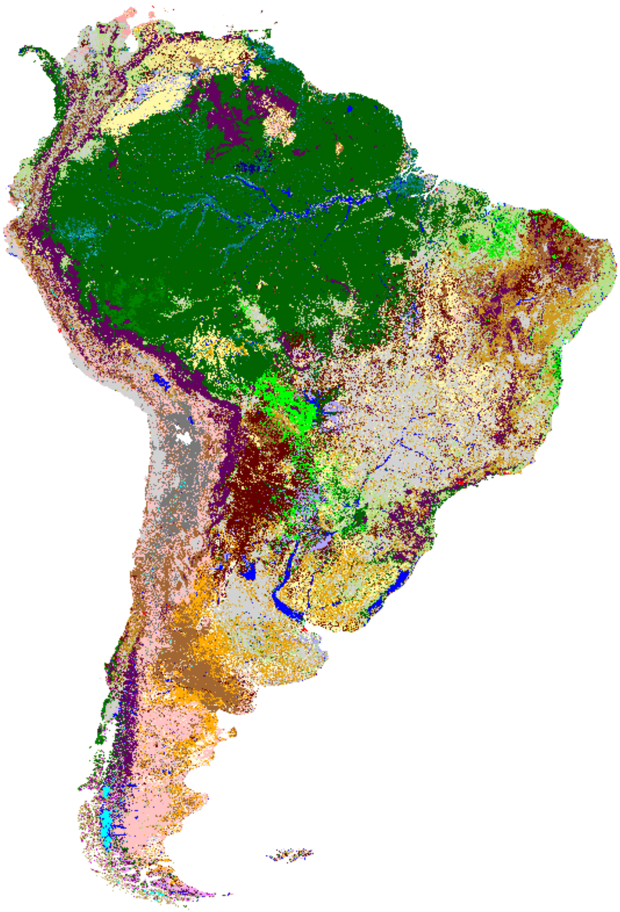
A VEGETATION MAP OF SOUTH AMERICA

MAPA DE LA VEGETACIÓN DE AMÉRICA DEL SUR

MAPA DA VEGETAÇÃO DA AMÉRICA DO SUL



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EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

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A VEGETATION MAP
OF SOUTH AMERICA

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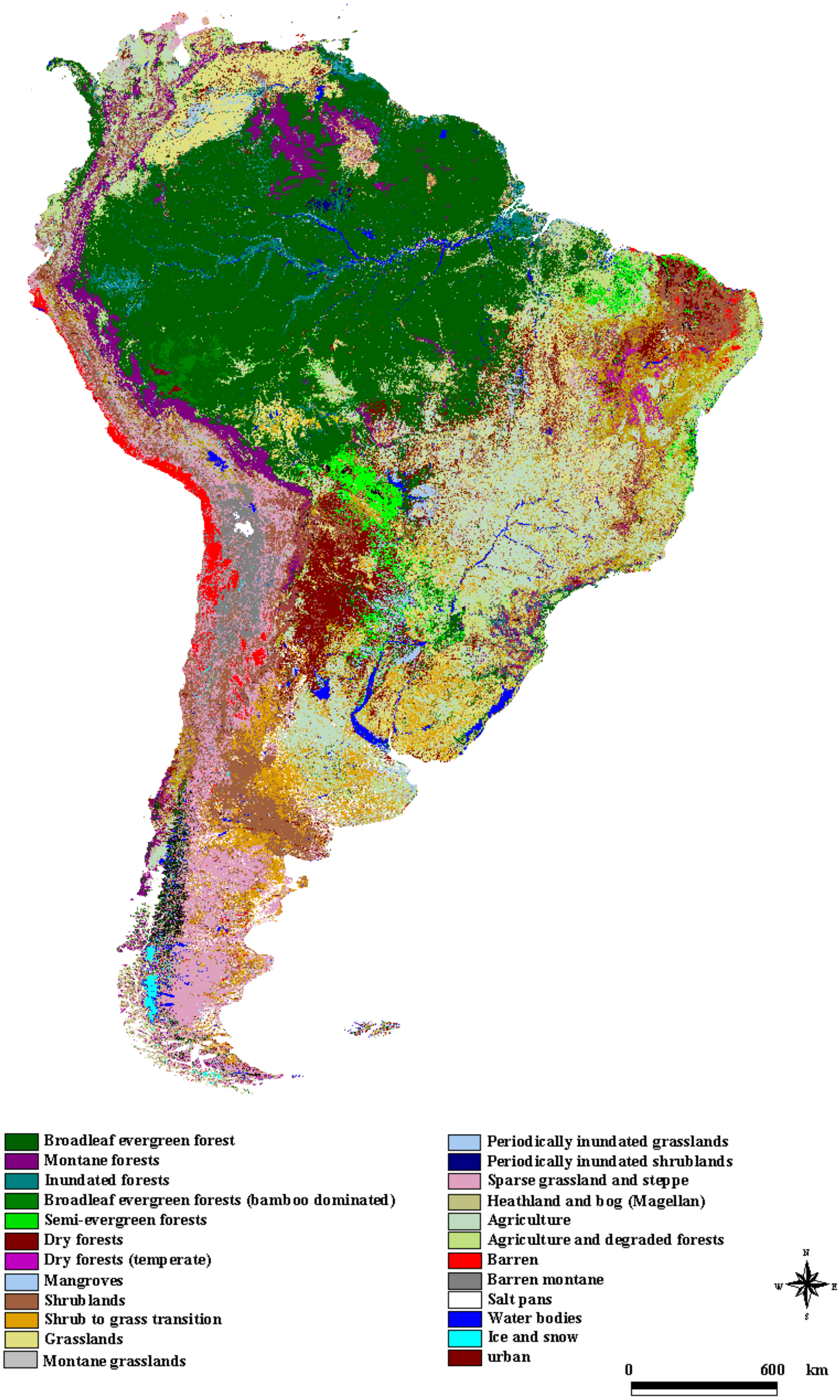

Figure 1: The South America map with generalised legend

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Acknowledgements

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Foreword

South America accounts for around 12% of the Earth's land surface. The continent is among the most physically, biologically and climatologically diverse of all Earth's land-masses. Climate ranges from arid desertic conditions, through to humid tropical regions and cold permanent ice caps. The continent boasts the largest rainforest in the world, the largest river and has some of the world's greatest concentrations of biodiversity. In addition to the largest tropical forest left on the Earth the continent accounts for nearly a quarter of the world's potentially arable land, around 12% of the current cropland, and 17% of all pastures (Gómez and Gallopin, 1991).

The UN Population Division puts the year 2000 population for Latin America and the Caribbean at 519 million and predicts this could rise to as many as 1,025 million by 2050 (United Nations, 2001). This will put ever-increasing pressure on the land to provide employment, food, fibre and fuel. To provide for the growing population the forests will very likely continue to be cleared to make way for agriculture, ranching and plantations. Commercial wood harvesting too is likely to increase. South America's humid tropical forests declined by by16 Mha between 1990 and 1997, an average rate of 0.38 % per year, though deforestation rates in hot-spots reached 4 % (Achard et al., 2002). All the indications are that this process has not stopped.

Deforestation could lead to reductions in regional water cycling and precipitation, as well as affecting the global carbon cycle (Zeng, 1999). Many of the continent's dry land ecosystems are already subject to desertification (UNEP, 1999), grassland production could be reduced because of increasingly variable precipitation and likewise agricultural activities in specific parts of the continent may change in response to climatic shifts (Rosenzweig and Hillel, 1998). Determining likely climate change scenarios, modelling impacts of climate change, socio-economic planning and protecting the continent's biodiversity all call for regular monitoring of land cover.

Systematic land cover maps for the entire continent have only been produced every decade or so since the 1970's. Earlier maps were compiled from diverse sources and are produced on coarse scales. Maps dating from the 1990's are based on data collected by Earth Observing satellites. Compared with the earlier maps these benefit from uniformity of observation across the continent and offer improved spatial detail. They do not however offer the thematic richness of the earlier products. The Land Cover map of South America for 2000 presented here offers a combination of spatial and thematic detail previously unavailable. The map uses data from microwave and optical sensors on Earth Observing satellites to map South America's land cover into more than 40 classes at a spatial resolution of 1 km. Mapping to these levels of detail has only been possible because of recent advances in Earth Observing satellite technology and because of the involvement of scientists from South America and Europe with profound expertise in the continent's regional land cover. The quality of the final product stands testimony to the advantages of international scientific co-operation and provides an essential assessment of the continent's land resources at the turn of the new millennium.

