CIAT

Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

TREES PROJECT

Latacunga – Ecuador

(Path 010, Row 060, Quarter 4)

Joint Research Centre (JRC)

and

CIAT

Technical Report

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INTRODUCTION

Phase 2 of the TREES project is developing a prototype for an operational system for monitoring forests in the tropical belt (TFIS). The capacity to detect deforestation hot spots is being improved by analysing a sample of high-resolution imagery over known hot-spot areas (JRC, 1997). This work is being done partly by local organisations, in order to build partnerships for TFIS. Many locations scattered over virtually all of South America show evidence of accelerated deforestation, but principally so in the Colombian, Ecuadorian and Peruvian Andes and the western part of the Amazon region (JRC, 1997).

The objective of this component of TFIS development is to identify and quantify recent deforestation in the period between 1989-1991 and 1996-1998 for the selected samples. The changes of forest area between both dates were measured using high-resolution remote sensing data and techniques.

The International Centre for Tropical Agriculture (CIAT, its Spanish acronym) was responsible for studying 13 sample areas located in Colombia, Ecuador and Peru, covering some of the principal South American hot spots.

The methodology of this study involved the use of georeferenced satellite images, such as Landsat TM SPOT, and on-screen digitising of land-use and land-cover units, which are greater than 50 hectares for recognition purposes. Digitising was on a 1: 100 000 scale. The recognition and assignment of land-use codes to the image interpretation was supported by the use of historical data, such as land-use and forest maps, to evaluate past and present changes.

This report involves the study of an area located in the North Ecuadorian Andes.

DEFORESTATION PATTERNS IN SOUTH AMERICA

According to WRI-UNEP-UNDP-World Bank (1998), an average of 0.5% annual deforestation occurred in South America during the 1990-1995 period. However, it is highly variable between countries, from 0% (Guyana and Uruguay) to 2.6% (Paraguay). Annex 5 gives statistics for South America's forests in the period 1990-1995.

The clearing of tropical forest shows different kinds of spatial patterns, which are influenced by the size of the remaining forest area and the customs of the inhabitants. One spatial pattern is of a small remnant of forest like an island within the cleared area. In this way, deforestation is increasingly advancing along the borders (Rudel, 1993).

In the case of a wide area of forest, such as the Amazon basin, the deforestation pattern has another shape; along the forest margins, in similar circumstances to the forest-island, fringes are opening into the border of the forest. This situation can be seen where the Amazon basin borders the Andes region. "The population overflowing from the Andes down to the Amazon plains do not settle there. They advance like a slow burning fire, concentrating along a narrow margin between the land they are destroying and are about to leave behind, and the forests lying ahead of them" (Myers, 1984). The land is used until yields begin to decline, then it is ceded or sold to cattle ranchers and the settlers move farther into the forest to restart the cycle of forest clearing and abandonment (Stearman, 1985). In some cases, the deforested area is abandoned for 5 to 10 years before secondary forest growth is established (Navas, 1982).

Deforestation may also occur along defined corridors, such as roads and rivers. One of the first situations revealing this pattern is in the upper reaches of the Amazon basin; the first spots of cleared land emerge in a linear pattern along mule trails from the Andes to the Amazon. Farther east, navigable rivers provide access to markets, so the first clearings occur in corridors of land along rivers (Rudel, 1993).

The governments sponsor colonisation zones into the forest, often resulting in grids with cleared land along the roads and islands of forest in the centre of the squares created by the roads. Both sides of the roads have a uniform width of farm clearings. These clearings form an additional corridor of cleared land that parallels the roadside corridor several kilometres into the forest (Hiroaka and Yamamoto, 1980). Other road-building agents are the "highly capitalised organisations like timber companies that begin the deforestation process by building a penetration road, and colonists quickly clear a corridor of land along the road. The subsequent construction of feeder roads induces further deforestation and swaths of cleared land appear in the zone, reducing the forests to island remnants away from the roads" (Rudel, 1993).

The building of a new road into the forest sometimes does not generate a corridor of cleared land. In Colombia, the penetration road into the state of Caqueta generated considerable land clearing, while the construction of a similar road into the state of Guaviare did not (Ortiz, 1984). Areas such as Guaviare and Amazonas in Colombia, even after roads had been completed, remained far from major markets and have had little economic or population growth.

In Frohn's (1998) study of the causes of landscape change in Rondonia, Brazil, he observed that the amount of deforested area is negatively correlated with the distance to the inhabited centres. The farmers closer to urban centres have difficult access to the forest because of lack of transport and services.

Many factors may have helped produce deforestation hot spots: political decisions, migration, marketplaces, fuelwood gathering, livestock farming, increase of population, climatic and compounded-impact, infrastructure, fires, illegal plantation, logging, appropriateness of land uses, dams, mining (Utting, 1993; Adger and Brown, 1994). But the causes of deforestation can be abridged into three principal ones, (1) land use conversion, (2) overexploitation of forest and (3) natural and environmental changes (Adger and Brown, 1994).

Deforestation has global consequences with respect to the carbon cycle. It has local impacts of increased rates of soil erosion, capacity of soils to retain water, other pollutants emitted from biomass burning, loss of biological diversity, loss of cultural diversity (when the indigenous people are displaced) and loss of indigenous knowledge (Adger and Brown, 1994).

THE ANDES

The Andes is the longest of all mountain ranges. It is over 4500 miles long, stretching along the entire western coast of South America. In several places, this mountain range rises to over 6000 m, the highest mountain being Aconcagua in Argentina at 6960 m. The tropical regions of the Andes reach heights of 5007 m in Venezuela, 5775 m in Colombia, 6310 m in Ecuador and 6768 m in Peru. These high mountains form a barrier of great importance to circulation of air masses, resulting in extreme changes in climate conditions over short distances. Two characteristics of the Andes are:

1) Abrupt changes in altitude giving ecozones ranging from rainy forest to desert at the lowest to snow and ice at the highest extreme (Gastó, 1993).

2) Compensation of the latitudinal increment by the altitudinal increment generated continuous ecozones of simultaneous latitudinal - altitudinal gradients (Czaijka, 1968).

