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*Full Length Research Paper*

# Detection and geographical distribution of clearing areas in the savannas (‘*lavrado*’) of Roraima using Google Earth web tool

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**The objective of this study was to detect clearing areas (anthropogenic disturbance) and evaluate the geographical distribution of different land uses in the savannas (*lavrado*) of Roraima, Brazilian Amazonia. Data were obtained from visual interpretation of very high (Ikonos and QuickBird - 2001 to 2007) to high (Landsat TruEarth® - Mosaic 1999 to 2002) resolution images offered by Google Earth™ application version 5.1.3533.1731. The visual interpretation resulted in the generation of polygons representing land use categories including information on land use change (natural to anthropogenic). Spatial analysis was conducted and the polygons corresponding to different land use categories were juxtaposed with thematic layers of municipality divisions, limits of protected areas and indigenous lands. 42,706 km$^2$ were defined as ‘lavrado’. Of this total, 1986.7 km$^2$ (4.65%) were considered anthropogenic disturbed areas: 17.8% in forest (alluvial and contact) and 82.2% in non-forest (savannas) ecosystems. The majority of land cleared occurred in "unprotected areas" (81.46%), while “indigenous lands“(18.53%) and “protected areas” (0.01%) represented smaller portions of the total area. Shifting cultivation (seasonal agriculture or crop rotation) in non-forested systems (611.32 km$^2$) was the land use most observed (30.8%). Our geographical data suggest that anthropogenic land use in the ‘lavrado’ has a pattern of distribution associated with areas close to roads that cross the capital of Roraima, Boa Vista.**

**Key words:** Savanna, lavrado, cerrado, Amazonia, land use.

## INTRODUCTION

The remaining area of native open vegetation (savannas and other natural grassland types) occupies ~5% of Brazilian Amazonia (~200,000 km$^2$) (FUNCATE, 2006). The savanna located in the northeastern state of Roraima, is the largest contiguous area of native open vegetation of such biome, representing the Brazilian part of a large complex of savannas in the northernmost part of Amazonia including Brazil, Guyana, Suriname and Venezuela (Barbosa et al., 2007). This large complex of vegetation can be considered as part of the southern lowlands of the Guyana Shield (Rull, 2005; Huber, 2006). In Roraima, this region is denominated as ‘lavrado’, a traditional term from Portuguese language introduced in the late nineteenth century, much used by local people (Vanzolini and Carvalho, 1991). The vegetation of the ‘lavrado’ of Roraima is mainly composed of different phytophysiognomies of non-forest vegetation, also very common in other savannas of Northern South America (Miranda et al., 2002)

Since the late 1970s, the ‘lavrado’ has suffered a continuous process of change derived from the establishment and expansion of roads to strengthen agricultural and livestock projects with objective to stimulate local economic growth (Barbosa, 1993; Barros, 1995). Population growth has also been a driver of changes in this

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same way. Roraima's population was approximately 80,000 inhabitants in the late 1970s, rising to 451,227 in 2010 (IBGE, 2011). About 75% of the population is concentrated in the 'lavrado', where the agribusiness sector is most rapidly expanding (sugar cane, soybeans, rice, afforestry, etc.). This process is similar to that of the biome Cerrado - a biome of savannas situated in the Central Brazil region (Olson et al., 2001), where large land expansions have been used to increase export of commodities (WWF, 1995).

The expansion and consolidation of large agricultural projects in the 'lavrado' of Roraima are economically appealing to the region because of legal restrictions on land use in forested areas since the promulgation of Brazilian Environmental Crimes laws in 1998 (Brazil, 1998). Another important factor that can accelerate the future land use changes in the open systems in- and outside the Amazon are international agreements to reduce carbon emissions, known as REDD (Reducing Emissions from Deforestation and Forest Degradation). The REDD program may have a negative effect on savannas and other grassland systems, as a result of increased human pressure and demand for food and biofuels, which could lead to loss of environmental services like natural carbon storage, water quality and biodiversity (Miles and Kapos, 2008; Sutherland et al., 2009). The consequences of this program can be (1) direct, because of the appeal of redirecting agricultural activities previously developed in forests to new areas of savanna or (2) indirect, through the replacement of food crops already established in savannas/grasslands by crops for biofuels (like sugarcane).

The lack of an effective, regional planning program for sustainable economic use of the 'lavrado' of Roraima has resulted in increasing agricultural occupation of this Amazonian region without any kind of socio-environmental criteria defined by monitoring of clearing areas. The non-forest lands in Amazonia do not have a monitoring system as advanced as that of forest systems provided by PRODES - Monitoring of the Brazilian Amazonia Forest by Satellite (PRODES, 2011). The lack of monitoring and criteria of land use in the 'lavrado' originates from the local, political pressure that directly encourages the expansion of agriculture to meet the regional and national market demand (mainly rice, soybeans and sugarcane). State laws encourage agricultural expansion in two ways: (1) By generating employment and income through public subsidies, without, however, establishing socio-environmental criteria for maintenance of these benefits (Roraima, 1998, 2003) and (2) By establishing state laws that override more restrictive, federal environmental legislation, limiting the use of Brazilian natural resources (Roraima, 2009). Thus, three major consequences can be highlighted: (1) The development of agriculture and poorly planned roads in the 'lavrado' legally occupied by indigeneous communities threatens the natural resources (fauna, flora and water) used by these communities, thereby increasing social conflicts over ownership and land use (Lauriola et al., 2007), (2) In 2010, the State government rejected a proposal by the federal government to create Roraima's first environmentally protected area of 'lavrado' (Pinto et al., 2008), and (3) Municipalities containing large expanses of 'lavrado' develop these areas to immediately benefit rural populations, without first defining strategies for sustainable and effective land use. The latter consequence applies to the entire region of the Guyana Shield, as well (Schut, 2004)

The general aim of this study was to assess the status of land use change (natural to anthropogenic) in the 'lavrado' of Roraima and the spatial distribution of different types of land use through visual interpretation of very high and high spatial resolution images provided by Google Earth™ application (http://earth.google.com). Specifically, our objectives include: (1) To quantify the total area of 'lavrado' affected by anthropogenic changes, (2) To define the main types of land use (land cover), (3) To identify in which municipalities clearing areas occur, both at the small- and large-scale, (4) To verify if indigenous lands and environmentally protected areas are affected by anthropogenic land use, and (5) To describe the mechanisms driving land changes in the 'lavrado'

## METHODS

### Study area: The 'lavrado' of Roraima

Roraima's 'lavrado' forms part of the landscape of the Guyanan Savanna ecoregion (Figure 1). There are three separated large areas of this type of open vegetation within the Amazon located in Roraima, Eastern Amapá, and in the Serra do Tumucumaque region (WWF, 2011). Part of these areas extends from Brazil through Venezuela, Guyana and Suriname (Capobianco et al., 2001; WWF, 2004). The largest area of the Guyanan Savanna ecoregion is located within Brazil (74.6%; 62,952 $Km^2$), followed by Venezuela (13.0%; 11,033 $Km^2$), Guyana (11.8%; 10,041 $Km^2$) and Suriname (0.6%; 487 $Km^2$). The boundaries of the 'lavrado' are established within the lowlands (80 to 100 m) of the Branco and Rupununi Rivers (Eden, 1970), and part of the highlands of the Roraima Formation (> 2000 m), that extends through the Venezuelan Gran Savanna (Brasil, 1975). This geographical set represents the southern lowlands of the Guyana Shield (Schubert, 1995).