Alan Belward

Head of the Global Vegetation Monitoring Unit
December 2002

Figure 2: SPOT VGT mosaic of South America.

1. Introduction

1.1. Objectives and presentation of the map

The need to document the extent and condition of the world's ecosystems is well recognised. This is especially true in tropical areas, where land cover change has been unprecedented in recent decades. The advent of Earth orbiting satellites has facilitated the task of mapping and monitoring many of the areas, hitherto difficult to access. This map follows the first TREES map (Eva et al., 1999), which focused on the humid forests of tropical South America and was based on 1992 satellite imagery. The new map is much more than an update of the TREES I map, in that it presents a larger geographic region (all of South America), has more reliable spatial data, and a higher thematic content. These improvements are due to the increased availability of higher quality satellite data. The original TREES I map was created from a single source data(NOAA-AVHRR), which were designed for meteorological purposes, rather than for vegetation monitoring. The new map enables us to monitor some of the major trends in deforestation that have occurred over the last ten years. Whilst the spatial resolution of the satellite imagery is not adequate to detect small openings in the forest cover or selective extraction, it is capable of detect the main changes that occur. It is therefore a valuable document both from which to base finer studies and for directing research, aid and development programmes. The data are available for downloading through the internet.

1.2. Previous maps of South America

Several continental cartographic studies have already been undertaken: Holdridge et al. (1971), a "life-zone system" based on bio-climatic factors, rainfall and temperature; Hueck's (1972) map of potential vegetation (at 1: 8.000.000); the UNESCO (1981) Vegetation map of South America at 1:5.000.000 classifying vegetation types considering their bioclimatic and ecological context and according their physiognomic and phenologic characteristics. The World Conservation Monitoring Centre (WCMC) has collated information from national map sources to produce continental forest cover information (Harcourt and Sayer, 1996). The Woods Hole Research Center (Stone et al., 1994) and the International Geosphere Biosphere Program (IGBP) (Loveland et al. 1999) have both produced maps of South America using data from the same satellite as was used for the TREES I map.

1.3. Applications of such maps

The spatial resolution of the map (1 km pixel resolution) does not allow for accurate determination of land cover trends. For many classes the spatial fragmentation of the land cover leads to an overestimation / underestimation of land cover classes depending on the spatial arrangement of that class. However, for most of the continent this resolution obtains good results taking into account the mean size of agricultural areas or vegetation communities.
The thematic accuracy of such maps is high at aggregated levels. Thus leaving the classification at the level of forests, shrublands and grasslands results in a higher class confidence than more specific class labels. At the same time, comparisons with the previous maps should only be made at the qualitative level. It would be exceedingly rash to attempt to measure land cover change between the current map and the previous TREES map. An appropriate approach for such an exercise would be to use the perceived changes between such maps in stratification approach for the application of finer spatial resolution data (Achard et al., 2002).

2. Methodological approach

2.1. Use of multi-resolution satellite data

A number of different types of remotely sensed data are available for vegetation mapping at continental scales, each of these sources has its own potential application. Whilst previous maps have been derived from single source data, we use four sets of satellite information to create the map. Each of the sources of data used, outlined below, contribute to mapping a specific ecosystem or land cover, seasonality or water regime.

2.1.1. Along Track Scanning Radiometer

The Along Track Scanning Radiometer (ATSR-2) is on board the ERS-2 satellite. The sensor acquires data in two 'looks', one forward and one at nadir, each with a 500 km swath. The data are at nominal 1 km spatial resolution, and available in visible, near-infra read, middle infra-red and thermal bands. The data are provided with embedded geolocation points, which allow for an automatic correction. A repeat cycle of 9 days is possible at the equator. The middle infra-red and thermal bands allow good discrimination between dense humid forests and non-forests (Figure 3). The fine spectral bandwidths allow for the detection of some specific humid forest types, notably mangroves and bamboo dominated areas. Between 1999 and 2001 over 1000 ATSR images of Latin America were acquired in near-real-time through the European Space Agency's world wide web server. The ATSR data were corrected to top of atmosphere reflectance, by applying the calibration tables provided by the sensor designers, Rutherford Appleton Laboratories (http://www.atsr.rl.ac.uk/). The data were composited together into a continental mosaic by selecting pixels with the highest surface temperature. This produced a "dry season" mosaic, in which the evergreen forests, both tropical and temperate, are clearly delineated from the seasonal formations.

2.1.2. SPOT VGT instrument

The SPOT VGT sensor onboard the SPOT 4 satellite is similarly a 1 km resolution sensor. It is one of the first sensors to be specifically designed for global vegetation monitoring. It has a 2000 km swath enabling a daily acquisition of data even at the equator. It samples data in the visible (blue and red), near and middle infra-red, but has no thermal imaging capacities. The daily availability of data, make the VGT instrument invaluable in monitoring the seasonality of vegetation formations, especially in tropical areas, where cloud free data are difficult to acquire. The VGT data were provided by VITO in both S10 (ten day composites) and S1 (daily) images were acquired (www.vgt.vito.be). The S10 data were composited into four mosaics, boreal winter, spring, summer and autumn (Figure 2). The selection process was undertaken by selecting the image with the lowest SWIR value after cloud screening. At the same time the ten day vegetation (Normalised Difference Vegetation Index, NDVI) profiles were synthesised into monthly products.

2.1.3. JERS-1 radar data

The Global Rain Forest Mapping project (GRFM), an international collaborative effort led and managed by the National Space Development Agency of Japan (Rosenqvist, 1996) has produced regional satellite mosaics of the humid tropical ecosystems of the world derived from the JERS-1 L band SAR. The data come as full mosaics covering the humid forests, geometrically corrected at a nominal 100m pixel with backscatter scaled to 8 bit resolution. Two mosaics were produced of South American tropical forests, one *the high water mosaic,* coinciding with the high water period of the Amazon river at Manaus, (May-July 1996) and the other *low water mosaic* produced from data (September-December 1995) to coincide with the low water period. The radar backscatter is amplified by the presence of water under the forest canopy, in an effect called double bounce. Thus an inter-comparison of the two mosaics gives an indication of areas of major regions of flooded forests.

