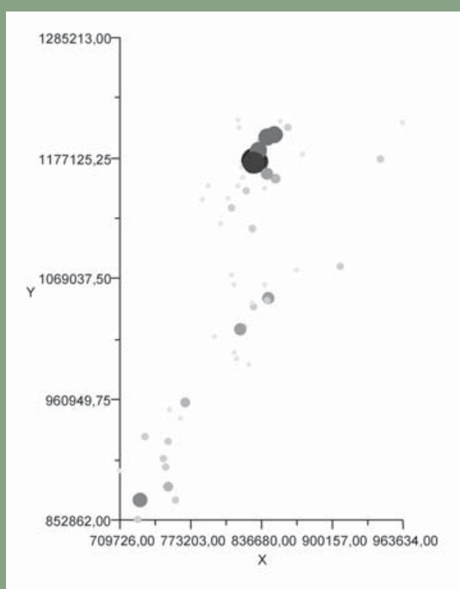
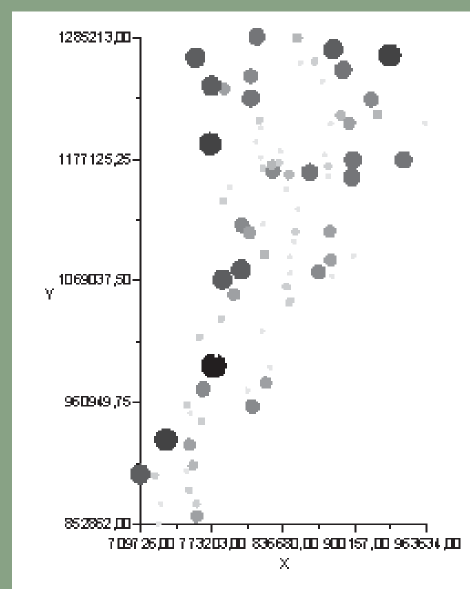


Figura 24. Spatial distribution of the percentage of natural ecosystem in 1987



We compared the correlation results with and without spatial autocorrelation, and most correlations were confirmed (Table 9), although some correlations differ. Table 10 summarises the results with a focus on those associated with natural and antropic land cover. Appendix 2 describes the meaning of each one of the variables.

Table 9. Pearson correlations and comparison of the probabilities associated to the statistic test. Significancy with both tests with and without spatial autocrrelation considerations