Clouds are observed frequently and constantly in the Andes and are an important factor in determining the distribution of several types of vegetation. In the tropical regions on both sides of the Andes, associated with the mantles of clouds, forest has developed with 1500-2500 m as its lower limit and 2400-3300 m as its upper limit (Stadmüller, 1987).

"The arboreal vegetation often forms the superior limit of the tropical montane forest or it covers the summits and hills of isolated mountains. The trees of this vegetation are characterised generally by their low stature, their trunks twisted with profuse ramifications, and by a great quantity of epiphytes, especially mosses that could cover trunks, branches and the surface of the floor completely" (Stadtmüller, 1987).

STUDY AREA

LOCATION

The study site is located in the northern part of the Ecuadorian Andes. It is bounded in the south by the Cotopaxi volcano, in the north by the Chiquita slopes near to Laguna Grande de Mojanda, in the west by the Rucu Pichincha and Guagua Píchincha volcanoes and in the east by the eastern side of the Cordillera Oriental in the Amazon region. The total area covered is 842 778ha.

TOPOGRAPHY

"Two parallel ranges, a southern extension of the Colombian ranges – the Cordillera Occidental and the Cordillera Central – make up the highland region. The two ranges are separated by a succession of 10 major basins that form part of a long and deep rift valley. The intense volcanic activity characteristic of this rift valley has produced the discontinuities that resulted in a series of basins.

Many peaks in both ranges rise to over 4000 m and some are higher than the snow line" (Brawer, 1991).

VEGETATION

"Large parts of the lower slopes, especially in the north, are covered by forests; these thin out toward the south and gradually change to scrub in the drier areas and in the deep, sheltered slopes and valleys" (Brawer, 1991).

In the highest mountain parts, sub-paramo vegetation develops at 3200-3900 m in the Cordillera Occidental and at 3000-3600 m in the Cordillera Oriental. Within these strata we find the vegetation of Rockrose Montane Forest, Wet Montane Forest, Very Wet Montane Forest and Pluvial Montane Forest.

The paramo is located above the sub-paramo vegetation, covering the altitudinal band between 3600 and 4700 m in the Cordillera Oriental and extends from 3900-4700 m in the Cordillera Occidental. The predominant vegetation is grassland and small shrubs (Cañadas, 1993).

Three important Ecological Reserves and one National Park cover the remaining montane rainforest and some paramo that can be seen in the image. The three reserves are in the eastern part, covering some of the paramo and the cloud forest (Natural Reserve of Antisana, Cayambe Coca and National Park Sumaco-Napo Galeras); they together cover about 750 000 ha. The other important National Park is Cotopaxi, where the paramo vegetation is principally protected. But these areas are not free of forest harvesting. The agricultural border advances according to the invasion of new settlers or oil and timber exploitations in the zone (Vásconez, 1995).

PRODUCTION SYSTEMS

The basins are mostly filled with densely inhabited valleys, including Quito and others important urban centres. Most of the rural population practices subsistence agriculture. In the higher basins, the main crop is potato; grown up to an altitude of about 3400 m. Maize, wheat, barley and various vegetables are grown in the lower basins. The higher basins and adjacent slopes are used mostly for pasture. The paramo is partly used as a grazing area for sheep. Its lower area is sparsely populated by small Indian villages (Brawer, 1991).

Forest plantations have also been planted on the mountain range, especially of eucalyptus (55%), pine (40%), cypress (3%) and other species (2%). Given the almost total absence of natural forests, this region produces most of Ecuador's timber to fill the need for wood for such uses as construction materials (INEFAN, 1993).

METHODOLOGY

MATERIALS

For this work we used the fourth Instituto Geográfico Militar (IGM) quarter of two Landsat TM images (path 010, row 060: 010060911015Q4geo.lan, 010060960724Q4geo.lan). The radiometric quality of the image data was good, although the second image had clouds covering almost all the region of montane tropical forest in the Amazon region. The first image only had clouds in two corners of the image.

Land use was interpreted using as reference land-use maps at a 1:50 000 scale from the Ministerio de Agricultura y Ganadería (MAG) for 1991-1993.

The interpretation key that we used for this project is given in annex 4.

GEOCODING

Both images were georeferenced to Universal Transversal of Mercator (UTM), zone 18 WGS84, using the Georeferencing module of the PCI software. Geographic reference information was extracted from topographical maps and associated to the image of the first date as ground control points. In the case of the second image, the georeferencing process used as a reference the product obtained from georeferencing the first image (first date). The topographical maps at a scale of 1:100 000 that were used for georeferencing were produced by the Instituto Geográfico Militar (IGM) of Ecuador. Annex 1 gives a list of maps used for georeferencing, root mean square (RMS) error for both processes as well as parameters and other georeferencing information.

Figures 1 and 2, in Annex 2, give an overview of the study area in both images after the georeferencing process.

LAND-USE AND LAND-COVER DIGITISING

Land uses and land cover were digitised on screen over the TM 4-5-3 colour composite. This process was completed using the Imageworks module of PCI software with the minimum mapping unit as described in TREES technical annex (50 ha; 300 m width for linear features). The images were displayed at a scale of 1:100 000 and all distinguishing characteristics were digitised and associated to a specific class code established by TREES (see Annex 3).

Digitised vectors on the first image were overlaid on the second and then the changes in land use and cover greater than 25 hectares were digitised. The result of this process forms the digitised product of land use and cover for the second image.

BUILDING POLYGONS

Both data groups were transferred to ARC/INFO to correct remaining errors (dangles, codes) and to build polygon coverages for both dates as well as their intersection.

In the intersection coverage, some polygons with size less than half the minimal mapping unit (i.e. 25 ha) were suppressed by using the ELIMINATE command, which allowed us to merge small polygons to the polygons with the longest common boundary. This was particularly useful to simplify areas with scattered clouds.

The intersection coverage was submitted to a final edition process in ArcView 3.1, using the imagery for both dates as background. In this step, remaining code errors and inconsistencies, as well as remaining digitising errors, were corrected on the intersection coverage. For example, polygons might be found going from a young regeneration stage to primary forest, which is impossible in a period of 9 years.