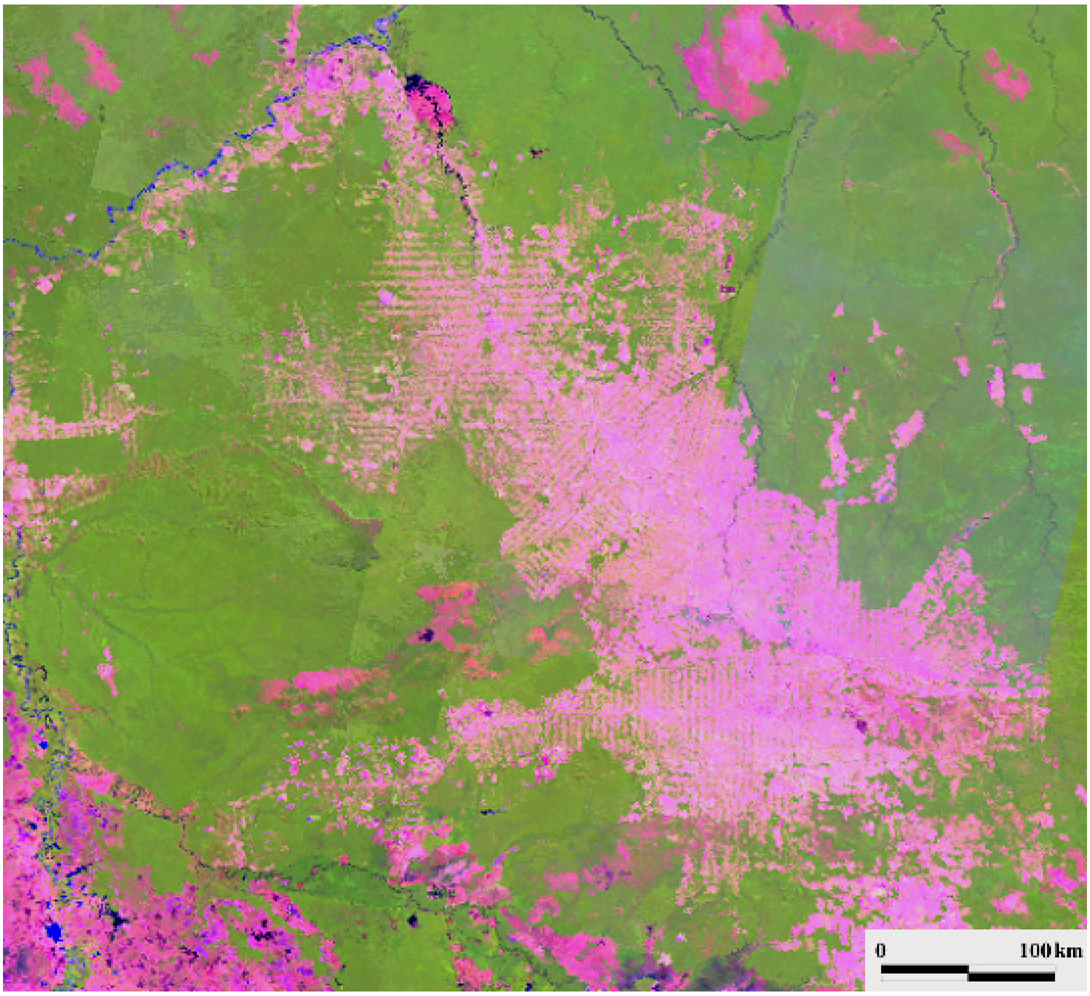

Figure 3: ATSR-2 image of Rondônia

2.1.4. DMSP data

The Defence Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) has a unique low light imaging capability originally developed for the detection of clouds using moonlight. It can also detect human settlements, fires, gas flares, heavy lit fishing boats, lightning and aurora (Elvidge et al., 1997). The sensor has two spectral bands (visible and thermal infra-red) and a swath of around 3000 km. The OLS has low light sensing capabilities which go down to 9-10 watts which is much lower than comparable bands of other sensors such as NOAA AVHRR or Landsat Thematic Mapper. By monitoring the frequency of light sources, the location of human settlements can be determined, so-called "stable lights".

2.1.5. The digital elevation model - GTOPO30

Altitude thresholds for the montane forests were set using the US Geological Survey's 30 arc-second database "GTOPO30" (USGS, 1997; Bliss and Olsen, 1996). This database was amended in Venezuelan Guayana according to the topographic map of the region provided by Berry et al. 1995.

2.2. Image classification techniques

2.2.1. Humid forest cover from ATSR data

An unsupervised clustering algorithm (ISODATA) was used to produce 50 spectral classes from the ATSR mosaic. The fifty classes were then assigned as humid forest, interface class or non-humid forest. The class assignment was done using visual interpretation aided by thematic maps and class spectral statistics. The interface class was usually interpreted as a seasonal forest formation, an open forest or humid forest formations degraded by anthropogenic activity. It was noticed that two distinct forest formations, bamboo dominated areas and mangroves, formed separate spectral classes.

2.2.2. Other vegetation formations from SPOT VGT data

The ATSR forest humid forest class was used to mask out the humid forest areas from the SPOT VGT data. The remaining area "non humid forest" was classified using the unsupervised clustering algorithm into fifty classes. The interpretation of these classes was again undertaken by visual examination of the classes in conjunction with the examination of the monthly NDVI profiles and local maps.

2.2.3. Flooded forests from JERS data

A difference mosaic was created from the two JERS mosaic, highlighting the areas where a significant radiometric change occurred between the two acquisition dates (high water and low water). Visual interpretation was used to set an appropriate threshold to discriminate areas of flooding from signal fluctuation. The resultant layer was crossed with the forest layer obtained from the ATSR data, to give a seasonally flooded forest layer.

2.2.4. Urban areas from the DMSP stable lights

Due to the scattering of light, the DMSP data tend to overestimate the urban extent. The data set have therefore been used as a seeding layer to locate the presence of large urban areas in the SPOT VGT data set. A mask was created from the stable lights data to extract the corresponding areas from the SPOT data, which was then classified using ISODATA into ten thematic classes. Visual interpretation was used to retain those classes related to urban areas.

2.2.5. Ancillary data sets

Forest and land cover maps were assembled to aid in the labelling of spectral classes. These cover the majority of the land surface of South America, from continental maps to country and regional maps. In addition to this, maps and information on the spatial distribution and characteristics of ecosystems were collected from the literature (Tables 1 & 2).

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Table 1: Ancillary sources of information for class labelling

Biome	Source
Tropical rain forests	Wirth et al. 2001, Oliveira & Nelson 2001, Ducke & Black 1953, De Granville 1988, Gentry 1990 1995 & 1996, Pires & Prance 1985, Clark & Clark 2000, Berry et al. 1995, Veillon 1989, ter Steege et al. 1995 2000, Molino & Sabatier 2001, Pires 1984, Prance 1989, FAO 1981, Huber 1995, Huber et al. 1988b.
Tropical dry forests	Bullock et al.1995, Parker et al. 1993, Bucher 1982, Sampaio 1995, Adamoli et al. 1990, Spichiger & Ramella 1988, FAO 1981, Ratter 1992, Killeen et al. 1998, Kellman et al. 1994.
Flooded forests / mangroves	Adis 1984, Junk 1989, Lescure & Tostain 1989, Pires & Prance 1985.
Montane forests	Haber et al.2000, Stadtmüller 1987, Cavelier & Etter 1995
Montane grasslands	Balslev & Luteyn 1992.
Shrublands	Huber 1988a, Berry et al. 1995, León, et al.1998, Paruelo et al. 1998a & b APN 1999.
Tropical grasslands	Huber et al. 2001, Berry et al. 1995, Sarmiento 1983, Ratter 1992, Barbosa 1996, Eiten 1982, Pires & Prance 1985, Killeen 1990, Klink et al. 1993.
Temperate grasslands	Guerschman et al 2002, Soriano 1993 ,León, et al. 1998 Paruelo et al. 1998 2001 , APN 1999.
Temperate forest	Armesto et al. 1998, Veblen et al. 1996, CI 1992, Neira et al. 2002 ,León, et al. 1998, Paruelo et al.1998 APN 1999

Table 2: Maps available for class labelling

Region	Map
Continental	Holdridge 1971, Hueck & Seibert 1972, UNESCO 1981, World Bank 1995.
Argentina	APN 1999.
Bolivia	MDSMA 1995.
Brazil	IBGE 1995, RADAMBRAZIL 1973-1978, SOSMA 1992.
Chile	Neira et al. 2002.
Colombia	IGAC 1987.
Guianas	Huber et al. 1995, ter Steege 2001.
Ecuador	Sierra 1999, Sierra et al. 1999b.
Peru	INRENA 1996.
Venezuela	Huber and Alarcón 1988, Huber 1995.

Table 3: Correspondence between the regional legend and the global legend

GLOBAL LEGEND	REGIONAL LEGEND
Tree Cover, broadleaf evergreen	Closed evergreen tropical forest
	Open evergreen tropical forest
	Bamboo dominated forest
	Closed semi-humid forest
	Open semi-humid forest
	Temperate closed evergreen broadleaf
	Montane evergreen forests
Tree Cover, broadleaf, deciduous	Closed deciduous forest
	Open deciduous forest
	Closed semi deciduous forest
	Open semi deciduous forest
	Semi deciduous transition forest
	Temperate closed deciduous broadleaf
	Temperate open deciduous broadleaf
	Montane deciduous forests
Tree Cover, regularly flooded: Mangrove	Mangroves
	Fresh water flooded forests
	Permanent swamp forests
Tree Cover, needleleaf, evergreen	Forest plantation*
Tree Cover, mixed phenology or leaf type	Temperate mixed evergreen broadleaf
	Montane mixed forests
Cultivated and managed areas	Agriculture – intensive
Cropland / Other natural vegetation (non-trees)	Mosaic agriculture / degraded vegetation
Cropland / Tree Cover	Mosaic agriculture / degraded forest
Herbaceous Cover, closed-open	Grass savannah
	Shrub savannah
	Moorlands / heathlands
	Closed montane grasslands
	Open montane grasslands
	Closed steppe grasslands
Sparse Herbaceous or sparse shrub cover	Open shrublands
	Open steppe grasslands
	Sparse desertic steppe shrub /grassland
Shrub Cover, closed-open, evergreen	Closed shrublands
Regularly flooded shrub and/or herbaceous cover	Periodically flooded shrublands
	Periodically flooded grasslands
Bare Areas	Barren / bare soil
	Desert
	Salt pans
Water Bodies (natural & artificial)	Water bodies
Snow and Ice (natural & artificial)	Permanent snow /ice
Artificial surfaces and associated areas	Urban

3. Legend

3.1. Classification scheme

The classification scheme for the legend is based on vegetation structural categories (Eiten, 1968). At the first level, the classes are broadly grouped as:

- forests
- shrublands
- grasslands
- agricultural lands
- barren surfaces
- water, ice and snow

Subsequently, we introduce percentage vegetation cover (open/closed), seasonality, flooding regime, climate and altitude. The latter two, altitude and climate, are introduced for ecological reasons – a separation of tropical vegetation forms from temperate ones, and of highland ones from lowland ones. At times this presents methodological problems, notably in areas of low vegetation cover which may be classified as - steppe / barren / desertic. Details of the class definitions are given in Table 3. The map legend has been prepared in four different languages (Tables 6 & 7, Annex 6.3).