The climate in this region is Awi (semi- humid; tropical with a dry season lasting 4 to 5 months during winter) according to the Köppen's classification system, with the driest months occurring between December and March, and the rainiest months between May and August (Nimer, 1989). Average annual rainfall is 1600 to 1700 mm/year, according to the Meteorological National Institute (INMET) station in Boa Vista, which is the capital of Roraima (Barbosa, 1997; Araújo et al., 2001). The phytophysiognomy most occurring in the 'lavrado' is typically non-forest (open grassland, scrubby savanna and open woody savanna). However, forest formations are also part of the 'lavrado' and are characterized by forest patches of semi-deciduous perennial vegetation, riparian forests, which are alluvial forests along rivers and streams, extending beyond many forested borders of forest-savanna contact areas (ecotones). All of these areas are constantly impacted by

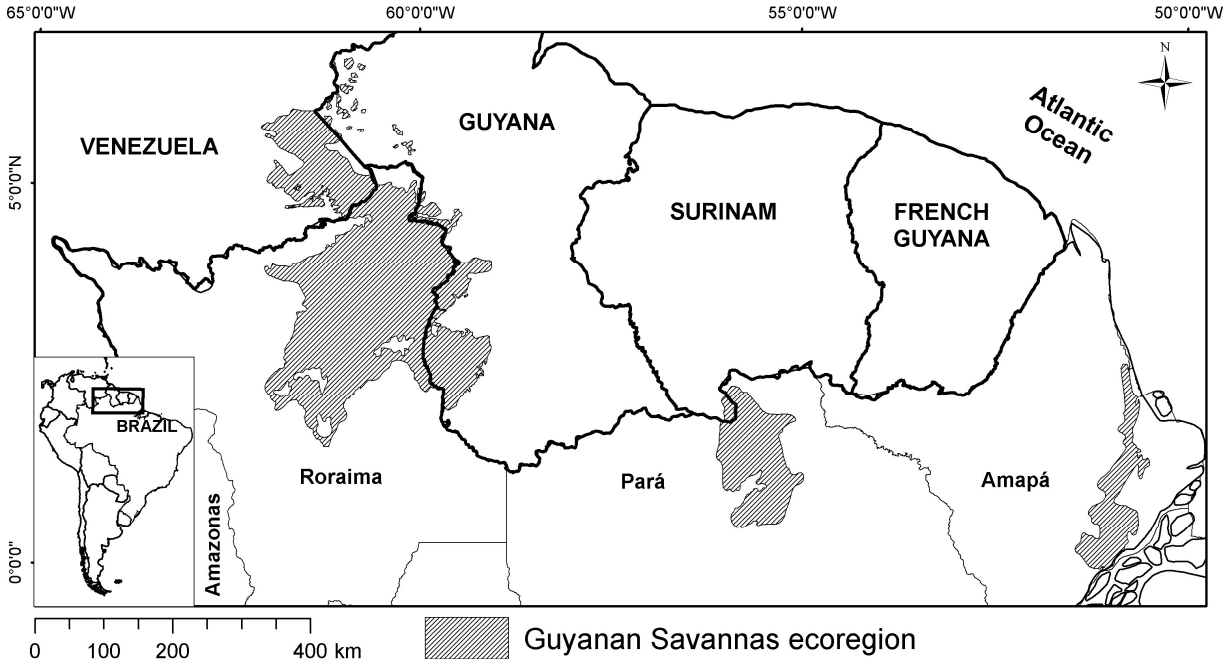


**Figure** 1. Location of "Guyanan Savanna ecoregion" shared by Brazil, Venezuela, Guyana and Suriname (WWF, 2011).

intense human activities, which include deforestation for shifting cultivation, and uncontrolled burning.

**Geospatial base**

Geographical data for assessing land use distribution and change analysis in the 'lavrado' of Roraima were obtained for the dates of May, 2009 to January, 2010, using available images from Google Earth™, version 5.1.3533.1731 (http://earth.google.com).

This software is a geographic information system (GIS) freely available on the World Wide Web, with high-resolution aerial and satellite images of the entire Earth's surface, adjusted to simple cylindrical projection (latitude/longitude) and Datum WGS84. This application has been used in different disciplines (Sheppard and Cizek, 2009). Examples of applications include detection of ecological habitats (Mawdsley, 2008), global analysis of rain-dependant cultivated areas (Biradar et al., 2009) and the vectorization (shape files derived from raster images) of buildings and urban environments for three-dimensional city modeling (Elshehaby and Taha, 2009).

Thirty images of very high spatial resolution were found to be totally or partially available for 'lavrado' areas from different satellites: 14 from Ikonos/GeoEye (resolution of 0.82 m) and 16 from QuickBird/DigitalGlobe (resolution of 0.60 m). The other remaining areas of 'lavrado' are a mosaic denominated Landsat TruEarth® 15-meter (http://www.truearth.com), with spatial resolution of 15 m derived from GeoCover project by NASA (https://zulu.ssc.nasa.gov) that used images from Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) (1999 to 2002). In this study, we did not make any kind of image importation/exportation to new interpretations by another GIS because Google Earth provides images only in the web version. Many of these images have limitations for geophysical spatial analysis using other software. Therefore, images of TruEarth, Ikonos and QuickBird were specifically used for the purpose of visual interpretation and vectorization of anthropogenic changes, 'lavrado' boundaries, and part of the Guyanan Savanna ecoregion.

**Detection of clearing areas and delimitation of borders**

For the demarcation of the 'lavrado' both for the Roraima region and the entire Guyanan Savanna ecoregion block shared by Brazil, Venezuela and Guyana, we used the polygon creation tool of Google Earth to draw shape files. The vectorization was made manually along all contact areas between open vegetation (non-forest) and continuous forest formation, using ~1500 m as maximum altitude of remote observation between the terrestrial target and the observer (~1:4000). This method was possible because the Google Earth web tool allows for control of distance and work scale to facilitate alignment of the images, permitting a more accurate interpretation of these images. Riparian and gallery forests connected to continuous forests, with a maximum width of 100 m, were included as part of the Guyanan Savanna ecoregion.

Detection of disturbed landscape was made by visual interpretation exclusively inside the area delimited as 'lavrado' of Roraima. Our previous knowledge of geographical spatial distribution of the largest agricultural development projects in the 'lavrado' of Roraima also facilitated visual scanning. Thus, disturbed areas were detected by visual observation of existing scars in forest and non-forest systems and easily visible on Google Earth images. Spectral differences between these two ecosystems are easily detected by visual interpretation without any digital processing. Scars are detectable in non-forest systems because tractors leave marks on the soil, while deforestation in forest systems represents geometric figures with remarkable spectral differences. In this way, all clearing areas were vectorized individually by creating polygons in very high and high resolution, using the same method described above for 'lavrado' delimitation. The vectorization scale varied as a function of the size of the clearing area to improve visualization of the target area and minimize errors caused by manual vectorization.