Final coverages for the overlapping area from both dates were produced from the corrected intersection coverage using the DISSOLVE command of ARC/INFO. These were used to generate the statistics reported in Annex 3. In compliance with contract requirements, the coverages for the total area covered by each image were obtained by merging (making codes and borders compatible) those produced by DISSOLVE with the originals (i.e., before intersection).

The attribute table of the intersection coverage was used to produce the land use change statistics and confusion matrix (see Annex 3).

INTERPRETATION OF CHANGES

Natural forest covers almost 15.7% of the area if we exclude the area taken by clouds and shadows (later referred to as overlap area). Deforestation was 0.7 % in 5 years at an annual rate of 0.1 %. This is much less than the reported 1.6% annual deforestation reported for Ecuador (annex 5). The annual forest recovery rate was low, only 0.005%.

Forest plantations (*Pinus* sp. and *Eucalyptus* sp.) cover only 0.9% of the overlap area. However, the annual plantation logging rate was 3.2%, with 16.2% of the planted area logged in 5 years. Most of these plantations reached the desired tree size for logging, but not all the area was reforested.

The paramo was the most important land use / land cover, this with others grassland formations (dry grassland and unknown grassland) covering almost 35.1% with a 0.3% rate of conversion to other land uses (772 ha yr^{-1}). Other types of natural vegetation, water bodies and soil cover in natural condition covered 19.7 of the overlap area. The mosaic types covered 3.3% of the overlap area. Because the images covered an important area around the city of Quito, agricultural activities are of great importance in the analysis; the smallholdings and other types of agricultural covered almost 21.9 % of the overlap area and increased in area to 4793 hectares (3.2%) in 5 years. These activities took over natural forest, forest plantation, savannahs and paramo.

The Quito urban and suburban area covered 14243 hectares in 1997, or 2.1% of the overlap area, with an annual increment of 4.5% (641.2 ha yr^{-1}). These don't invade to the forest land directly: the expansion of the urban area favors the development of agriculture, which takes over the forest.

CONCLUSIONS

The main causes of deforestation are the intensive logging in the remaining Andean forest, shifting cultivation and agricultural expansion on the Andean volcano and Amazon slopes.

A massive pattern of deforestation showed in the areas of pine and eucalyptus commercial plantation, and islands of deforestation showed in the natural forest caused by shifting cultivation and agricultural expansion. The principal focus of deforestation is along the highway from Quito to Baeza in the Amazon region. Although these images showed important deforestation, the logging of commercial plantations represent most of it.

This quarter scene mainly involved small holdings, urban areas and paramo, distributed over all the image, while the natural forest is located only on the image east border.

This study site shows important land-use dynamics; the growth of the city of Quito produces a constant movement of productive activities towards natural land, impacting on the natural forest and paramo.

In future studies, better images must be selected free of cloud cover over the tropical forest. The cloud cover present in the current images does not permit a good analysis of deforestation. Should obtaining imagery free of clouds present difficulty, the study of this forest area could be completed by the use of radar imagery (i.e.: JERS).

Annex 1

Geocoded image information

Latacunga (Path 010, Row 060, Quarter 4)

Maps Used for Georeferencing

IGM. 1982. Sangolquí, CT-ÑIII-B, 3993, Provincia de Pinchincha-Ecuador, Topograhic map, Scale 1: 100 000, Instituto Geográfico Militar, Serie J621, Edition 1. Quito, Ecuador..

IGM. 1992. Pintag, CT-ÑIII-D, 3992, Provincia de Pinchincha-Ecuador, Topograhic map, Scale 1: 100 000, Instituto Geográfico Militar, Serie J621, Edition 1. Quito, Ecuador..

IGM. 1994. Cotopaxi, CT-ÑIII-F, 3991, Cotopaxi-Ecuador, Topograhic map, Scale 1: 100 000, Instituto Geográfico Militar, Serie J621, Edition 1. Quito, Ecuador.

IGM. 1982. Otavalo, CT-ÑII-F, 3994, Provincia de Imbabura-Ecuador, Topograhic map, Scale 1: 100 000, Instituto Geográfico Militar, Serie J621, Edition 1. Quito, Ecuador..

IGM. 1990. Nono, CT-ÑIII-A2, 3893-I, Provincia de Pichincha-Ecuador, Topograhic map, Scale 1: 50 000, Instituto Geográfico Militar, Serie J721-Edition 3, Quito-Ecuador.

IGM. 1990. Quito, CT-ÑIII-A4, 3893-II, Provincia de Pinchincha-Ecuador, Topograhic map, Scale 1: 50 000, Instituto Geográfico Militar, Serie J721-Edition 3, Quito-Ecuador.

Geocoded image information

Landsat TM image, Quarter 4
Path 010 Row 060
Date 15/10/91
Image name: **010060911015Q4geo.lan**

Channel 1	TM Band 3
Channel 2	TM Band 4
Channel 3	TM Band 5

Number of columns	3993
Number of lines	3705

Reference projection	UTM 17 M WGS84		Lat/Long WGS84	
Units	Metres		Degree	
Upper left corner	749845	10015530	78.7552 W	0.1403 N
Lower right corner	869635	9904380	77.6796 W	0.8636 S

Resampling mode	Nearest
Transformation order	1
Georeferencing error (pixel)	1.0
Number of GCP	22

Geocoded image information

Landsat TM image, Quarter 4
Path 010 Row 060
Date 24/07/96
Image name: **0100060960724Q4geo.lan**

Channel 1	TM Band 3
Channel 2	TM Band 4
Channel 3	TM Band 5

Number of columns	3992
Number of lines	3985

Reference projection	UTM 17 M WGS84		Lat/Long WGS84	
Units	Metres		Degree	
Upper left corner	762388	10012600	78.6426 W	0.1137 N
Lower right corner	882148	9893050	77.5673 W	0.9658 S

Resampling mode	Nearest
Transformation order	1
Georeferencing error (pixel)	1.2
Number of GCP	29

Annex 2

False colour composites

Latacunga (Path 010, Row 060, Quarter 4)