3.2. Correspondence with the GLC 2000 global legend

Within the scope of the GLC 2000 mapping exercise (Belward et al., 2003), a common global legend has been proposed to satisfy the requirements of global mapping, whilst remaining thematically accurate at the local level. To this end a global legend, based on the FAO LCCS (Land cover classification system - Di Gregorio and Jansen, 2000) has been developed. Table 3 shows the correspondence between the South America regional map legend and the Global map.

3.3. Forest classes

Tree canopy cover is greater than 40% and height greater than 5 metres. Closed forests are with canopy cover greater than 70% and open forests with canopy cover between 40 and 70%.

3.3.1. Humid tropical forest

Evergreen broadleaf forests

Forests with less than 1 month dry season. This includes the *terre firme* forests of the Orinoco and Amazon basins, the Colombian *Choco*, the Guiana shield and the Atlantic forests of Brazil. Within this domain, certain areas exhibit a minor dry season. In the current version of the map, it has not been possible to discriminate these areas.

Evergreen broadleaf forests with bamboo dominance

The bamboo-dominated forests (*pacales*) of the Brazilian state of Acre and of east Peru have been mapped. Whilst areas of bamboo-dominated forest exist on many mountain areas, these have been impossible to distinguish from illumination effects and from degradation

.

Semi-humid evergreen forests
Forests with less than 3 months dry season. Forests located in the north-east Brazil on the interface between the dry *caatingas* and the humid evergreen forest. These forests exhibit a small dry season of around 2 months.

3.3.2. Dry tropical forests

Deciduous and semi-deciduous tropical forest
Forests with more than 3 months dry season. The main contiguous areas are the Bolivian *Chaco* and the *Caatingas* of north east of Brazil. Both these areas are heavily affected by anthropogenic activity. The *Chaco* is often described as a low forest, mainly as much of the high grade timber has been removed. The *Caatingas* are a more open forest, combined with a dense shrub undergrowth. The formations on the uplands of eastern Brazil, from the Serra da Capivara down through the Chapada Diamantina (forest to *cerradão*) are also included in this class. Dry forest formations occur in the Peruvian Andes and the Caribbean coast of Venezuela as well as gallery forests of the Venezuelan *llanos*.

Semi-deciduous transition tropical forest
A geographically specific forest formation. The *Chiquitania* forest of northern Bolivia forms a transition between the humid closed evergreen forests of the Amazon basin and the more open dry deciduous forests of the *Chaco*. As such, the forest has a short dry season, around September.

3.3.3. Flooded tropical forests

Coastal flooded tropical forests - mangroves
Forests permanently under the influence of salt water. Due to the course spatial resolution of the sensor only the major mangrove areas are mapped. These are found almost continually along the coast from the Orinoco delta to northern Amapá. In northeast Brazil the major formations occur between Belém and São Luis and again at Salvador. In Colombia, mangroves have been mapped at Santa Marta and around Tumaco. Further south they are found at Guayaquil in Ecuador and Tumbes in Peru.

Periodically fresh water flooded tropical forests
Riparian forests flooded for less than 5 months a year. Many *igapó* and *várzeas* are found along the water courses of South America. Those mapped are the major areas which include stretches of the Amazon, with significant flooded forests at Mamirauá along the Solimões, the Purus, and the Guaporé on the Brazil-Bolivian frontier, as well as the upper reaches of the Rio Negro. In southern Amazonas, Venezuela, the region between the Orinoco and Amazon basin also has large areas of flooded forest. In central Guyana the upper reaches of the Repununi and Mazaruni rivers have extensive flooded forests. Coastal flooded forests and swamps are found from the delta of the Orinoco to the river Maroni on the Suriname-French Guiana border, and again from northern Amapá (Cabo Orange) down to the mouth of the Amazon, where the west of the island of Marajó is dominated by this ecosystem.

Permanently flooded forests
Forests flooded for more than 5 months a year. The major area mapped in this class is in Peru where the large swamp region of the Pastaza fan exhibits seasonal flooding resulting in open palm swamps (*Aguajales*) and permanent swamps. In Brazil, parts of the forest near the Amapá coast, and the western part of the island of Marajó and the courses of the Guaporé river are found to be permanently inundated.

3.3.4. Temperate forests

Evergreen broadleaf temperate forests, evergreen mixed broad and needleleaf forests, seasonal broadleaf forests.

Forests occurring at latitudes south of the 30° S parallel

The three classes of temperate forests mapped occur in the southern cone of Chile and Argentina and consist of evergreen, deciduous, needle and broadleaf forests dominated by the *nothofagus* species. It was not found possible to discriminate pure needleleaf forests. The evergreen rain forests (Valdivian, North Patagonian and Magellanic) are on the Pacific coast of South America from Valdivia to Tierra del Fuego, while the seasonal broadleaf forests predominate between Santiago de Chile and Concepción, and on the east side of the Andes down to Patagonia and Tierra del Fuego.

3.3.5. Montane forests

Forests occurring between 500m and 1000 m and at greater than 1000m above mean sea level are classed separately. The montane forests occur predominately in the Andes and in the Guiana shield.

3.4. Shrubland classes

Shrub canopy cover is greater 20% and canopy height less than5 metres

3.4.1. Shrublands

Extensive shrubland formations have been mapped in Argentina (*espinal* and *monte* vegetation formations); *matoral* formations are found along the Andes reaching down into Chile; in Brazil the *cerradão* and degraded formations in the *caatingas* are mapped in this class. In Bolivia part of the dry *chaco* is mapped as shrublands rather than forest. The transition between *monte* and steppe grasslands is mapped as open shrublands.

3.4.2. Periodically flooded savannah shrublands

Shrublands flooded for 2 or more months a year .The region north of the Rio Negro and along the Rio Branco in Roraima, Brazil, have several shrublands periodically inundated.

3.5. Grassland classes

Herbaceous cover greater than 10% .Tree and shrub canopy cover less than 20%.

3.5.1. Tropical savannahs

Savannah grasslands

*Herbaceous tropical vegetation with a dry seaso greater than 4 months.*The main tropical savannah regions mapped are the Venezuelan *llanos*, the Gran Sabana / Rio Branco / Rupununi savannah, the Bolivian *llanos* of Moxos , and *campos limpos* in Brazil. In Uruguay and Argentina the *pampa* is classified as agriculture or steppe grasslands.

Shrub savannah

Tropical grasslands with 10 to 20% shrubs. The Brazilian *cerrado* is classed as a shrub savannah, although much of is now under agricultural development. The Puciari-Humaitá savannahs near Pôrto Velho are in this class.

Periodically flooded savannah grasslands

Savannahs with less than 5 months flooding a year. Five main areas of flooded savannah are distinguished on the map; in the llanos of Venezuela/ Colombia extensive areas flood as do the northern parts of the Río Atrato and the Río Magdalena in northern Colombia. Along the Amazon and its tributaries, many *campos de várzea* are found. In central Brazil the Ilha do Bananal on the Rio Araguaia, and in Mato Grosso the Pantanal, see a seasonal extension of the wetlands, along with the east of the island of Marajó and savannahs in Amapá. In Bolivia, parts of the *llanos* of Moxos, and further south on the west bank of the Paraguay river, the wet *Chaco* are seasonally flooded. Extensive flooding is also found south of the confluence of the Paraná and the Paraguay and on the lower reaches of the Río Plata.