The impacts of fire on the 'lavrado' were not included in this investigation because of the low temporal permanence of fire scars

(Krug et al., 2004), and consequently, the difficulty to detect fire scars without a historical series of images. All of the polygons generated (Guyanan Savanna ecoregion and clearing areas in 'lavrado') were saved in KML (Keyhole Markup Language) format, and converted to SHP (shape) files using the program ExpertGPS version 3.81, also freely available in the Web (http://www.expertgps.com). Each polygon presented one single continuous area, with a defined land use category described as follows.

#### Definition of anthropogenic land use categories

Cleared areas were grouped into eight land use categories, following IBGE (2005):

Shifting cultivation (crop rotation or seasonal agriculture), which included (a) recently established fields and (b) fields in the harvesting, or soil preparation stages, or that apparently had been abandoned; (2) Permanent crops (a) Afforestry/forestry and (b) Fruit tree plantations; (3) Rural infrastructure: (a) Isolated farm houses, (b) Ranches, (c) Barns, and d) other isolated rural buildings, including extended live areas such as home gardens; (4) Deforestation: scars exclusively in (a) contact forests (ecotones) and (b) alluvial forests; (5) Urban centers: (a) Cities and (b) Villages (indigenous and rural) representing human agglomerates established in areas with streets and public services; (6) Artificial accumulation of water: (a) Dams in water courses of varying purposes, (b) Pisciculture and (c) 'cacimbões' (soil excavations to accumulate water for livestock); (7) Mineral extraction: (a) Areas where soil was removed for road construction, (b) Extraction of material for civil construction (sand, clay, stone) and (c) Mining (tracks of mine areas); (8) Other disturbed areas: Physical changes of the 'lavrado' caused by heavy machinery such as tractors.

#### Data analysis

All the polygons in SHP format were processed in the program ArcView 3.2 (ESRI, 1996) to determinate the areas ($Km^2$) of (a) the ecoregion shared by Brazil-Guyana-Venezuela, (b) Roraima's 'lavrado', (c) very high and high coverage images provided by Google Earth web tool and (d) clearing areas distributed by the land use (land cover) categories. To verify the spatial distribution of changes in landscape, the polygons were super-imposed to thematic layers of various data: Municipal political borders (IBGE – Brazilian Institute of Geography and Statistics), indigenous lands (FUNAI – National Indian Foundation and ISA – change for "Socioenvironmental" Institute) and protected areas (ICMBio – Chico Mendes Institute for Biodiversity Conservation). Data were exported to Microsoft Excel, where calculations were made for each thematic layer, to answer the research questions.

#### Ground truth

From September 11 to 30, 2009, four field trips were made to verify and refine land use categories. Ground truth was concentrated at the intersection of the four main roads dividing the city of Boa Vista, the State's urban and economic hub (Figure 2). We conducted field sampling to verify that the land use categories previously set by visual interpretation were accurate. We traveled over 445 km on the following roads:

1. RR 205: State highway connecting the city of Boa Vista to the Alto Alegre (western sector). 98 km were traveled on 11 September, 2009. This stretch is dominated by permanent crops (citrus fruits and afforestry of *Acacia mangium* Willd.), temporary crops (sorghum, soybeans and fallow areas, several disturbed areas in the riparian forests of the Cauamé River, Indigenous communities, and several small farms (Figure 2A).
2. BR 401: Federal highway linking Brazil to Guyana. We traveled 115 km from Boa Vista to the city of Bonfim (eastern and northeastern sectors) on 21st September, 2009. This region is characterized by temporary crops (sugar cane, soybeans, irrigated rice, corn and fallow areas, permanent crops (cashew fruit and afforestry of *A. mangium*) and large farmhouses with barns and sheds (Figure 2B);
3. BR 174 South: 54 km were traveled between Boa Vista and the city of Mucajaí (southern sector) on 23rd September, 2009. This stretch is characterized by permanent crops (cashew fruit and afforestry of *A. mangium*), farmhouses and several small, recreation areas along streams (creeks) used by the populations of Boa Vista and Mucajaí (Figure 2C). Lavrado areas cultivated with the use of heavy machinery (no specific usage) were also observed;
4. BR 174 North: We covered 185 km between Boa Vista and the indigenous community of 'Boca da Mata' (northern section) on 30th September, 2009. This region is characterized by temporary crops (irrigated rice, corn and fallow areas), permanent crops (afforestry of *Eucalyptus* spp. and *A. mangium*), farmhouses, settlements by family farmers and indigenous lands (Figure 2D).

## RESULTS

### The lavrado of Roraima and Guyanan Savanna ecoregion areas

The area comprising Guyanan Savanna ecoregion shared by Brazil, Venezuela and Guyana totaled 68,145 $Km^2$, with the Brazilian portion, known as 'lavrado', representing 62.7% (42,706 $Km^2$) of this total (Table 1).

Ten of the fifteen municipalities of the state of Roraima border with the 'lavrado': Boa Vista (99.3%), Normandia (97.0%) and Bonfim (90.5%) have the largest occupation of this landscape, while Mucajaí (0.02%), Caracaraí (1.9%) and Cantá (7.4%) occupy only small areas of 'lavrado' situated at the borders of contact forest (Figure 3).

### Very high and high resolution coverage images

The very high resolution images that were available at Google Earth only cover 32.5% of the whole 'lavrado' region (Table 2). The municipalities of Cantá and Boa Vista are those with the highest percentile of 'lavrado' area covered by very high resolution images (96.8 and 87.7%). The coverage by very high resolution images is smaller in other municipalities with larger areas of 'lavrado', as Uiramutã (3.2%), Amajari (11.5%), Pacaraima (19.3%), Normandia (40.3%) and Bonfim (44.5%) (Figure 4A). The urban zones and surrounding areas of Pacaraima and Normandia are covered by very high resolution images, while Amajari, Uiramutã and Normandia have coverage restricted to the rural zones.

Very high resolution images are highly concentrated surrounding Boa Vista, where the main highways such as BR-174, BR-401, and RR-205 occur. High resolution