Variable 1	Variable 2	Pearson correlation	Probabiliy associated to the test estadistic – CRH adjustment	Probabiliy associated to the test estadistic – Dutilleul adjustment	Change in the significancy (-): loss y (+): gains signif-
INDIECO93	POB00	0,9887	0	0	0
INDIECO93	EDU SECUN SICA	0,2526	0,0027	0,0059	0,0059
INDIECO93	POBREZA SICA	-0,187	0,0275	0,0371	0,0374
INDIECO00	POB00	0,9721	0	0	0
INDIECO00	EDU SECUN SICA	0,2377	0,0048	0,0087	0,0087
POB93	INDEPERCAP00	0,3929	0	0	0
POB93	INDEPERCAP93	0,4126	0	0	0
POB00	IEAGUAMED96	0,3865	0	0	0
INDPERCAP93	PNBI93	-0,6147	0	0	0
INDPERCAP93	ICVTOT93	0,6733	0	0	0
INDPERCAP00	PNBI93	-0,5509	0	0	0
INDPERCAP00	ICVTOT93	0,6571	0	0	0
PNBI93	ICVTOT93	-0,8529	0	0	0
PNBI93	PEND ESCARP	0,4855	0	0	0
PNBI93	CN87	0,4159	0	0,0001	0
PNBI93	SN87	0,5617	0	0,0004	0
PNBI93	CNSN87	0,4604	0	0,0001	0
PNBI93	CN00	0,3583	0	0,0001	0,0001
PNBI93	SN00	0,5308	0	0	0
PNBI93	CNSN00	0,4242	0	0	0
ICVTOT93	CN87	-0,2794	0,0009	0,0068	0,0044
ICVTOT93	SN87	-0,4277	0	0,0044	0,0013
ICVTOT93	CNSN87	-0,3167	0,0001	0,004	0,0021
ICVTOT93	CN00	-0,234	0,0056	0,0112	0,0095
ICVTOT93	CNSN00	-0,2761	0,001	0,0036	0,0025
VIOL95	CA87	-0,2242	0,008	0,027	0,0264
DESPL02EXP	CA87	0,2528	0,0027	0,0098	0,0095
DESPL02EXP	CN87	0,312	0,0002	0,0005	0,0005
DESPL02EXP	SN87	0,3822	0	0	0
DESPL02EXP	CNSN87	0,3397	0	0,0002	0,0002
DESPL02EXP	CA00	0,2383	0,0047	0,0156	0,0153
DESPL02EXP	CN00	0,3023	0,0003	0,0007	0,0007
DESPL02EXP	SN00	0,4178	0	0	0
DESPL02EXP	CNSN00	0,3495	0	0,0001	0,0001
ED NING SICA	CN87	0,4153	0	0,0001	0,0001
ED NING SICA	CN00	0,3843	0	0,0002	0,0002
ED NING SICA	SN00	0,5415	0	0	0
ED NING SICA	CNSN00	0,4472	0	0,0001	0
EDU SECUN SICA	CN87	-0,2303	0,0064	0,0087	0,0086
EDU SECUN SICA	CNSN87	-0,2499	0,003	0,0049	0,0048
EDU SECUN SICA	SN00	-0,273	0,0011	0,0024	0,0023
EDU SECUN SICA	CNSN00	-0,2349	0,0054	0,0071	0,007
PEND ESCARP	CN87	0,8957	0	0	0
PEND ESCARP	SN87	0,6865	0	0	0
PEND ESCARP	CNSN87	0,9148	0	0	0
PEND ESCARP	CN00	0,8933	0	0	0
PEND ESCARP	SN00	0,8386	0	0	0
PEND ESCARP	CNSN00	0,9218	0	0	0
CA87	CN87	0,4373	0	0	0
CA87	CN00	0,4598	0	0	0

Table 10. Pearson correlations and comparison of the probabilities associated toe the statistic test. Differences in significancy between both tests with and without spatial autocrrelation considerations

Variable 1	Variable 2	Pearson correlation	Probabiliy associated to the test estadistic – CRH adjustment	Probabiliy associated to the test estadistic – Dutilleul adjustment	Change in the significancy (-): loss y (+): gains signif-
INDIECO93	CA00	0,0273	0,7498	0,766	0,7655
INDIECO00	CA00	0,0421	0,6226	0,644	0,6434
POB93	CA87	0,1612	0,0579	0,0708	0,0704
POB93	CA00	0,07	0,4128	0,4441	0,4434
INDPERCAP93	CN87	-0,1585	0,0623	0,0873	0,0883
INDPERCAP00	CN00	-0,0518	0,5446	0,5685	0,5679
EDU PRIMA SICA	CNSN87	-0,0844	0,3231	0,3473	0,344
POBREZA SICA	CN87	0,1562	0,0663	0,1033	0,0989
POBREZA SICA	CN00	0,1192	0,1621	0,2056	0,2022

Appendix III illustrates how to make adjustments when taking into account spatial autocorrelation.

3. Synthesis

This assessment addressed only a limited number of issues, we mainly undertook a spatial temporal comparative study of several social, economic, demographic and environmental variables at different scales. This assessment aims to offer region-specific information to support decision-making in the area. It focuses on both quantifying ecosystem and population changes and the changes in the structure of ecosystems that have taken place over time in the area. It also points out how they might be related to changes in the demographic and economic structure of this area. In order to analyze the impact of human pressures on natural ecosystems and the possible determinants of ecosystem changes we undertook correlation analysis with the results presented above.