3.5.2. Moorlands

Mosaic class of bogs, herbaceous and shrub vegetation in the humid temperate region with more than 20% vegetation cover all year round. This class is mapped in the south of Chile and Argentina on the Pacific coast and is sometimes known as Magellan moorlands, with water-logged soils, scattered bogs and heaths.

3.5.3. Montane grasslands

Herbaceous vegetation at altitudes greater than 1000 m with open (10 - 40%) and closed (>40%) formations. The Andean grasslands, *parimo*, *jalca* and *puna* are distinguished from the tropical and temperate grasslands in this class.

3.5.4. Steppe vegetation

Herbaceous vegetation in the sub tropical zone (south of 22 S)with a clear dry season. Open (10-40%) and closed (>40 %) formations. Parts of the *pampa* of Uruguay and Argentina have been mapped as closed steppe grassland. Some of the dry montane *puna* is mapped as open steppe vegetation along with Patagonian grasslands, which are more desertic.

3.6. Land with little or sparse vegetation

Areas with less than 10% vegetation cover.

3.6.1. Sparse vegetation

Vegetated (up to 10% cover) for more than 4 months a year. Sparse vegetation includes xerophytic coastal vegetation from the Caribbean coast to Chile and desertic steppe in Patagonia. Small areas of the altiplano also come under this class.

3.6.2. Barren or bare soil

Unvegetated. Areas deemed as barren, often volcanic or with a high saline content, are found in the altiplano , and sometimes called desertic *puna*. In northeast Brazil several areas in the *caatingas* are found to be barren.

3.6.3. Deserts

Vegetated (up to 10% cover) for less than 4 months a year. Found mostly on the pacific coast stretching from south of Tumbes in Peru, to Antofagasta in Chile. In the Bolivian Andes several regions are mapped under this class.

3.6.4. Salt pans

The two main salt pans, *Salar de Uyuni* and *Salar de Coipasa*, in Bolivia are mapped.

3.6.5. Permanent ice and snow

In tropical America, the Cordillera Blanca (mt. Huascarán at 6768m) is the main area in this class. In the southern cone, the Patagonian ice gaps and permanent snow on the Cordillera Darwin are mapped.

3.6.6. Water bodies

No distinction is made between natural and man-made water bodies.

3.7. Agricultural classes

3.7.1. Intensive agriculture

Areas with over 70% cultures or pastures. Regions of intensive cultivation and/or sown pasture fall in this class. The main areas under such occupation are found in northwest Colombia, central and southern Brazil, and in Argentina. From a remote sensing point of view these areas are usually characterised by a period of bare soil (Gueschman et al., 2002).

3.7.2. Mosaic of agriculture and non-forest vegetation

Part of the Andean altiplano and of the north-east of Brazil (*sertão*) come under this class. It is often a mixture of pasture, cultivation and degraded natural vegetation. Degraded formations of dry forest, pasture and shrub savannah between the rivers Arauca and Portugues in the Venezuelan llanos are mapped in this class.

3.7.3. Mosaic of agriculture and degraded forest formations

This is a common class across South America and corresponds to shifting cultivations, agro-forestry, fragmented forests and secondary forest and rural complex (Mayaux et al. 1997). Major areas include settlements within the Amazonian forest (Rondônia, Acre, Florencia, Napo), valleys in Colombia, and the Esmeraldas coast of Ecuador. In Brazil northeast Pará is dominated by this class, as is much of the east coast from Natal to Vilha Velha, where the landscape is dominated by degraded formations of the Atlantic forest along with agriculture. In southern Brazil the region from São Paulo down to Santa Caterina exhibits similar land cover.

3.7.4. Forest plantations

The only forest plantations mapped are the pine plantations in the east of the Venezuelan *llanos*.

Table 4: Land cover class criteria

1. Forests: tree canopy cover is >40% and height >5 metres
   - Evergreen forests: less than 1 month dry season
   - Semi-evergreen forests: less than 3 months dry season
   - Deciduous forests: more than 3 months dry season
   - Closed forests: canopy cover > 70%
   - Open forests: canopy cover 40-70%
   - Temperate forests: forests occurring at latitudes > 30° south.
   - Lowland forests: forests occurring at altitudes < 500m amsl.
   - Montane forests: forests occurring at altitudes > 500 < 1000 m amsl; forests occurring > 1000 m amsl.
   - Mangroves: forests permanently under influence of sea water
   - Periodically flooded fresh water forests: riparian forests flooded for less than 5 months a year
   - Permanent swamp forest: forests flooded for more than 5 months a year

2. Shrublands: shrub canopy cover is >20% and height <5 metres
   - Dry shrublands without prolonged flooding
   - Periodically flooded fresh water shrublands flooded for 2 or more months a year

3. Grasslands: tree and shrub canopy cover <20%, herbaceous cover > 10 %
   - Savannahs: herbaceous tropical vegetation with a dry season >4 months
   - Shrub savannahs: herbaceous tropical vegetation with 10-20% shrubs and a dry season >4 months
   - Moorlands and heaths: mosaic class in the temperate region of bogs, herbaceous and shrub vegetation with > 20% vegetation cover all year round.
   - Montane grasslands: herbaceous vegetation at altitudes > 1000 m with open (10 - 40%) and closed (>40%) formations.
   - Steppe grasslands: herbaceous vegetation in the sub tropical zone (> 22 S)with a clear dry season. Open (10-40%) and closed (>40 %) formations.
   - Periodically flooded fresh water grasslands: flooded for more than 2 months
   -

4. Sparse and barren surfaces: < 10 % vegetation cover
   - Sparse desertic steppe shrub / grassland: vegetated (< 10% cover) for more than 4 months a year
   - Desert: vegetated (< 10% cover) for less than 4 months a year
   - Barren bare soil: unvegetated
   - Salt pans

5. Agriculture
   - Intensive agriculture: areas with over 70% cultures or pastures
   - Mosaic of degraded forest and agriculture
   - Mosaic of agriculture and other degraded natural vegetation

6. Non-vegetated land cover types:
   - Permanent snow/ice: snow/ice present throughout the year
   - Water bodies: Open water fresh or salt including seas, lakes, reservoirs and rivers
   - Urban: buildings, roads and other structures of anthropogenic origin

4. The distribution of the main vegetation formations

4.1. Thematic detail

An example of the thematic detail of the new vegetation map is shown in figure 4. The region from Manaus to Boa Vista in Roraima is shown. The map classes can be combined to show more generalised land cover distributions.

4.2. Continental distributions

In figures 5 to 8 we show the continental distributions of evergreen and seasonal forests, of shrublands, of grasslands and of wetlands. For the wetlands, the classes flooded forests, mangroves, flooded shrublands and flooded grasslands are shown.

4.3. Surface areas of major land cover types

The actual percentage cover of each land cover type is expressed in Table 5. The landcover of the continent is estimated to be 46% forests, 24% agriculture, 26% grasslands and steppe, 3% barren and 1 % water bodies.