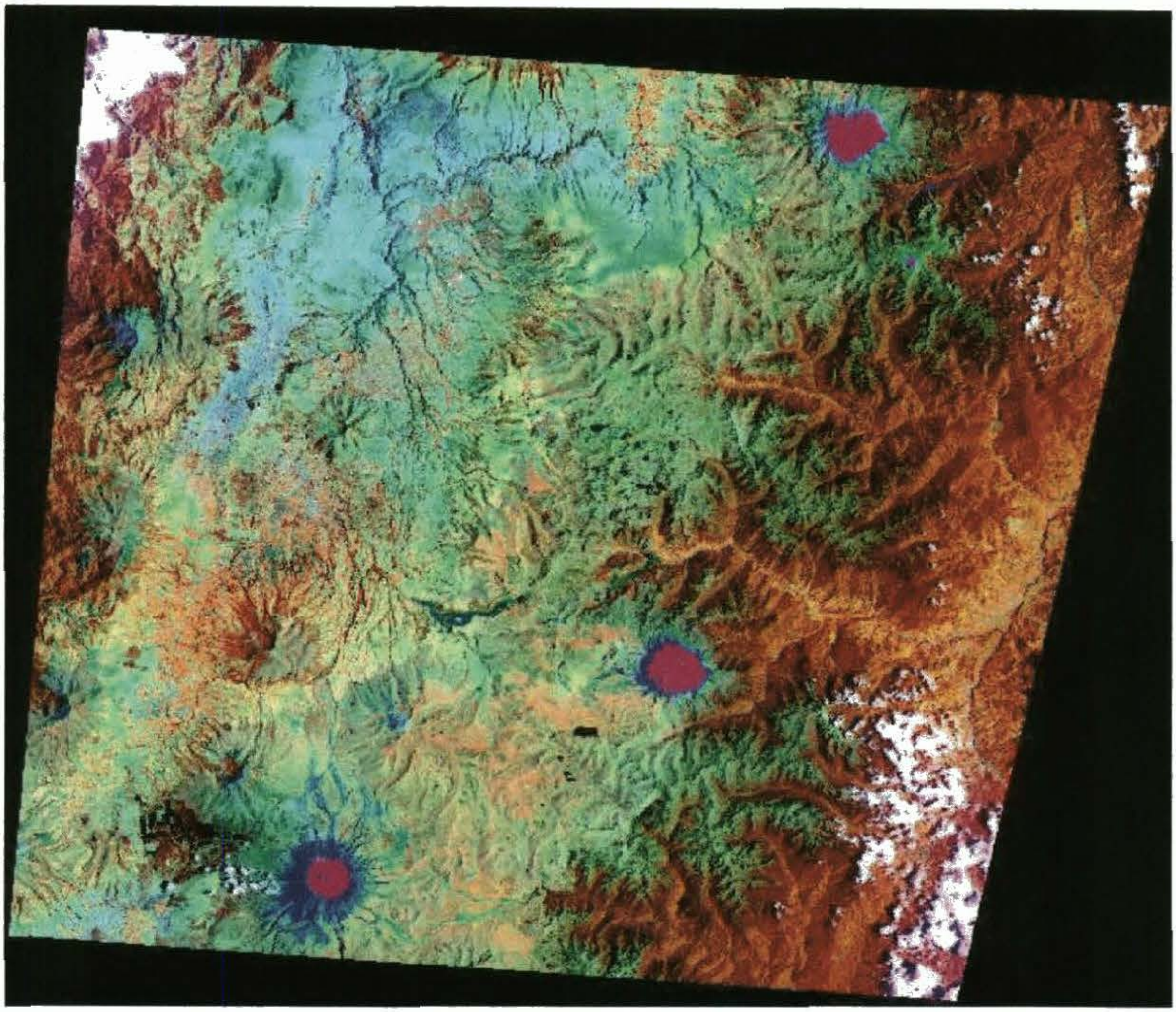


Figure 1. Landsat TM satellite image, bands 4, 5, 3, path 010, row 060, quarter 4, date 15-10-91. Upper left corner 78.7572 W, 0.1403 N, Lower right corner 77.6796 W, 0.8636 S.