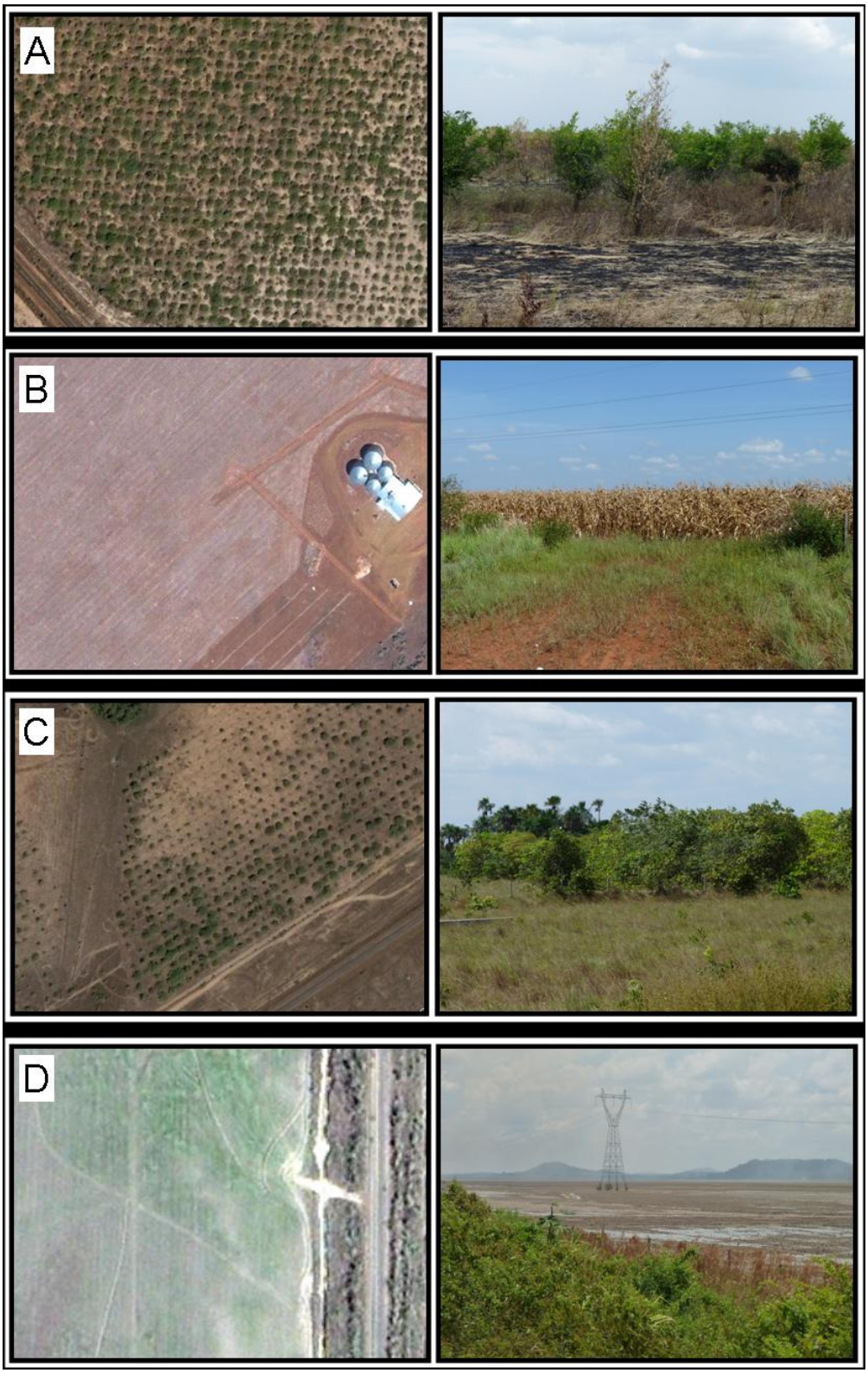


**Figure 2.** Images from Google EarthTM (left) and field work (right). (A) permanent cultivation of citrus (lemon) near the highway RR-205 (02° 53' 03,40° N / 60° 53' 10,07" W); (B) seasonal crop of corn near the highway BR-401 (03° 07' 48,55" N / 60° 17' 17,61" W); (C) permanent crop of cashew fruit near the highway BR-174, south part (02nd (02° 42' 41,10" N / 60° 50' 25,59" W); (D) seasonal crop (irrigated rice fields) near the highway BR-174, northern part (04° 01 09,07" N / 61° 02' 37,98" W). (Google Earth Images: A and C – January, 2003; B – March, 2007; D – December, 2007).

**Table 1.** Area of Guyanan Savanna ecoregion (km$^2$) shared by Brazil (lavrado), Guyana and Venezuela.

| Ecoregion | Area (km$^2$) | Municipalities | Area (km$^2$) | Lavrado area | |
|---|---|---|---|---|---|
| | | | | km$^2$ | Percentage |
| Brazil-Lavrado | 42705.9 | Boa Vista | 5711.9 | 5672.5 | 99.3 |
| | | Normandia | 7007.9 | 6800.6 | 97.0 |
| | | Bonfim | 8131.5 | 7363.0 | 90.5 |
| | | Pacaraima | 8063.9 | 6615.3 | 82.0 |
| | | Uiramutã | 8090.7 | 6138.3 | 75.9 |
| | | Amajari | 28598.4 | 5507.7 | 19.3 |
| | | Alto Alegre | 26109.7 | 3136.4 | 12.0 |
| | | Cantá | 7691.0 | 569.5 | 7.4 |
| | | Caracaraí | 47623.6 | 900.0 | 1.9 |
| | | Mucajaí | 11981.5 | 2.6 | 0.02 |
| Guyana | 14500.0 | - | - | - | - |
| Venezuela | 10939.0 | | | | |
| Total | 68144.9 | - | - | - | - |

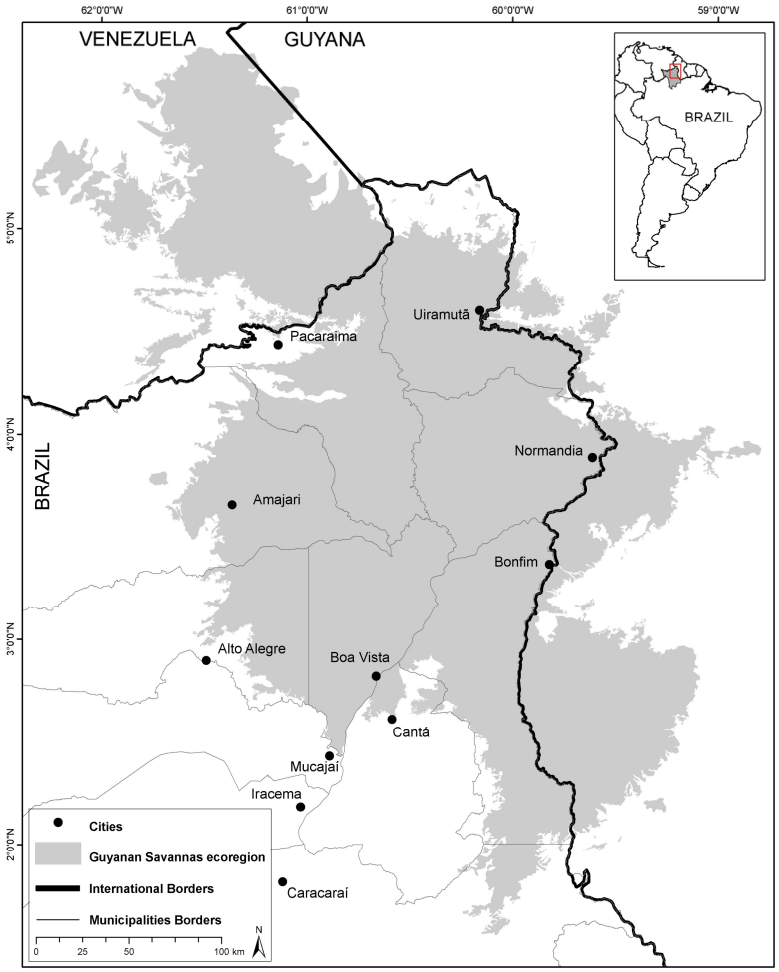


**Figure** 3. Distribution of the continuous savannas (gray) shared by Brazil (*lavrado*), Venezuela and Guyana, and the distribution into the municipalities of the Roraima state, Brazil.