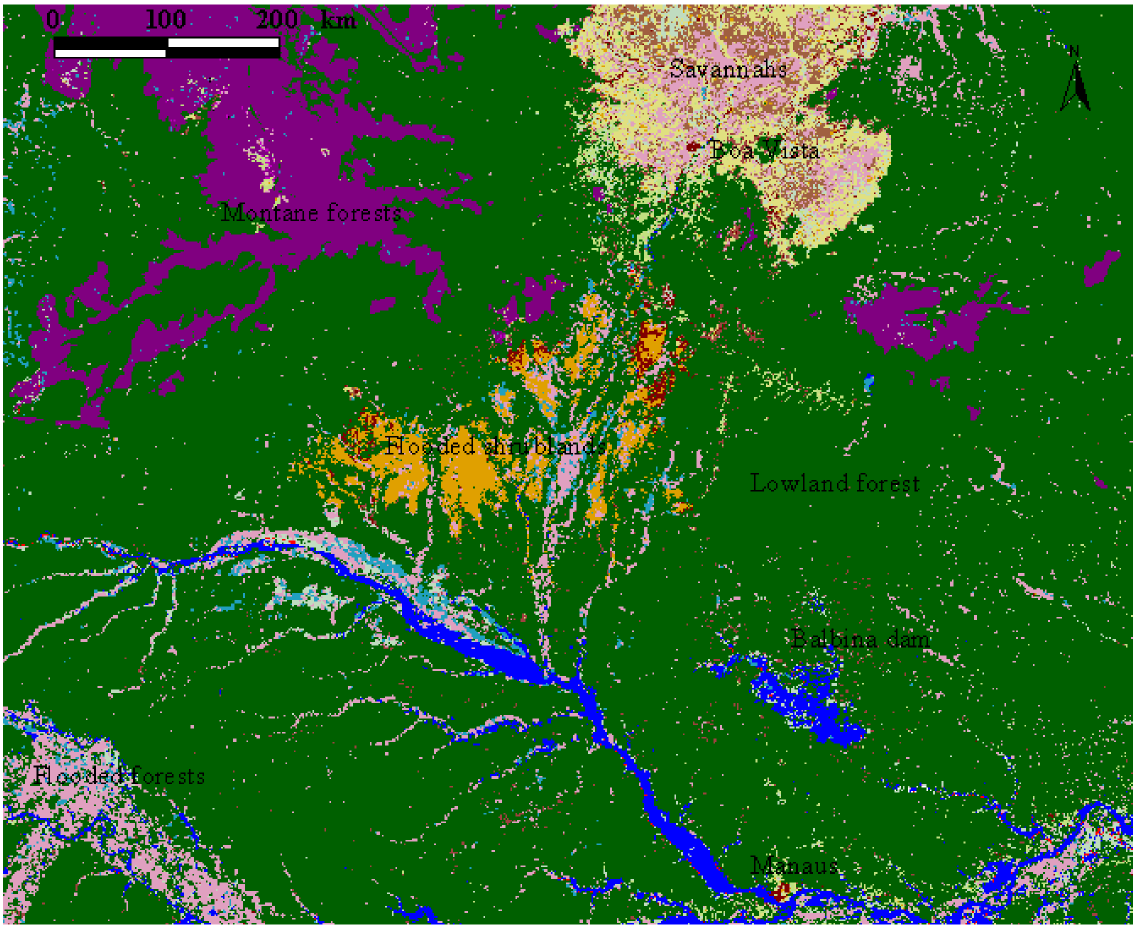

Figure 4: Map detail from the Rio Negro, north Brazil.

Table 5: Distribution of land cover classes in South America

Land cover class			*Surface area (sqkm)*	*Percentage*
Humid forests				
	Evergreen broadleaf -		6,218,476	35.0%
		Closed		
		Open		
		Bamboo dominated		
	Semi humid broadleaf		86,811	0.5%
		Closed		
		Open		
Dry tropical forests				
	Deciduous forests		1,115,736	6.3%
		Closed		
		Open		
	Semi deciduous forest		142,102	0.8%
		Closed		
		Open		
	Semi deciduous transition forest		209,354	1.2%
Flooded tropical forest				
	Coastal flooded forests - mangroves		17,290	0.1%
	Fresh water flooded forests		199,281	1.1%
	Swamp forests - open with palms		53,907	0.3%
Temperate forests				
	Evergreen broadleaf		61,720	0.3%
		Closed		
		Open		
	Evergreen mixed broad and needle leaf		29,556	0.2%
	Deciduous forests		105,519	0.6%
		Closed		
		Open		
Agriculture				
	Intensive		2,024,656	11.4%
	Mosaic of degraded non-forest vegetation		735,347	4.1%
	Mosaic of degraded forest vegetation		1,513,575	8.5%
	Forest plantations		3,360	0.0%
Grass and shrub lands				
	Savannah		350,934	2%
	Shrub savannah		738,371	4%
	Flooded savannah		320,941	2%
	Shrublands		1,425,769	7.9%
	Flooded shrublands		12,957	0.1%
	Moorlands / Heath		106,896	0.6%
	Montane grasslands		280,282	1.6%
		Closed		
		Open		
Steppe vegetation				
	Closed grassland		343,148	1.9%
	Open grassland		322,964	1.8%
	Sparse shrubland		566,717	3.2%
Land with little or sparse vegetation				
	Bare soil / barren		346,008	1.9%
	Desert		194,540	1.1%
	Salt pans		9,409	0.1%
Water bodies				
	Natural and artificial water bodies		220,219	1.2%
	Permanent ice and snow		23,877	0.1%
Urban			11,442	0.1%
			17,778,207	100.0%

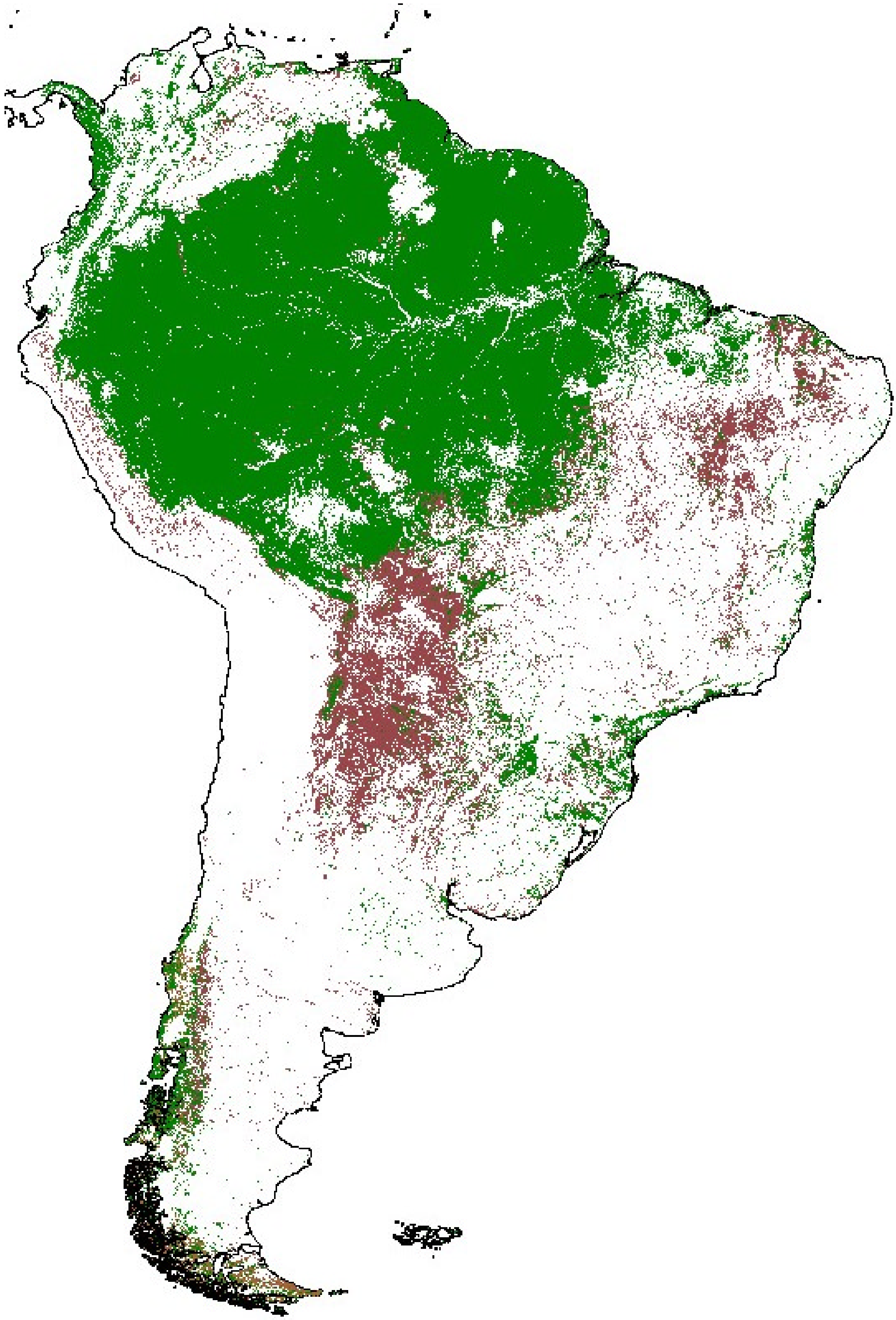

Figure 5: The distribution of humid and dry forests.