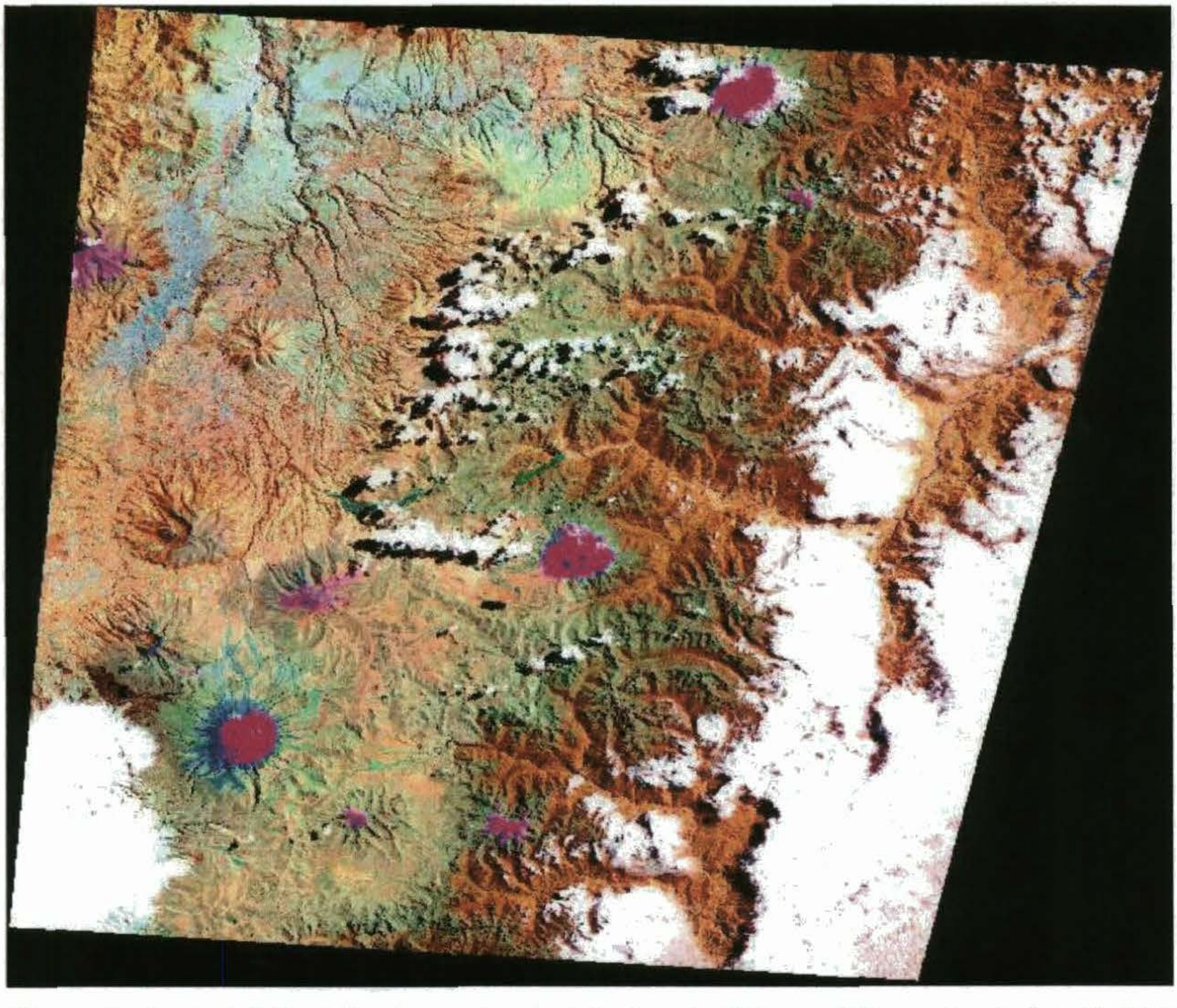


Figure 2. Landsat TM satellite image, bands 4, 5, 3, path 010, row 060, quarter 4, date 24-07-96. Upper left corner 78.6426 W, 0.1137 N, Lower right corner 77.5673 W, 0.9658 S.

Annex 3

Land use / Land cover change
(Overlap area)

Latacunga (Path 010, Row 060, Quarter 4)

Land use / Land cover present in 1991 image

Latacunga (Path 010, Row 060; ecu_ciat_lat_91_cds.xls

Code	Description
112A	Closed high Density Montane Forest
112B	Closed Medium Density Montane Forest
112C	Open Montane Forest
112D	Fragmented Montane Forest
129B	Closed Medium Density Other Deciduous Forest
132A	Closed high Density Swamp Forest
152C	Open Pine Plantation
152D	Fragmented Pine Plantation
153B	Closed Medium Density Eucalyptus Plantation
153C	Open Eucalyptus Plantation
153D	Fragmented Eucalyptus Plantation
211	Mosaic of Shifting Cultivation & forest with less than 1/3 cropping
212	Mosaic of Shifting Cultivation & forest with more than 1/3 cropping
22	Cropland & Forest
23	Other Vegetation & Forest
311	Woodland savannah
312	Tree savannah
313	Shrub savannah
319	Other Wood & Shrubland
320	Unknown Grassland
321	Dry Grassland
39	Other Non-forest Vegetation
429	Other Plantations
43	Ranching
44	Small holding
51	Urban
54	Bare soil
59	Other Non-Vegetated
621	Natural Lake
622	Artificial Lake
81	Cloud
82	Shadow

Land use / Land cover present in 1996 image

Latacunga (Path 010, Row 060; ecu_ciat_lat_96_cds.xls)

Code	Description
112A	Closed High Density Montane Forest
112B	Closed Medium Density Montane Forest
112C	Open Montane Forest
112D	Fragmented Montane Forest
129B	Closed Medium Density Other Deciduous Forest
132A	Closed High Density Swamp Forest
152B	Closed Medium Density Pine Plantation
152C	Open Pine Plantation
152D	Fragmented Pine Plantation
153D	Fragmented Eucalyptus Plantation
211	Mosaic of Shifting Cultivation & forest with less than 1/3 cropping
212	Mosaic of Shifting Cultivation & forest with more than 1/3 cropping
22	Cropland & Forest
23	Other Vegetation & Forest
311	Woodland Savannah
312	Tree Savannah
313	Shrub Savannah
319	Other Wood & Shrubland
320	Unknown Grassland
321	Dry Grassland
33	Regrowth of Vegetation
39	Other Non-forest Vegetation
429	Other Plantations
43	Ranching
44	Small holding
51	Urban
54	Bare soil
59	Other Non-Vegetated
621	Natural Lake
622	Artificial Lake
81	Cloud
82	Shadow

Statistics for 1991 image

Latacunga (Path 010, Row 060; ecu_ciat_lat_91_sts.xls)

Code 91	No. Polygons	Total Area	Mean Area	S. D. Area
112A	4	751	188	89
112B	14	137597	9828	29759
112C	12	16441	1370	2351
112D	28	15599	557	605
129B	1	244	244	0
132A	2	1466	733	342
152C	1	152	152	0
152D	2	4684	2342	2744
153B	1	38	38	0
153C	2	910	455	528
153D	6	4680	780	655
211	5	3951	790	978
212	1	1794	1794	0
22	2	13681	6841	7587
23	14	14473	1034	2704
311	3	1740	580	289
312	3	1980	660	1043
313	8	28967	3621	4375
319	51	67023	1314	3406
320	5	1687	337	220
321	29	37794	1303	3144
39	17	240733	14161	54878
429	5	10412	2082	3084
43	1	322	322	0
44	24	146492	6104	22620
51	11	14243	1295	2841
54	17	38926	2290	5694
59	4	6327	1582	1070
621	6	449	75	65
622	1	36	36	0
81	35	25001	714	1671
82	52	5046	97	86

Statistics for 1996 image

Latacunga (Path 010, Row 060; ecu_ciat_lat_96_sts.xls)