This assessment was self funded by Humboldt Institute and this meant the possibility of only undertaking a quick overview of the situation in coffee systems in Colombia. Biodiversity inventories at the species level were not undertaken and in fact the only primary information processed and obtained from remote sensing with some field work was land cover and land use for the years 1987 and 2000. Nevertheless the assessment allowed us to start testing different analytical approaches that will need further development. Also the scale effect and the implications for the measures and analysis undertaken, and the effects of spatial autocorrelation have not been deeply explored.

Considering the fact that the coffee growing region is affected strongly by human activities but is also an important area for biodiversity conservation, future assessment work will include an analysis of future scenarios and potential responses, which will be an essential part of the work in order to have a greater impact on the main stakeholders of the coffee sector, the National Federation of Coffee Growers of Colombia.

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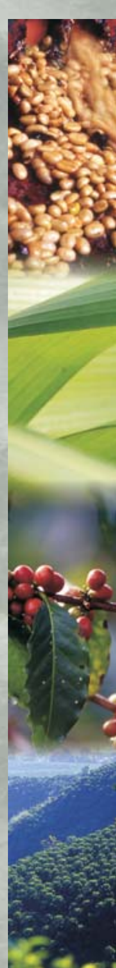

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Appendix I. List of variables used in correlation analysis, abbreviations used and sources

#	Variables	Variable	Source
1	INDIECO93	Actividad Económica - 1993	Dane, estimación Instituto Humboldt
2	INDECO00	Actividad Económica - 2000	Dane, estimación Instituto Humboldt
3	INDIECAMB	Cambio Actividad Económica - (1993 -2000)	Dane, estimación Instituto Humboldt
4	POB93	Población (Número de habitantes) 1993	Dane
5	POB00	Población (Número de habitantes) 2000	Dane
6	POBCAMB	Cambio de Población - (1993 - 2000)	Dane, estimación IAVH
7	INDPERCAP93	Per-cápita Actividad económica - 1993	Dane, estimación IAVH
8	INDPERCAP00	Per-cápita Actividad económica - 2000	Dane, estimación IAVH
9	INDEPER CAMB	Cambio Per-cápita Cambio Actividad Económica (1993 - 2000)	Dane, estimación IAVH
10	GINI97	GINI - 1997	Federación Nac. de Cafeteros
11	PNBI93	Porcentaje NBI - 1993	Dane
12	ICVTOT93	Indice de Condiciones de Vida - 1993	DNP
13	EAR95	Causas de Mortalidad aparato Respiratorio (%)- 1995	DNP-UDS-DIGS-SISD
14	EAD95	Causas de Mortalidad aparato Digestivo (%)- 1995	DNP-UDS-DIGS-SISD
15	VIOL95	Causas de Mortalidad por Violencia (%) - 1995	DNP-UDS-DIGS-SISD
16	DESPL02EXP	Número de Hogares Expulsados - Desplazados - 2002	Presidencia de la República – Red de solidaridad social
17	IEAGUAMED96	Indice de Escasez de Agua -Período Medio - 1996	Ideam
18	IEAGUASEC96	Indice de Escasez de Agua -Período Seco - 1996	Ideam
19	HOMIC93	Número de Homicidios - 1993	Fundación Social
20	CAPFIN93	Captaciones Financieras - 1993	Fundación Social
21	MINPOR95	Porcentaje de Minifundios - 1995	IICA y Ministerio de Agricultura
22	PASTOS97	Pastos (% -?) - 1997	
23	PASTOS00	Pastos (%-?) - 2000	
24	DENPO93	Densidad de Pobloación 1993	Dane, estimación Instituto Humboldt
25	ED NING SICA	Porcentaje Sin Educación	SICA
26	EDU PRIMA SICA	Porcentaje Educación Primaria	SICA
27	EDU SECUN SICA	Porcentaje Educación Secundaria	SICA
28	EDU UNIV SICA	Porcentaje Educación Universitaria	SICA
29	POBREZA SICA	Porcentaje de Pobreza	SICA
30	POBREZA SICA	Porcentaje de Miseria	SICA
31	Gasto Amb 97 (no)	Gasto Ambiental - 1997	Controlaría General de la República
32	Gast Amb 98	Gasto Ambiental - 1998	Controlaría General de la República
33	Gasto Amb 01	Gasto Ambiental - 2001	Controlaría General de la República
34	pend escarp	Area de pendiente escarpada - 2000	IGAG-Corpoica
35	CA87	Area Cobertura Antrópica - 1987	Instituto Humboldt
36	CN87	Area Cobertura Natural - 1987	Instituto Humboldt
37	CO87	Area Otras Coberturas - 1987	Instituto Humboldt
38	SN87	Area Cobertura Seminatural - 1987	Instituto Humboldt
39	SI87	Area Cobertura Sin Información - 1987	Instituto Humboldt
40	CNSN87	Area Natural + Seminatural -1987	Instituto Humboldt
41	TOT87	total de Cobertura municipal - 1987 -	Instituto Humboldt
42	PCA87	Porcentaje de Area Cobertura Antrópica - 1987	Instituto Humboldt
43	PCN87	Porcentaje de Area Cobertura Natural - 1987	Instituto Humboldt
44	PCO87	Porcentake de Area Otras Coberturas - 1987	Instituto Humboldt
45	PSN87	Porcentaje de Area Cobertura Seminatural - 1987	Instituto Humboldt
46	PSI87	Porcentaje de Cobertura Sin Información - 1987	Instituto Humboldt
47	PCNSN87	Porcentaje de Area Natural + Seminatural -1987	Instituto Humboldt
48	CA00	Area Cobertura Antrópica - 2000	Instituto Humboldt
49	CN00	Area Cobertura Natural - 2000	Instituto Humboldt
50	CO00	Area Otras Coberturas - 2000	Instituto Humboldt
51	SN00	Area Cobertura Seminatural - 2000	Instituto Humboldt
52	SI00	Area Cobertura Sin Información - 2000	Instituto Humboldt
53	CNSN00	Area Natural + Seminatural - 2000	Instituto Humboldt
54	TOT00	total de Cobertura municipal - 2000-	Instituto Humboldt
55	PCA00	Area Cobertura Antrópica - 2000	Instituto Humboldt
56	PCN00	Porcentaje de Area Cobertura Natural - 2000	Instituto Humboldt
57	PCO00	Porcentake de Area Otras Coberturas - 2000	Instituto Humboldt
58	PSN00	Porcentaje de Area Cobertura Seminatural - 2000	Instituto Humboldt
59	PSI00	Porcentaje de Cobertura Sin Información - 2000	Instituto Humboldt
60	PCNSN00	Porcentaje de Area Natural + Seminatural - 2000	Instituto Humboldt