Figure 6: The distribution of shrublands

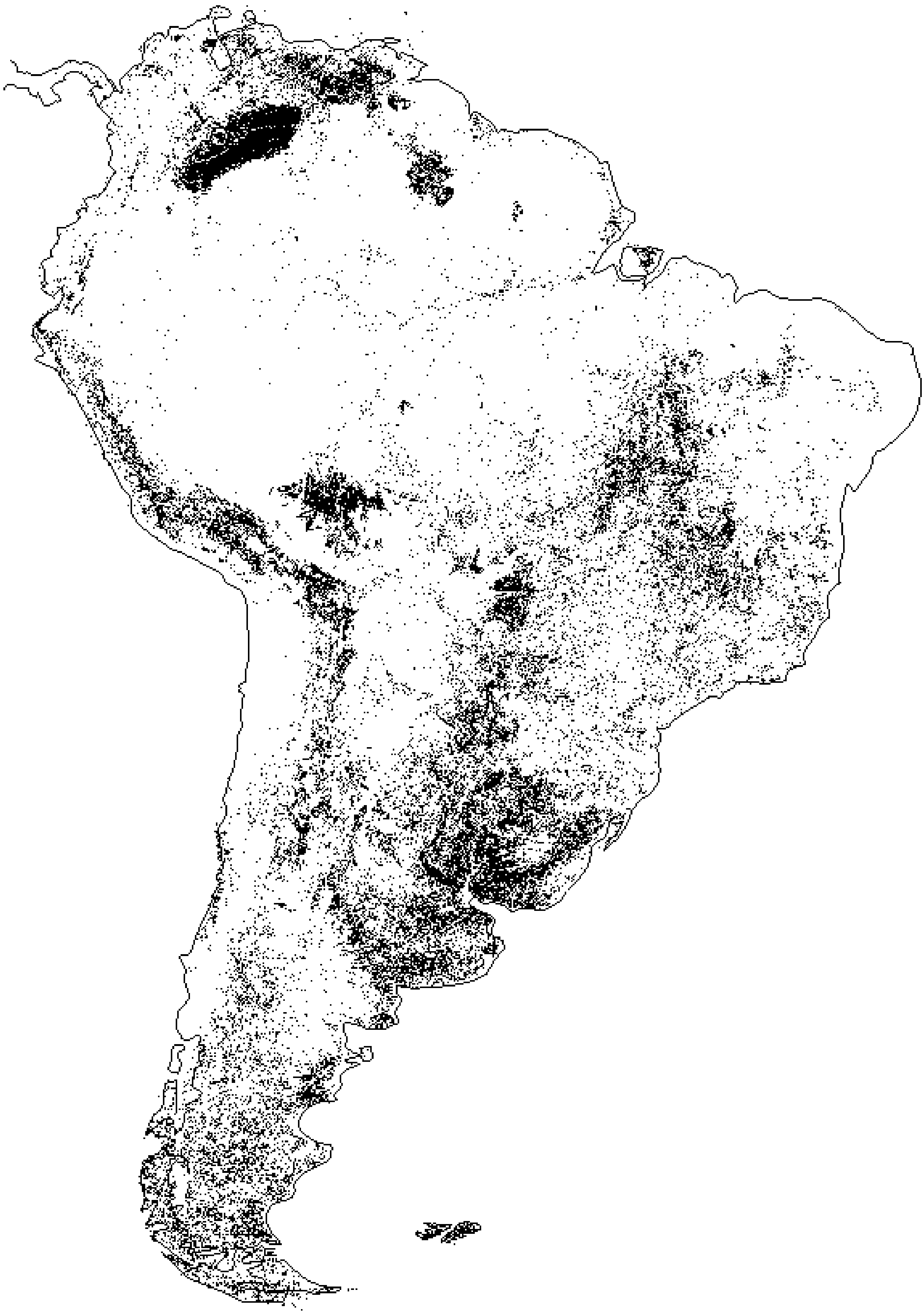

Figure 7: The distribution of grasslands

Figure 8: The distribution of wetlands

5. Data access and update

The map of South America along with these explicative notes can be requested from the Joint Research Centre, either through the Web pages of the Global Vegetation Monitoring Unit, or by electronic mail to the authors or the GLC 2000 project.

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Details of the digital data format are given in section 6.4 of this document. When using the ditigal data, please use this document as a reference.

H.D.Eva, E.E.de Miranda, C.M.Di Bella, V.Gond, et al., 2002, *A Vegetation map of South America*, EUR 20159 EN, European Commission, Luxembourg.

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8. Technical specifications

The data are available from the ftp site in BINARY or ESRI format.

Classes are grouped by thematic type (table 9), with lowland forests using classes between 10 and 44, non-forest classes between 50 and 90 and montane forests from 110 to 190. Note that many digital numbers are unassigned.

Table 6: Class groupings in the digital data

Classes	*Land cover types*
10-14	Lowland (< 500m) evergreen tropical forests
20-24	Lowland (< 500m) deciudous tropical forests
30-33	Lowland (<500m) forests under flooding regime
40-44	Lowland (< 500m) temperate forests
50-53	Agricultural classes
60-75	Grass and shrublands
80-84	Unvegetated
90	Urban
110-114	Montane forests 500-1000m - evergreen
120-124	Montane forests 500-1000m - deciduous
130-133	Montane forests 500-1000m - flooded
140-144	Montane forests 500-1000m - temperate
160-164	Montane forests >1000m - evergreen
170-174	Montane forests >1000m - deciduous
180-183	Montane forests >1000m - flooded
190-194	Montane forests >1000m - temperate

To create the montane classes, the digital evelation data was crossed with the basic land cover map. Then, 100 was added to those classes occurring on land between 500m and 1000m above sea level, and 150 was added to classes occurring on land over 1000m above mean sea level. Hence, closed semi-humid forests (class 13) occurring above 500m would be re-labeled as 113; closed semi-humid forests occurring above 1000m would are reclassed as 163. Note that a number of these classes, while mathematically possible, do not exist - *e.g.* flooded montane forests.

Table 7: Digital numbers of the land cover classes

Class	*Land cover*
10	Closed evergreen tropical forest
11	Open evergreen tropical forest
12	Bamboo dominated forest
13	Closed semi-humid forest
14	Open semi-humid forest
20	Closed deciduous forest
21	Open deciduous forest
22	Closed semi deciduous forest
23	Open semi deciduous forest
24	Semi deciduous transition forest
30	Mangroves
31	Fresh water flooded forests
33	Permanent swamp forests
40	Temperate closed evergreen broadleaf forest
42	Temperate mixed evergreen broadleaf forests
43	Temperate closed deciduous broadleaf forests
44	Temperate open deciduous broadleaf forests
50	Agriculture - intensive
51	Mosaic agriculture / degraded vegetation
52	Mosaic agriculture / degraded forests
53	Forest plantations (Llanos of Venezuela)
60	Grass savannah
61	Shrub savannah
63	Periodically flooded savannah
64	Closed shrublands
65	Open shrublands
66	Periodically flooded shrublands
67	Moorlands / heathlands
68	Closed montane grasslands
69	Open montane grasslands
70	Closed steppe grasslands
71	Open steppe grasslands
75	Sparse desertic steppe shrub /grasslands
80	Barren / bare soil
81	Desert
82	Salt pans
83	Water bodies

Class	*Land cover*
84	Permenent snow /ice
90	Urban
110	Montane forests 500-1000m - dense evergreen
111	Montane forests 500-1000m - open evergreen
112	Montane forests 500-1000m - bamboo
113	Montane forests 500-1000m - closed semi humid
114	Montane forests 500-1000m - open semi humid
120	Montane forests 500-1000m - closed deciduous
121	Montane forests 500-1000m - open deciduous
122	Montane forests 500-1000m - closed semi -deciduous
123	Montane forests 500-1000m - open semi- deciduous
124	Montane forests 500-1000m - transition forest
130	Montane forests 500-1000m - flooded forest
131	Montane forests 500-1000m - flooded forest
133	Montane forests 500-1000m - flooded forest
142	Montane forests 500-1000m - temperate mixed
143	Montane forests 500-1000m - closed temperate deciduous
144	Montane forests 500-1000m - open temperate deciduous
160	Montane forests >1000m - dense evergreen
161	Montane forests >1000m - open evergreen
162	Montane forests >1000m - bamboo dominated
163	Montane forests > 1000m - closed semi humid
164	Montane forests > 1000m - open semi humid
170	Montane forests >1000m - closed deciduous
171	Montane forests >1000m - open deciduous
172	Montane forests >1000m - closed semi -deciduous
173	Montane forests >1000m - open semi- deciduous
174	Montane forests >1000m - transition forest
180	Montane forests > 1000m flooded forest
181	Montane forests > 1000m flooded forest
182	Montane forests > 1000m flooded forest
183	Montane forests > 1000m flooded forest
190	Montane forests >1000m -temperate closed broadleaf
192	Montane forests >1000m - temperate mixed
193	Montane forests >1000m - closed temperate deciduous
194	Montane forests >1000m - open temperate deciduous

9. Legend translations

Tables 6 and 7 on the following pages give the translations of the legend in French, Spanish and Portuguese.