Code 96	No. Polygons	Total Area	Mean Area	S. D. Area
112A	1	84	84	0
112B	30	83669	2789	6926
112C	14	13941	996	1778
112D	26	9192	354	307
129B	1	244	244	0
132A	3	1342	447	219
152B	1	100	100	0
152C	1	120	120	0
152D	2	2586	1293	1260
153D	5	3229	646	634
211	2	614	307	116
212	1	1794	1794	0
22	2	7222	3611	3020
23	9	12709	1412	3354
311	2	1041	521	382
312	4	1101	275	394
313	8	28874	3609	4366
319	53	58703	1108	2207
320	5	1687	337	220
321	31	30241	976	2334
33	1	67	67	0
39	26	206299	7935	37467
429	5	12145	2429	3390
43	1	322	322	0
44	25	140729	5629	19881
51	13	18960	1458	3717
54	13	32676	2514	6446
59	5	11065	2213	1145
621	6	449	75	65
622	1	36	36	0
81	98	134783	1375	5656
82	118	27618	234	535

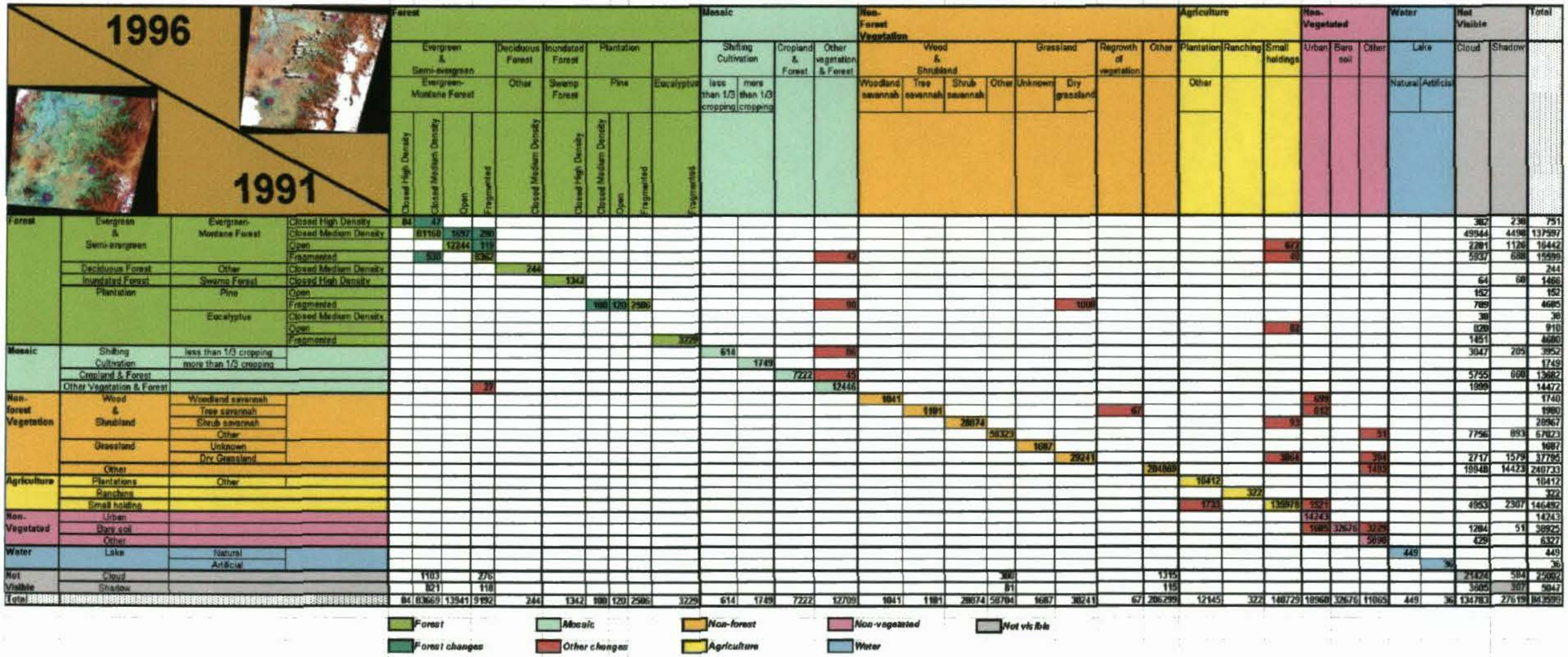
Land use change area for 1991 and 1996 images

Latacunga (Path 010, Row 060; ecu_ciat_lat_chg.xls)
Images: **010060911015Q4geo.lan** **0100060960724Q4geo.lan**

No. Polygons	Code 91	Code 96	Total Area
1	112A	112A	84
1	112A	112B	47
2	112A	81	382
1	112A	82	238
30	112B	112B	81168
10	112B	112C	1697
2	112B	112D	290
32	112B	81	49944
32	112B	82	4498
10	112C	112C	12244
1	112C	112D	119
1	112C	44	672
10	112C	81	2281
5	112C	82	1126
1	112D	112B	530
20	112D	112D	8362
1	112D	23	42
1	112D	44	40
11	112D	81	5937
4	112D	82	688
1	129B	129B	244
3	132A	132A	1342
2	132A	81	64
1	132A	82	60
1	152C	81	152
1	152D	152B	100
1	152D	152C	120
2	152D	152D	2586
1	152D	23	90
2	152D	321	1000
2	152D	81	789
1	153B	81	38
1	153C	44	82
1	153C	81	828
5	153D	153D	3229
1	153D	81	1451
2	211	211	614
1	211	23	86
4	211	81	3047
2	211	82	205
1	212	212	1794
2	22	22	7222
1	22	23	45
9	22	81	5755
4	22	82	660
1	23	112D	27
5	23	23	12446
10	23	81	1999
2	311	311	1041
1	311	51	699
4	312	312	1101
1	312	33	67
3	312	51	812
8	313	313	28874
1	313	44	93
55	319	319	58323
1	319	59	51
31	319	81	7756
11	319	82	893
5	320	320	1687
30	321	321	29241
1	321	44	3864
2	321	59	394
8	321	81	2717
11	321	82	1579
26	39	39	204869
7	39	59	1493
69	39	81	19948
74	39	82	14423
5	429	429	10412
1	43	43	322
5	44	429	1733
24	44	44	135978
4	44	51	1521
10	44	81	4953
10	44	82	2307
11	51	51	14243
3	54	51	1685
13	54	54	32676
7	54	59	3229
6	54	81	1284
1	54	82	51
4	59	59	5898
4	59	81	429
6	621	621	449
1	622	622	36
6	81	112B	1103
3	81	112D	276
5	81	319	300
7	81	39	1315
34	81	81	21424
7	81	82	584
6	82	112B	821
2	82	112D	118
2	82	319	81
3	82	39	115
41	82	81	3605
5	82	82	307