Appendix II Methodological aspects of Pearson correlation with spatial autocorrelation considerations

For each pair of variables the Pearson correlation coefficient is estimated from the pairs . $(i = 1,2,...,n)$.

$$r = \frac{S_{xy}}{S_x S_y}$$

Where:

$$S_{xy} = \frac{1}{n-1}\left(\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)\right)$$; X and Y estimated covariance

$$S_x = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}$$; X estimated standard deviation (the same, S_y for variable Y)

In order to take into account the spatial correlation structure, a distance *D* matrix was defined, for each pai of gravity centers *(i, j)* with geographic coordinates (x_i', y_i') y (x_j', y_j'). The Euclidean distance between the centers is define as

$$d(i, j) = \sqrt{(x_i' - x_j')^2 + (y_i' - y_j')^2}$$

The whole group of distances were divided into stratus (distance intervals) S_0, S_1, S_2, ...,

(x_i, y_i)

Within each stratum (*k* = 0, 1, 2, ...,) the spatial assocoation is estimated using all the pairs of that stratum (A_k) following the next example for variable *Y*:

$$\hat{C}_y(k) = \frac{\sum_{A_k}(y_\alpha - \bar{y})(y_\beta - \bar{y})}{n_k},$$

the subíndices (α, β) represente two gravity centers belonging to the *k* stratum.