Table 8: The legend in French English Spanish and Portuguese – Forest classes

Forêts de plaine et d'altitude	**Lowland and upland Forests**	**Bosque de areas bajas y altas**	**Florestas de terras altas e baixas**
Forêts humides	*Humid forests*	*Bosque húmedo*	*Florestas úmidas*
Forêts feuillues sempervirentes	Evergreen broadleaf -	Latifoliadas siempreverdes	Florestas ombrófilas
Fermées	Closed	Cerrado	Densa
Ouvertes	Open	Abierto	Aberta
Bambous dominant	Bamboo dominated	Domindado por Bambú	Dominada por Bambú
Forêts feuillues semi-humides	Semi humid broadleaf	Latifoliadas subhumedas	Florestas estacionais semi-deciduais
Fermées	Closed	Cerrado	Densa
Ouvertes	Open	Abierto	Aberta
Forêts tropicales sèches	*Dry tropical forests*	*Bosque tropical xerico*	*Florestas tropicais secas*
Forêts décidues	Deciduous forests	Bosques caducifolio	Florestas estacionais deciduais
Fermées	Closed	Cerrado	Densa
Ouvertes	Open	Abierto	Aberta
Forêts semi-décidues	Semi deciduous forest	Bosque semi caducifolio	Florestas estacionais semi deciduais
Fermées	Closed	Cerrado	Densa
Ouvertes	Open	Abierto	Aberta
Forêts semi-décidues de transition	Semi deciduous transition forest	Bosques semideciduos de transicion	Florestas de transição semi deciduais
Forêts tropicales inondées	*Flooded tropical forest*	*Bosque tropical inundable*	*Florestas tropicais inundáveis*
Forêts côtières inondées - mangroves	Coastal flooded forests - mangroves	Bosques costeros inundables - manglar	Manguezais
Forêts inondées en eau douce	Fresh water flooded forests	Bosque inundable de agua dulce	Igapós, Várzeas
Forêts galeries	Gallery forests	Bosques en galeria	Florestas de galeria
Forêts marécageuses - ouvertes avec des palmiers	Swamp forests - open with palms	Bosque de humedal - abierto con palmeras	Florestas hidrófilas - abertas com palmeiras
Forêts tempérées	*Temperate forests*	*Bosques templados*	*Florestas temperadas*
Forêts feuillues sempervirentes	Evergreen broadleaf	Latifoliadas siempreverdes	Latifoliadas sempre-verdes
Fermées	Closed	Cerrado	Densa
Ouvertes	Open	Abierto	Aberta
Forêts sempervirentes mixtes de conifères et de feuillus	Evergreen mixed broad and needle leaf	Bosque mixto de coniferas y latifolidas siempreverde	Florestas mistas de coníferas e latifoliadas sempre-verdes
Forêts décidues	Deciduous forests	Bosque caducifolio	Florestas estacionais deciduais
Fermées	Closed	Cerrado	Densa
Ouvertes	Open	Abierto	Aberta

Table 9: The legend in French English Spanish and Portuguese – Non-forest classes

Classes non-forestières	Non-forest classes	Clases no Bosque	Classes não florestais
Agriculture	*Agriculture*	*Agricultura*	*Agricultura*
Intensive	Intensive	Intensiva	Intensiva
Mosaïque de végétation non-forestière dégradée	Mosaic of degraded non-forest vegetation	Mosaico de vegetacion no arborea degradada	Mosaico de vegetação não arbórea degradada
Mosaïque de végétation forestière dégradée	Mosaic of degraded forest vegetation	Mosaico de vegetacion arborea degradada	Mosaico de vegetação arbórea degradada
Forêts de plantation	Forest plantations	Plantaciones florestales	Plantações florestais - Reflorestamentos
Fourrés et prairies	*Grass and shrub lands*	*Praderas y arbustales*	*Campos, cerrados e estepes*
Savanes tropicales	Tropical savannahs	Sabanas tropicales	Savanas tropicais
Savanes	Savannah	Sabanas graminosas	Savanas
Savanes arbustives	Shrub savannah	Sabanas graminosas y arbustivas	Savanas arbustivas
Savanes herbeuses	Sparse grassland	Pastizal abierto	Campos limpo
Savanes inondées	Flooded savannah	Sabanas inundables	Campos inundáveis
Fourrés	Shrublands	Arbustales	Formações arbustivas
Fermés	Closed	Cerrado	Fechado
Ouverts	Open	Abierto	Aberto
Fourrés inondés	Flooded shrublands	Inundables	Campinarama
Landes	Moorlands / Heath	Turberas	Campos rupestres
Prairies de montagne	Montane grasslands	Pastizales de altura	Campos de altitude
Ouvertes	Closed	Cerrado	Denso
Fermées	Open	Abierto	Aberto
Steppes	Steppe vegetation	Vegetación de estepa	Estepes
Prairies fermées	Closed grassland	Pastizal cerrado	Campos fechados
Prairies ouvertes	Open grassland	Pastizal abierto	Campos abertos
Steppes arbustives	Sparse shrubland	Arbustal poco denso	Arbustiva pouco densa
Terre avec peu ou végétation éparpillée	*Land with little or sparse vegetation*	*Suelo con vegetación escasa o dispersa*	*Solos com vegetação esparsa ou dispersa*
Sol nu	Bare soil / barren	Suelo desnudo y roca	Rochas e solo nu
Désert	Desert	Desierto	Deserto
Sel	Salt pans	Salar	Áreas salinizadas
Eau	*Water bodies*	*Cuerpos de agua*	*Corpos d'água*
Plans d'eau artificiels ou naturels	Natural and artificial water bodies	Cuerpos de agua naturales y artificiales	Corpos d'água naturais e artificias
Glace et neige permanentes	Permanent ice and snow	Hielos permanentes y nieve	Áreas com neves eternas
Milieu urbain	*Urban*	*Areas Urbanas*	*Áreas Urbanas*

European Commission

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Abstract

A vegetation map of South America has been produced using multi-sensor satellite observations at a spatial resolution of 1 km. The map highlights the major vegetation formations throughout the continent with an improved thematic content over previous land cover maps, identifying over 40 land cover classes. The majority of the data used were acquired in the year 2000 giving an unprecedented up-to-date overview of the continent's land cover.

10. Accompanying maps in the series

This map has been produced as part of the Global Land Cover mapping exercise and the Global Burnt Area mapping excerise, organised and led by the Joint Research Centre's Global Vegetation Monitoring Unit, based in the Insistute for Environment and Sustainability. A global land cover map and global burnt area map has been assembled from the regional maps produced by the GVM unit and partner institutions.

For an overview of the project:

E. Bartholomé, A. S. Belward, F. Achard, S. Bartalev, C. Carmona-Moreno, H. Eva, S. Fritz, J-M. Gregoire, P. Mayaux, and H-J. Stibig, 2002, *GLC 2000: Global Land Cover mapping for the year 2000,* EUR 20524 EN, European Commission, Luxembourg.

Grégoire J-M., K.Tansey, and J.M.N. Silva, 2003, The GBA2000 initiative: Developing a global burned area database from SPOT-VEGETATION imagery, *Int. J. Remote Sensing*, Vol. 24,in press.

Global map co-ordination and harmonization:

Etienne Bartholomé, Alan Belward, Steffen Fritz, JRC Ispra

Global burnt area map co-ordination and harmonization:

Jean-Marie Grégoire, Kevin Tansey, JRC, Ispra

Regional map co-ordination:

Africa –: Philippe Mayaux, JRC, Ispra

Asia –: Jurgen Stibig, JRC, Ispra

Australia –: Philippe Mayaux, JRC, Ispra

Europe –: Etienne Bartholomé, JRC, Ispra

Northern Eurasia –: Alan Belward, JRC, Ispra

North and Central America –: Tom Loveland, US Geological Service and Rasim Latifovic Canadian Center for Remote Sensing

South America- : Hugh Eva, JRC, Ispra

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