Land use change matrix

Latacunga (Path 010, Row 060; ecu_ciat_lat_mtx.xls)



1996 1991				Forest										Mosaic				Non-Forest Vegetation								Agriculture			Non-Vegetated			Water		Not Visible		Total
				Evergreen & Semi-evergreen				Deciduous Forest	Inundated Forest	Plantation				Shifting Cultivation		Cropland & Forest	Other vegetation & Forest	Wood & Shrubland				Grassland		Regrowth of vegetation	Other	Plantation	Ranching	Small holdings	Urban	Bare soil	Other	Lake		Cloud	Shadow	
				Evergreen-Montane Forest				Other	Swamp Forest	Pine			Eucalyptus	less than 1/3 cropping	more than 1/3 cropping			Woodland savannah	Tree savannah	Shrub savannah	Other	Unknown	Dry grassland			Other						Natural	Artificial			
				Closed High Density	Closed Medium Density	Open	Fragmented	Closed Medium Density	Closed High Density	Closed Medium Density	Open	Fragmented	Fragmented																							
Forest	Evergreen & Semi-evergreen	Evergreen-Montane Forest	Closed High Density	84	47																													382	238	751
			Closed Medium Density		81168	1697	290																											49944	4498	137597
			Open			12244	119																					672						2281	1126	16442
			Fragmented		530		8362										42											40						5937	688	15599
	Deciduous Forest	Other	Closed Medium Density					244																												244
	Inundated Forest	Swamp Forest	Closed High Density						1342																									64	60	1466
	Plantation	Pine	Open																															152		152
			Fragmented							100	120	2586					90						1000											789		4685
		Eucalyptus	Closed Medium Density																															38		38
			Open																									82						828		910
			Fragmented										3229																					1451		4680
Mosaic	Shifting Cultivation	less than 1/3 cropping												614			86																	3047	205	3952
		more than 1/3 cropping													1749																					1749
	Cropland & Forest															7222	45																	5755	660	13682
	Other Vegetation & Forest						27										12446																	1999		14472
Non-forest Vegetation	Wood & Shrubland	Woodland savannah																1041											699							1740
		Tree savannah																	1101					67					812							1980
		Shrub savannah																		28874								93								28967
		Other																			58323										51			7756	893	67023
	Grassland	Unknown																				1687														1687
		Dry Grassland																					29241					3864			394			2717	1579	37795
	Other																								204869						1493			19948	14423	240733
Agriculture	Plantations	Other																								10412										10412
	Ranching																										322									322
	Small holding																									1733		139978	1521					4953	2307	146492
Non-Vegetated	Urban																												14243							14243
	Bare soil																												1685	32676	3229			1284	51	38925
	Other																														5898			429		6327
Water	Lake	Natural																														449				449
		Artificial																															36			36
Not Visible	Cloud				1103		276														380				1315									21424	504	25002
	Shadow				821		118														81				115									3605	307	5047
Total				84	83669	13941	9192	244	1342	100	120	2586	3229	614	1749	7222	12709	1041	1101	28874	58784	1687	30241	67	206299	12145	322	148729	18960	32676	11065	449	36	134783	27619	843599

🟩 Forest	🟩 Forest changes
🟩 Mosaic	🟥 Other changes
🟧 Non-forest	🟨 Agriculture
🟪 Non-vegetated	🟦 Water
⬜ Not visible	

Annex 4

Land use interpretation key

The TREES project classification key was obtained from the first TREES II project proposal, modified during the TREES project workshop in Caracas, Venezuela (February-March 99), and finalised according to the recommendations of TREES advisor, Otto Huber.

During the Caracas workshop, the suitability of a TREES table codes proposal for describing real land use/land cover in the different Latin American countries (LAC) was discussed. The participants decided to add four classes in the 4th forest classification level (A, B, C, D), to add a "small holding" code (44) as well as "bare soil and rocks" code (54).

In July-August 99 Mr. Otto Huber visited the different institutions collaborating with the TREES project in South America to discuss and agree on the codes to be assigned to the different land-use and land-cover classes. Some important land uses/land cover appearing on the images that CIAT is processing did not have a specific code (even after the Caracas meeting). Following discussion we agreed to select existing codes to describe these ambiguous land uses/land covers instead of adding new ones. The "paramo" vegetation was assigned to code 39, the "jalca" and "puno" vegetation to 329, "shrimp farming" to 59, "deciduous forest" (129A, 129B, 129C, 129D) and snow cover to 59. The codes for "arable land for agriculture" (411 or 412) were used to describe industrial and technical high-input agriculture, such as sugar cane, cotton, pine, et cetera. Low-input, small area agriculture was assigned "small holding" code (44).

The "ranching" code (43) was used for large areas of cattle activities. This was a simple task for cases where the limits of the area were geometrical (e.g., a single large farm in the middle of the jungle). In other cases, the large area did not have geometrical boundaries, so it was impossible to tell if it corresponded to a single large farm or many small ones. We assumed that code 43 applied in these cases.

The regeneration areas ("vegetation re-growth" and "forest re-growth") are not easy to distinguish, especially because the period when the land was abandoned is unknown. In addition, the spectral response of healthy vegetation re-growth with forest re-growth is similar in some cases. We should reconsider the period of time that defines what is "vegetation re-growth "and "forest re-growth". In the tropical forest, re-growth can last 100 years until the forest structure corresponds to that of the primary forest. In theory, the succession process in the secondary forest starts at the moment the land is abandoned and ends when the tree species are totally replaced by primary forest.