Taking into account the spatial correlation, the estimated variante is:

$$\hat{\sigma}^2_r = \frac{\sum n_k \hat{C}_x(k)\, \hat{C}_y(k)}{n^2 S^2_x S^2_y}$$

where:

$$\hat{C}_x(k) = \frac{\sum_{A_k}(x_\alpha - \bar{x})(x_\beta - \bar{x})}{n_k}$$, permite estimar la correlación espacial teniendo en cuenta la variable *X*

$$\hat{C}_x(k) = \frac{\sum_{A_k}(y_\alpha - \bar{y})(y_\beta - \bar{y})}{n_k}$$, permite estimar la correlación espacial teniendo en cuenta la variable *Y*

Por lo tanto, se define una prueba t modificada con $\hat{M} - 2$ grados de libertad, $\hat{M}$ donde se estima como:

$$\hat{M} = 1 + \sigma_y^{-2}$$

a $\hat{M}$ se le denomina tamaño de muestra efectiva o equivalente, cuando se presenta una estructura de correlación espacial generalmente $\hat{M} > n$, si una de las variables presenta una estructura de autocorrelación negativa se espera que $\hat{M} < n$.

De esta forma los valores críticos correspondientes a una esta prueba t modificada sufren un ajuste comparados con la prueba t que no considera la estructura de correlación espacial de cada indicador (variable). Ver gráfico 1.

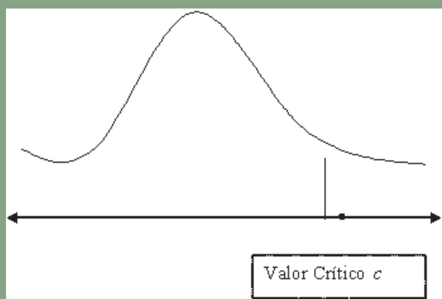


Gráfico 2. Distribución del estadístico de prueba, distribución t con $n-2$ grados de libertad, el punto en el eje horizontal indica un posible valor del estadístico de prueba, en este caso la regla de decisión sería rechazar la hipótesis nula, por lo tanto, la correlación entre las variables X y Y es significativamente diferente de cero.

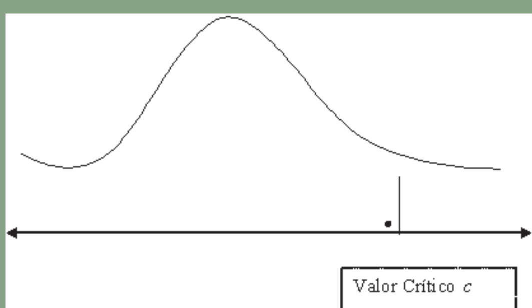
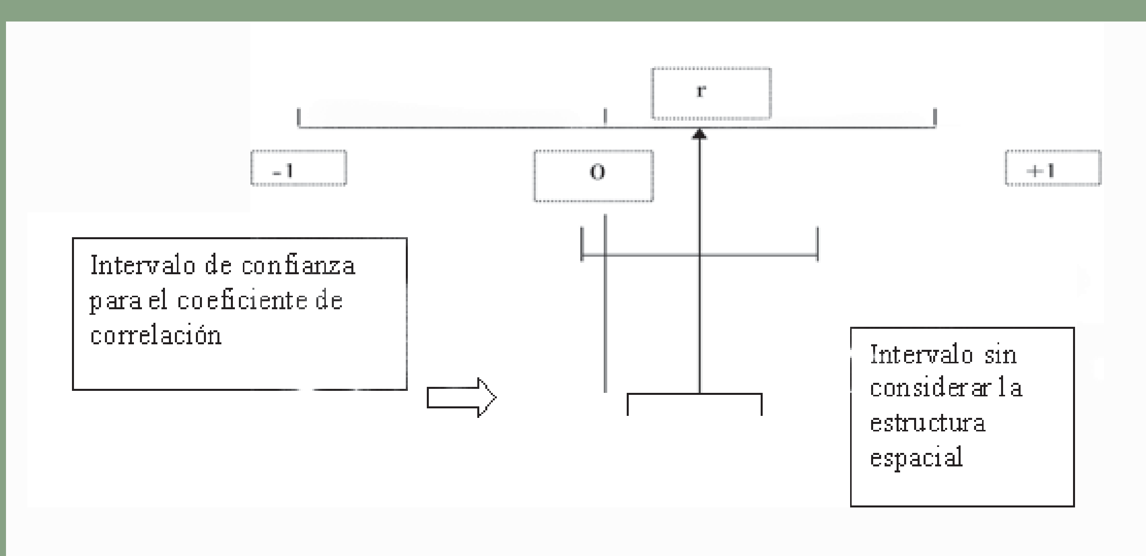