**Table 2.** Image coverage of very high (Ikonos and QuickBird) e high (Landsat TruEarth®) spatial resolution provided by Google Earth™ web tool to lavrado of Roraima, Brazilian Amazonia.

| Municipalities | Coverage year | Very high resolution ($km^2$) | Coverage (%) | High resolution ($km^2$) | Coverage (%) | Total ($km^2$) |
|---|---|---|---|---|---|---|
| Alto Alegre | 1999-2000 | 0.00 | 0.00 | 2963.40 | 94.48 | 2963.40 |
| | 2002 | 8.82 | 0.28 | 0.00 | 0.00 | 8.82 |
| | 2003 | 99.99 | 3.19 | 0.00 | 0.00 | 99.99 |
| | 2005 | 9.14 | 0.29 | 0.00 | 0.00 | 9.14 |
| | 2006 | 55.11 | 1.76 | 0.00 | 0.00 | 55.11 |
| Amajari | 1999-2000 | 0.00 | 0.00 | 4873.15 | 88.48 | 4873.15 |
| | 2002 | 196.17 | 3.56 | 0.00 | 0.00 | 196.17 |
| | 2003 | 22.53 | 0.41 | 0.00 | 0.00 | 22.53 |
| | 2006 | 87.46 | 1.59 | 0.00 | 0.00 | 87.46 |
| | 2007 | 328.34 | 5.96 | 0.00 | 0.00 | 328.34 |
| Boa Vista | 1999-2000 | 0.00 | 0.00 | 697.17 | 12.29 | 697.17 |
| | 2001 | 0.27 | 0.00 | 0.00 | 0.00 | 0.27 |
| | 2002 | 1127.45 | 19.88 | 0.00 | 0.00 | 1127.45 |
| | 2003 | 2916.88 | 51.43 | 0.00 | 0.00 | 2916.88 |
| | 2004 | 311.49 | 5.49 | 0.00 | 0.00 | 311.49 |
| | 2005 | 292.80 | 5.16 | 0.00 | 0.00 | 292.80 |
| | 2007 | 325.41 | 5.74 | 0.00 | 0.00 | 325.41 |
| Bonfim | 1999-2000 | 0.00 | 0.00 | 4083.19 | 55.45 | 4083.19 |
| | 2003 | 308.40 | 4.19 | 0.00 | 0.00 | 308.40 |
| | 2004 | 63.10 | 0.86 | 0.00 | 0.00 | 63.10 |
| | 2005 | 817.06 | 11.10 | 0.00 | 0.00 | 817.06 |
| | 2007 | 2092.17 | 28.41 | 0.00 | 0.00 | 2092.17 |
| Cantá | 1999-2000 | 0.00 | 0.00 | 18.11 | 3.18 | 18.11 |
| | 2002 | 44.18 | 7.76 | 0.00 | 0.00 | 44.18 |
| | 2003 | 46.24 | 8.12 | 0.00 | 0.00 | 46.24 |
| | 2004 | 35.75 | 6.28 | 0.00 | 0.00 | 35.75 |
| | 2005 | 424.97 | 74.66 | 0.00 | 0.00 | 424.97 |
| Caracaraí | 1999-2000 | 0.00 | 0.00 | 900.00 | 100.00 | 900.00 |
| Mucajaí | 2003 | 0.62 | 24.36 | 0.00 | 0.00 | 0.62 |
| | 2005 | 1.94 | 75.64 | 0.00 | 0.00 | 1.94 |
| Normandia | 1999-2000 | 0.00 | 0.00 | 4011.00 | 58.97 | 4011.00 |
| | 2007 | 2791.04 | 41.03 | 0.00 | 0.00 | 2791.04 |
| Pacaraima | 1999-2000 | 0.00 | 0.00 | 5340.11 | 80.73 | 5340.11 |
| | 2003 | 396.19 | 5.99 | 0.00 | 0.00 | 396.19 |
| | 2004 | 18.51 | 0.28 | 0.00 | 0.00 | 18.51 |
| | 2007 | 859.67 | 13.00 | 0.00 | 0.00 | 859.67 |
| Uiramutã | 1999-2000 | 0.00 | 0.00 | 5940.21 | 96.78 | 5940.21 |
| | 2003 | 197.89 | 3.22 | 0.00 | 0.00 | 197.89 |
| Total ($km^2$) | - | 13879.57 | 32.50 | 28826.35 | 67.50 | 42705.91 |

image coverage were obtained mostly for 2007 (6,397 $Km^2$) and 2003 (3,989 $Km^2$), distributed mainly among the municipalities of Boa Vista, Normandia and Bonfim, which are those occupying the largest percentage of 'lavrado'.

43.7% of the total of area covered by very high Resolution images represent "Indigenous Lands" and 56.3% "unprotected areas" (Figure 4B). Considering only the very high resolution images, coverage in "Indigenous Lands" was 24.7%. Coverage of "unprotected areas" (rural properties, settlements, cities and other public areas) was 42.9%.