The deciduous forest class should have a Level 3 code for the dry forests in the American Tropics (we used codes 129A-D, "other deciduous forests").

The classification key was translated to Spanish to ensure it could be clearly understood by our interpreters. Each translated code was checked and interpreted by Mr. Otto Huber to avoid interpretation mistakes.

Table 1. Spanish version of TREES Classification key used by CIAT

Nivel 1	Nivel 2	Nivel 3	Nivel 4
1 Bosque, mayor a 10% de coberturas de copas y mas del 40 % de cobertura forestal			
	1 Bosque siempre verde y semi siempre verde	0 Indefinido	A Cerrado alta densidad mas del 90% cobertura forestal
		1 Bosque siempre verde de tierras bajas (Selva Tropical)	
		2 Bosque siempre verde de montaña (Bosque montano o nublado)	B Cerrado media densidad 70-90% cobertura forestal
		3 Bosque semi siempreverde	
		4 Bosque de turba amazonica (Catinga)	C Abierto 60- 70% cobertura forestal
		5 Bosques de pinos	
		6 Bambú	D Fragmentado 40-60% cobertura forestal
		9 Otro	
	2 Bosque deciduo	0 Indefinido	
		1 Bosque seco denso (Africa)	
		2 Miombo (Africa)	
		3 Bosque seco de especies mixtas (Asia)	
		4 Bosque seco de Dipterocarpaceas (Asia)	
		9 Otro	
	3 Bosque inundado	0 Indefinido	
		1 Periodicamente inundado	
		2 Permanentemente inundado, (Bosque de pantano)	
		3 Bosque de pantano con palma (Aguajales)	
		4 Turba/Bosque (bosque de altura)	
		9 Otro	
	4 Bosque de galería (bordea los rios y esta rodeado de pasto)		
	5 Plantaciones	0 Indefinido	
		1 Teca	
		2 Pino	
		3 Eucalipto	
		9 Otro	
	6 Regeneración de bosques (más de 10 años)		
	7 Mangle		
	9 Otro		
2. Mosaico, entre un 10 y 40 % de cobertura forestal			
	1 Cultivos migratorios	0 Indefinido	
		1 Hasta 1/3 del area cultivada	
		2 Mas de 1/3 del area cultivada	
	2 Tierras agrícolas y bosques (pastos+cultivos+bosques)		
	3 Otra vegetación y bosque (regeneración y bosque)		
	9 Otro		
3. No bosque, menos del 10 % de cobertura de copas y menos del 10 % de cobertura forestal			
	1 Arboles y matorrales	0 Indefinido	
		1 Sabana con matorrales	
		2 Sabana arbolada	
		3 Sabana arbustiva	
		4 Bambu	
		5 Sabana inundada	
		6 sabana húmeda siempreverde (Asia)	
		7 Sabana seca (Asia)	
		9 Otro	
	2 Pradera	0 Indefinido	
		1 Pradera seca	
		2 Pradera inundadas (Pantanal)	
		9 Otro (Jalca, Puno)	
	3 Regeneración de vegetacion (menos a 10 años)		
	9 Otro (Páramos)		
4. Agricultura, menos del 10 % de cobertura de copas y menos del 10 % de cobertura forestal			
	1 Tierras arables (cultivos a gran escala)	0 Indefinido	
		1 Con riego artificial	
		2 Con riego natural (lluvia)	
	2 Plantaciones comerciales	0 Indefinido	
		2 Caucho	
		3 Palma africana (Palma aceitera)	
		3 Café, cacao, coca	
		9 Otro	
	3 Grandes fincas ganaderas		
	4 Pequeñas fincas		
	9 Otro		
5. No vegetación			
	1 Urbano (pueblo, ciudad)		
	2 Carreteras y caminos		
	3 Infraestructura	1 Minería	
		2 Hidrolelectrica	
		9 Otro (camaroneras, etc.)	
	4 Suelo descubierto y rocas		
	9 Otro		
6. Agua			
	1 Rios		
	2 Lago, Laguna	1 Natural	
		2 Artificial	
7. Mar			
8. No visible en la imagen			
	1 Nubes		
	2 Sombras		
9. Sin Información			

Annex 5

Forest cover change in South America

		Forest Area							
		Total Forest			Natural Forest			Plantations {a}	
	Land Area (000 ha)	Extent 1990 (000 ha)	Extent 1995 (000 ha)	Average Annual % Change 1990-95	Extent 1990 (000 ha)	Extent 1995 (000 ha)	Average Annual % Change 1990-95	Extent 1990 (000 ha)	Average Annual % Change 1980-90
SOUTH AMERICA	**1,752,925**	**894,466**	**870,594**	**0.5**	**887,187**	**863,315**	**0.5**	**7,264**	**5**
Argentina	273,669	34,389	33,942	0.3	33,842	33,395	0.3	547	1
Bolivia	108,438	51,217	48,310	1.2	51,189	48,282	1.2	28	4
Brazil	845,651	563,911	551,139	0.5	559,011	546,239	0.5	4,900	5
Chile	74,880	8,038	7,892	0.4	7,023	6,877	0.4	1,015	8
Colombia	103,870	54,299	52,988	0.5	54,173	52,862	0.5	126	12
Ecuador	27,684	12,082	11,137	1.6	12,037	11,092	1.6	45	4
Guyana	19,685	18,620	18,577	0.0	18,612	18,569	0.0	8	29
Paraguay	39,730	13,160	11,527	2.6	13,151	11,518	2.7	9	15
Peru	128,000	68,646	67,562	0.3	68,462	67,378	0.3	184	7
Suriname	15,600	14,782	14,721	0.1	14,774	14,713	0.1	8	4
Uruguay	17,481	816	814	0.0	660	658	0.1	156	1
Venezuela	88,205	46,512	43,995	1.1	46,259	43,742	1.1	253	11

Source: WRI-UNEP-UNDP-World Bank

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