Gráfico 3. Distribución del estadístico de prueba, distribución t con $\hat{M}-2$ grados de libertad, el punto en el eje horizontal indica un posible valor del estadístico de prueba, en este caso la regla de decisión sería no rechazar la hipótesis nula, por lo tanto, la muestra empleada no nos da una evidencia que nos permita rechazar la hipótesis nula.

En el gráfico siguiente se presenta las posibles implicaciones en la significancia del coeficiente de correlación. La primera situación representa el caso de incluir la estructura de correlación espacial en la cual la muestra de datos empleada nos da una evidencia para no rechazar la hipótesis nula, es decir, que el coeficiente de correlación sería estadísticamente igual a cero. Puesto que el intervalo de confianza para r contiene el cero.

Para la segunda situación que se supone que no se está considerando la estructura de correlación espacial, por lo tanto, en este caso, la regla de decisión sería rechazar la hipótesis nula, es decir, el coeficiente de correlación sería diferente de cero[1].

Gráfico 4. Efectos de la autocorrelación espacial sobre las pruebas de significancia de coeficientes de correlación, tomada de (Legendre, 1993).



[1] Ver Legendre, P. & Legendre, L., 2000, Numerical Ecology. Pags. 12-16.

Appendix III. Example of adjustment taking into account the spatial autocorrelation

Ejemplo etapas para realizar el ajuste teniendo en cuenta la estructura de correlación espacial

Con el propósito de detallar los aspectos implícitos en el ajuste de los estadísticos de prueba (ajuste de los grados de libertad) incluyendo la estructura de correlación espacial, se describen los siguientes pasos.

- Cálculo de distancias entre los pares de centros de gravedad

Teniendo en cuenta que son 139 municipios, se calculan las 9591 pares de distancia, correspondientes al total de parejas posibles, obtenidas de la combinatoria,

$$\binom{139}{2} = \frac{139!}{137!2!} = \frac{139*138}{2} = 9591$$

Por ejemplo, si tenemos cuatro municipios:

Tabla 1. Coordenadas planas – centros de gravedad de cuatro cabeceras municipales

DEPARTAMENTO	MUNICIPIO	X	Y
VALLE	Alcala	810840,61	1008863,85
ANTIOQUIA	Alejandria	882273,40	1196914,08
ANTIOQUIA	Amaga	820162,16	1159537,66
ANTIOQUIA	Amalfi	889908,62	1255657,03

Para hallar la distancia entre pares de municipios (expresada en metros), se realiza, así:

$$d(Alcalá, Amaga) = \sqrt{(810840,61 - 820162,16)^2 + (1008863,85 - 1159537)^2} = 150961,87$$

Es decir, 150,96 kilómetros.

- Intervalos de distancia

Después de realizar este cálculo del total de pares de distancias, se establece el rango de las distancias como la diferencia entre el par de centros de gravedad con distancia mayor y el par de centros de gravedad con distancia menor. De esta manera definimos 20 intervalos con igual cantidad de parejas de distancias, de acuerdo a la tabla siguiente:

Tabla 1. Coordenadas planas – centros de gravedad de cuatro cabeceras municipales

#	Intervalos (metros)		#	Intervalos (metros)	
1	0,0	28298,4	11	123574,8	135808,6
2	28298,4	40636,4	12	135808,6	149120,5
3	40636,4	51219,6	13	149120,5	163709,7
4	51219,6	62002,4	14	163709,7	179824,8
5	62002,4	72342,3	15	179824,8	197633,6
6	72342,3	82506,4	16	197633,6	218574,9
7	82506,4	92463,4	17	218574,9	243149,1
8	92463,4	102526,7	18	243149,1	276060,9
9	102526,7	112751,9	19	276060,9	321549,3
10	112751,9	123574,8	20	321549,3	464218,0

Al interior de cada intervalo aproximadamente se encuentran 480 parejas de distancias.