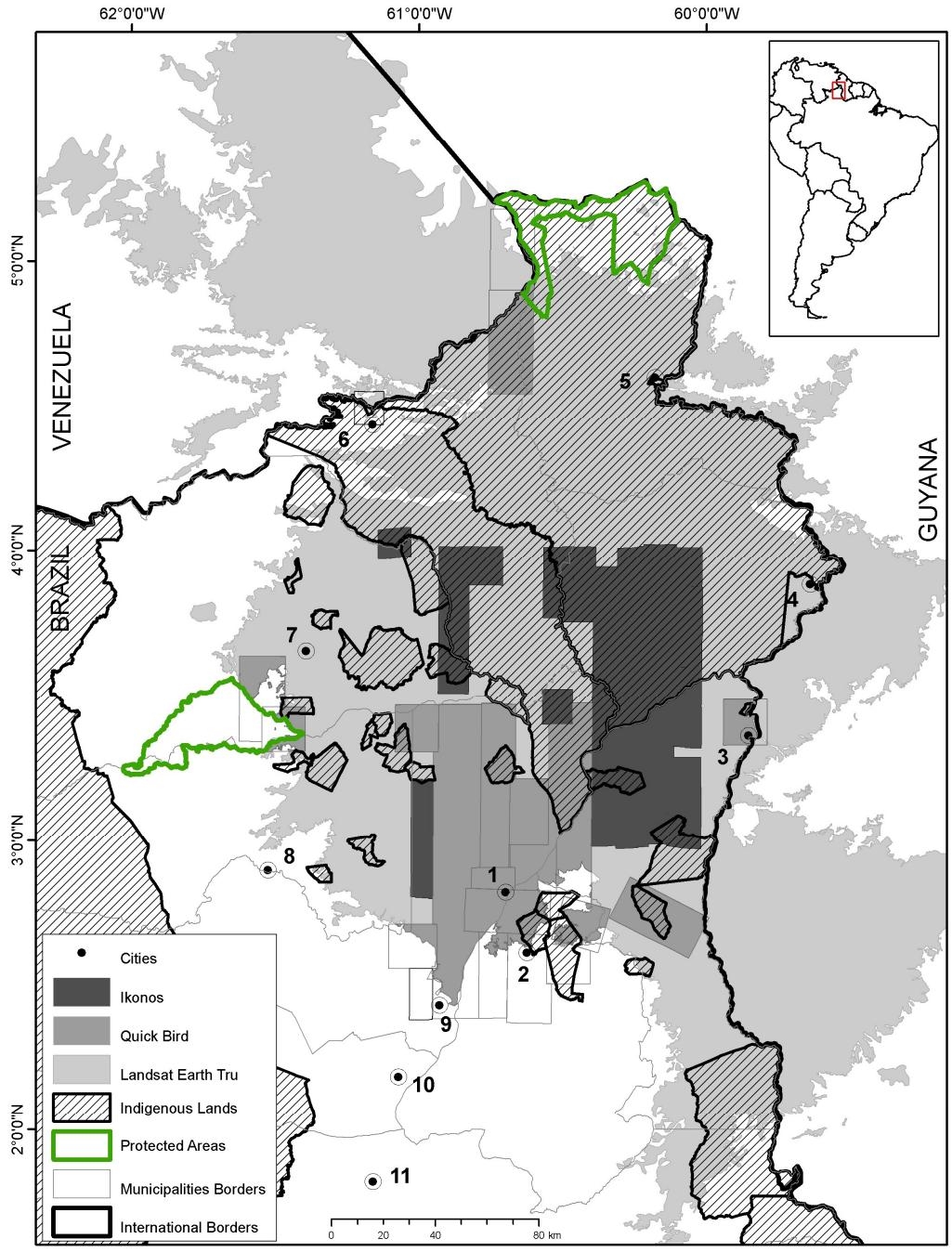


**Figure 4.** Very high (Ikonos and QuickBird) and high (Landsat EarthTru ®) resolution images coverage in the 'lavrado' of Roraima, available on Google EarthTM. Images coverage distribution: municipalities and environmentally protected areas (IBGE and ICMBio), and indigenous lands (FUNAI, ISA, 2010). Cities: (1) Boa Vista, (2) Cantá, (3) Bonfim, (4) Normandia, (5) Uiramutã, (6) Pacaraima, (7) Amajari, (8) Alto Alegre, (9) Mucajaí, (10) Iracema and (11) Caracaraí.

## Land cover change

### *Calculation of disturbed areas*

The sum of disturbed 'lavrado' (non-forest and forest ecosystems) areas mapped, taking into account the images of different years and spatial resolutions available on Google Earth, was 1,986.72 km$^2$ or 4.65% of the total area (Table 3 and Figure 5). Of this value, 82.2% was disturbed for non-forest systems that are distinct types of open vegetation (savannas and natural grasslands) and 17.8% in the forest systems (forest patches, alluvial,

**Table 4.** Distribution of clearing areas (km$^2$) in the 'lavrado' of Roraima by land use, land category and image resolution.

| Original system | Land category | Land use and image resolution | | | | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Other áreas (1) | | Indigenous land | | Environmental protected area | | | | |
| | | Very high | High | Very high | High | Very high | High | Very high | High | % |
| Forest | Water accumulation | 0.387 | 0.225 | - | - | - | - | 0.387 | 0.225 | 0.03 |
| | Mineral extraction | 1.495 | - | - | - | - | - | 1.495 | 0 | 0.08 |
| | Urban centers | - | - | 1.246 | 1.094 | - | - | 1.246 | 1.094 | 0.12 |
| | Rural infrastructure | 1.457 | 0.023 | 0.101 | 0.958 | - | - | 1.558 | 0.981 | 0.13 |
| | Shifting cultivation | 27.201 | 3.68 | 0.372 | - | - | - | 27.573 | 3.68 | 1.57 |
| | Deforestation | 96.732 | 130.37 | 35.59 | 52.345 | 0.107 | 0 | 132.429 | 182.715 | 15.86 |
| Sub-total | | 127.272 | 134.298 | 37.309 | 54.397 | 0.107 | 0 | 164.688 | 188.695 | - |
| Non-forest | Water accumulation | 7.919 | 1.583 | 0.392 | 0.208 | - | - | 8.311 | 1.791 | 0.51 |
| | Mineral extraction | 8.33 | 10.356 | 2.004 | 0.16 | - | - | 10.334 | 10.516 | 1.05 |
| | Rural infrastructure | 32 | 7.036 | 11.503 | 8.122 | - | - | 43.503 | 15.158 | 2.95 |
| | Urban centers | 142.145 | 11.085 | 18.45 | 13.581 | - | - | 160.595 | 24.666 | 9.32 |
| | Permanent crop | 216.956 | 6.042 | 0.203 | 0.124 | - | - | 217.159 | 6.166 | 11.24 |
| | Other disturbances | 368.368 | 99.777 | 19.665 | 36.011 | - | - | 388.033 | 135.788 | 26.37 |
| | Shifting cultivation | 371.424 | 73.834 | 90.164 | 75.893 | 0.001 | 0 | 461.589 | 149.727 | 30.77 |
| Sub-total | | 1147.142 | 209.713 | 142.381 | 134.099 | 0.001 | 0 | 1289.52 | 343.812 | - |
| Total | km$^2$ | 1274.41 | 344.01 | 179.69 | 188.50 | 0.11 | 0.00 | 1454.21 | 532.51 | - |
| | % | 64.15 | 17.32 | 9.04 | 9.49 | 0.01 | 0.00 | 73.20 | 26.80 | 100 |

(1) Land use category that includes small rural properties, settlements and also public areas not defined as environmental protected area or indigenous land.

riparian and gallery forests, etc).

**Indigenous lands and protected areas**

The presence of clearing areas was highest in the category "non-protected areas" (81.46%) and minor in "Indigenous Lands" (18.53%) and "protected areas" (0.01%) (Table 4).

Although Indigenous lands cover 57% of the entire 'lavrado' region, only 18.5% of the clearing areas detected in this study occurred within these territories (Figure 6). Furthermore, only 1.5% of 'lavrado' within indigenous lands was classified as clearing, while this value increased to 8.9% for "unprotected areas". However, given that the coverage of very high-resolution images on indigenous lands is only 25%, as compared to 43% on non-indigenous lands, it is expected that land use changes in these areas have been underestimated compared to other areas. The higher values of disturbed areas in the indigenous lands were found in the Canauanim (14.3%) and Moskow (20.7%), located near Boa Vista and under strong anthropogenic pressure (Table 5).

**Land use categories**

Shifting cultivation in the non-forested systems (611.32 km$^2$ or 30.8 %) was the most common land use detected in the clearing areas of 'lavrado' (Table 4). Indian lands present 39.2% of this total (166.06 km$^2$) while other areas present 60.7% (425.26 km$^2$).

As for the other land use categories, the highest proportions were "other disturbed areas" (26.37%) and "permanent crops" (11.24%) in the non-forest system, and deforestation (15.86%) in forest systems. The "other disturbed areas" in the 'lavrado' represent various effects from use of heavy machinery, (that is, tractors), although details of these effects are not available. These "other disturbed areas" are very widespread in the very high and high resolution images and, in the same way, in the "Indigenous Lands" (10.6 %) and "unprotected areas" (89.4 %).

69% of the clearing areas located on Indian lands were explained by seasonal agriculture (shifting cultivation) and deforestation. Within the environmentally protected areas (Maracá and Monte Roraima), disturbances comprised only 0.01% of total area representing few small

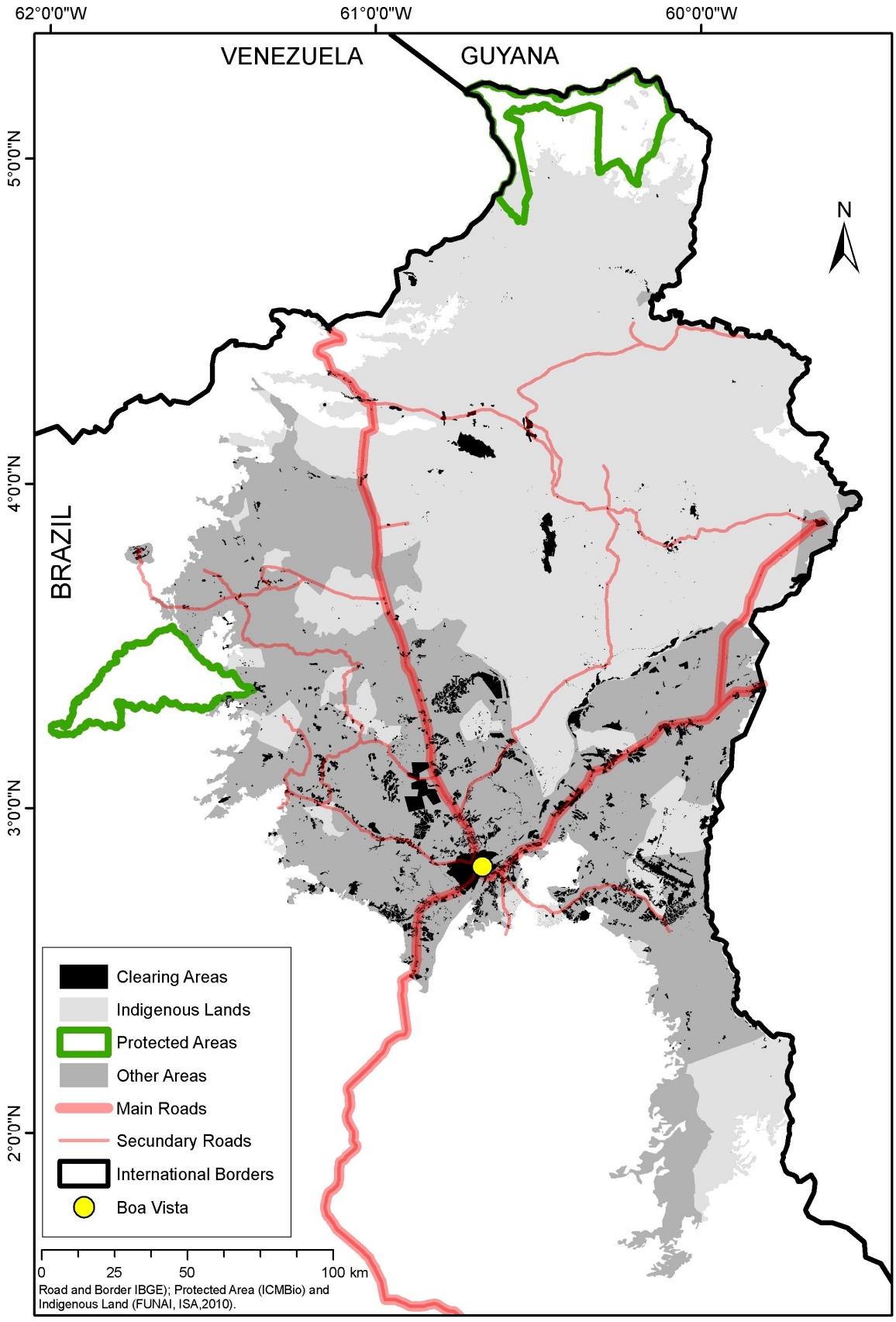


**Figure** 5. Clearing areas in the 'lavrado' of Roraima, distributed by Indian Lands and other areas unprotected.

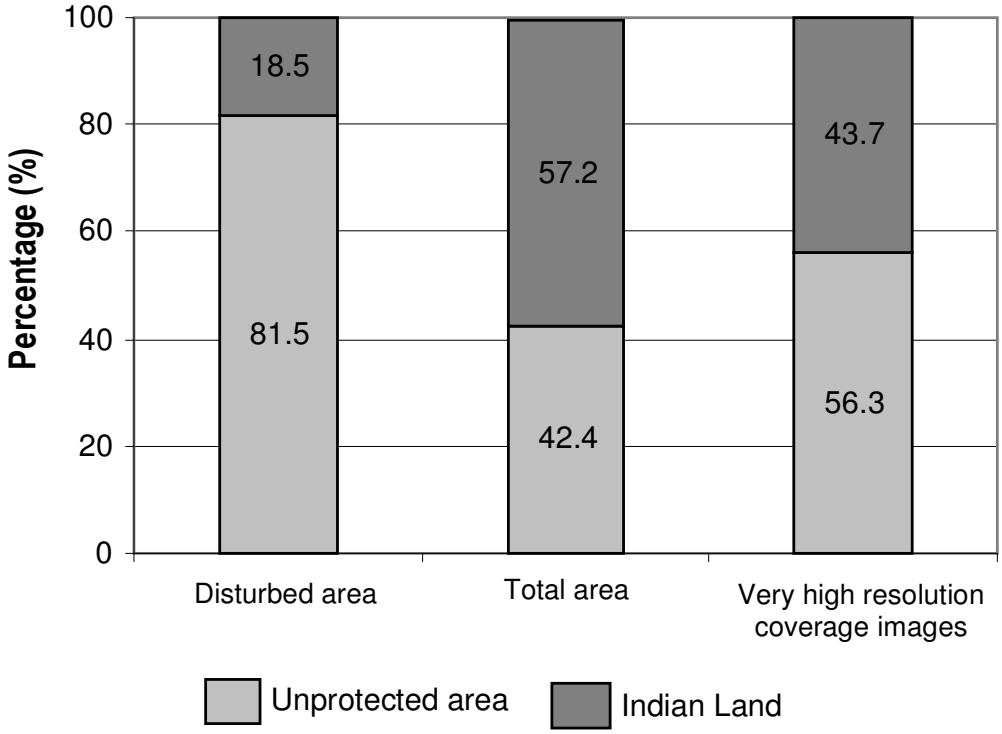


**Figure** 6. Distribution of clearing area, total area and high resolution coverage images in the 'lavrado' of Roraima, by Indian Lands and unprotected areas.

enclaves of 'lavrado' covered for very high-resolution images without possibility for a more detailed analysis. Deforestation in the forest systems of the 'lavrado' represent land use changes under different stages of forest succession for which we do not have historical information. Given the dynamics of land cover change in Amazonian forest systems, this study interpreted these disturbances as the results of the local population to establish seasonal agriculture or introduce pastures in the forest systems. Thus, "temporary crop" and deforestation represent (1) the traditional agriculture practiced in the rural areas and Indian lands (25.5%) and (2) crops using modern techniques on private, rural properties (small properties, settlements, farms, etc (74.5%).

## DISCUSSION

Considering all open areas (savannas and other types of open formations) according to FUNCATE (2006), the 'lavrado' of Roraima represents ~21.5% of all the open typologies of Amazonian biome. This figure highlights the importance of the 'lavrado' within the context of Amazonian open areas. For other hand, the different spatial and temporal resolution images from Google Earth web tool posed some difficulties in the analysis of spatio-temporal dynamics of land use change in 'lavrado'. However, this difficulty was minimized given that most of the business and agricultural production areas of the Roraima's 'lavrado' are concentrated directly around Boa Vista. Most of the very high resolution images are found along the main highways crossing the capital, Boa Vista, and surrounding areas. Almost 75% of the inhabitants of these areas are located near large agricultural (mainly soy) and afforestry plantations (*A. mangium*), as well as older areas of irrigated rice.