· Estimación de la estructura de correlación espacial

Se emplea el Indice de Moran para medir la estructura de correlación espacial, por ejemplo para el Indicador de actividad económica per cápita, se presenta el indice de Moran, se observa que para los dos primeros intervalos definidos arriba la estructura de correlación es positiva (1,16 y 0,059), para los intervalos del 3 al 10, la estructura de correlación es negativa (-0.104, -0.078, -0.181, -0.162, -0.148, -0.188, -0.062, -0.031). (ver gráfico 1).

Para el indicador de porcentaje de área de cobertura natural para el año de 1987, se presenta la estructura de correlación, se observa que para los primeros tres intervalos la correlación espacial es positiva (0.163, 0.024, 0.072). (ver gráfico 2).

Gráfico 1 . Correlograma para el Indicador de Actividad económica pér capita 1993

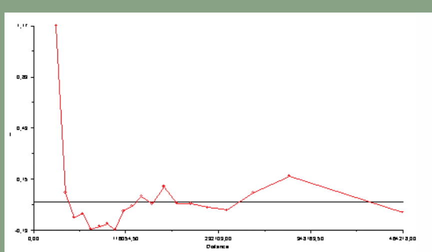
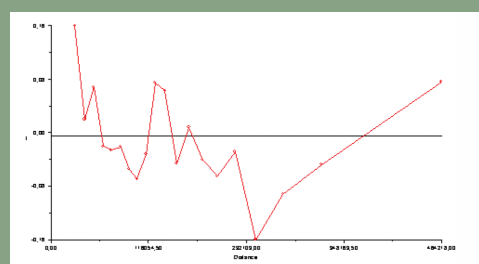


Gráfico 2. Correlograma para el Indicador de Porcentaje de Cobertura Natural -1987



· Ajuste del valor de probabilidad asociada al estadístico de prueba y regla de decisión

Para el par de indicadores señalados arriba el coeficiente de correlación de Pearson estimado es -0.1693, se presentan los valores de las probabilidades asociadas sin considerar la estructura de correlación espacial y se comparan con los valores de dichas probabilidad considerando dicha estructura de correlación.

Tabla 3. Correlación de Pearson y comparaciones de las probabilidades asociadas a los estadísticos de prueba

Indicador 1	Indicador 2	Correlación de Pearson	Probabilidad asociada al valor crítico, sin ajuste - correlación espacial	Probabilidad asociada al valor crítico – Ajuste CRH	Probabilidad asociada al valor crítico – Ajuste Dutilleul
INDPERCAP93	PCN87	-0,1693	0,0463	0,1353	0,1343

- Sin considerar la estructura de correlación espacial

La probabilidad asociada al estadístico de prueba sin considerar la estructura de correlación espacial es 0.0463.

La regla de decisión es rechazar la hipótesis nula si la probabilidad asociada al estadístico de prueba es menor que $\alpha = 0.05$. Por lo tanto en este caso la muestra empleada nos suministra una evidencia para rechazar la hipótesis nula, por lo tanto la correlación es significativamente diferente de cero.

- Considerando la estructura de correlación espacial

La probabilidad asociada al estadístico de prueba considerando la estructura de correlación espacial es 0.1353 (ajuste DRH) y 0.1343 (ajuste Dutilleul).

La regla de decisión es rechazar la hipótesis nula si la probabilidad asociada al valor del estadístico de prueba menor que . Por lo tanto, en este caso la muestra empleada no nos suministra una evidencia para rechazar la hipótesis nula.

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