Previous estimates of the clearing areas in the 'lavrado' were limited to rudimentary environmental analyses that large agribusinesses are required to submit to the State's environmental agency (FEMACT/RR - State Foundation of Environment, Science and Technology - Roraima). Using this information, Campos et al. (2008) analyzed official data belonging to the State and estimated that 650 $km^2$ of the 'lavrado' area was occupied by large agribusiness projects until 2008, mainly large cultivations of irrigated rice, soy and afforestry of *A. mangium*. This estimate corroborates the value found in this study (866 $km^2$) for permanent and shifting cultivation, considering that we included not just the large cultivations, but also small- scale agriculture. However, the methodology that large agribusinesses use to estimate the entire 'lavrado' area disturbed by human activities does not reflect all types of anthropogenic land use. Thus, our results obtained by images from Google Earth (~2,000 $km^2$) were more accurate than previous estimates, highlighting the better efficiency of this web tool to quantify specific

**Table 5.** Land use change detected in the indigenous lands of the lavrado of Roraima, and very-high resolution images coverage (Ikonos and QuickBird).

| Indigenous land (IL) | IL Located in 'lavrado' ($km^2$) | Clearing area ($km^2$) (%) | Very-high resolution coverage (%) |
|---|---|---|---|
| Moskow | 140.4 | 29.0 (20.7) | 99.8 |
| Canauanim | 21.8 | 3.1 (14.3) | 96.5 |
| Manoá-Pium | 449.1 | 30.7 (6.8) | 31.8 |
| Muriru | 30.6 | 1.8 (6.0) | 0.0 |
| Jaboti | 139.8 | 6.0 (4.3) | 99.7 |
| Bom Jesus | 8.9 | 0.36 (4.1) | 99.4 |
| Malacacheta | 53.9 | 1.9 (3.6) | 96.1 |
| Tabalascada | 73.1 | 2.5 (3.4) | 98.7 |
| Truaru | 56.8 | 1.9 (3.3) | 10.0 |
| Serra da Moça | 119.9 | 3.7 (3.1) | 90.6 |
| Barata-Livramento | 122.4 | 2.4 (2.0) | 39.5 |
| Mangueira | 20.6 | 0.3 (1.5) | 0.1 |
| Raposa - Serra do Sol | 15,005.1 | 213.9 (1.4) | 22.8 |
| Aningal | 69.4 | 1.0 (1.4) | 40.2 |
| Ponta da Serra | 158.5 | 2.2 (1.4) | 74.7 |
| São Marcos* | 5,424.2 | 58.5 (1.1) | 31.2 |
| Anaro | 319.6 | 3.1 (1.0) | 19.7 |
| Sucuba | 62.4 | 0.46 (0.7) | 0.0 |
| Raimundão | 18.1 | 0.1 (0.6) | 0.0 |
| Boqueirão | 162.5 | 0.8 (0.5) | 0.0 |
| Pium | 45.5 | 0.19 (0.4) | 0.0 |
| Araçá | 506.5 | 1.9 (0.4) | 0.0 |
| Jacamin | 1,148.9 | 1.9 (0.2) | 0.0 |
| Ouro | 155.8 | 0.24 (0.2) | 6.6 |
| Anta | 31.0 | 0.04 (0.1) | 0.0 |
| Ananás | 25.2 | 0.0 (0.0) | 0.0 |
| Cajueiro | 48.0 | 0.0 (0.0) | 0.0 |
| Santa Inês | 86.8 | 0.0 (0.0) | 0.0 |
| Total | 24,504.9 | 368.2 (1.5) | 24.8 |

specific land use.

We also observed that the land cover pattern in the 'lavrado' of Roraima is similar to that observed in studies carried out in the Cerrado biome. The studies of Machado et al. (2004), using the sensor MODIS (resolution of 1 km) and Sano et al. (2008) (Landsat 7 ETM; 25 m), both in the whole Cerrado biome, as well as Ferreira et al. (2009) (MODIS; 0.25 km) for Goiás state, indicate that shifting cultivation is the most common land use. In this biome, temporary agriculture is more related to the large monocultures (soy for export) than small farms or indigenous lands. Moreover, even considering the limitations of spatial and temporal resolution of images presented by Google Earth, the percentage value of clearing area that we found to 'lavrado' (4.65%) can be considered low in relation to > 30% detected by Mantovani and Pereira (1998) and 39.5% detected by Sano et al. (2008), both in the Cerrado biome using images Landsat of the early 1990s and 2002, respectively. In the same way, Vieira et al. (2006) observed up to 2005, 4.4% of the forest systems of the whole Guyanan Savanna ecoregion in the Brazilian Amazonia (Amapá, Tumucumaque Mountains, Roraima) had already suffered some kind of disturbance. The value observed in this study for disturbed areas exclusively detected in the forest systems of the 'lavrado' (0.82%) is five times smaller than the value presented by Vieira and collaborators. This difference may be explained by the fact that the 'lavrado' area, as defined in this study, does not include the large forested areas under strong deforestation pressure in Roraima, that are included in the Guyanan Savanna ecoregion in other studies (WWF, 2011). In Brazil, forest systems are monitored by a special program called PRODES that does not observe changes in non-forest ecossystems (Prodes, 2011).

The majority of clearing areas in forest systems of the

'lavrado' were detected in regions covered only by high resolution images (Table 2). This kind of impact is related to shifting agriculture in ecotones (contact forest) and especially large irrigated rice fields (in alluvial forest) that were still active when images were taken up to 2007. About 50% of irrigated rice plantations in the 'lavrado' region were located in the 'Raposa-Serra do Sol' Indigenous Reserve, and have been deactivated since 2009 after a historic Brazilian Supreme Court decision (Lauriola et al., 2007; Lauriola, 2010). This observation is important because most of the disturbed 'lavrado' in indigenous areas consist of small forest patches, and are considered low impact. This pattern of low anthropogenic impact within indigenous land was also observed by Rodrigues et al. (2007), using Landsat images to investigate the expansion and retraction of forests in the area of the Tiriyós indians (Tumucumaque mountains, Brazil-Suriname border, Pará state).

Our data suggest that indigenous lands play an important role in the conservation of the 'lavrado'. There are 32 Indigenous Reserves in Roraima State, 28 of them occurring entirely or partially within the 'lavrado' limits: In 18 Reserves, the sum of clearing areas was less than 2% of their total area, and in eight, this value fluctuated between 3 and 7% (Table 5). Even so, in our assessment, the majority of shifting cultivation detected within Indian lands (very high resolution images: 2001 to 2007 and high resolution images: 1999 to 2000) does not represent traditional Indigenous agriculture, but large fields of irrigated rice existing until 2009. Indigenous crops, traditionally occurs at a small scale and over a large expanse of land, causing low environmental impact. Our results are similar to those of Armenteras et al. (2009) in a Colombian region of the Guyana Shield. In this area, Armenteras and colleagues estimated that protected areas and indigenous lands have a positive role in conservation of natural resources due to a lower rate of deforestation within their boundaries in relation to unprotected areas. The role of indigenous lands has been identified as an important factor in the conservation of natural resources in the Brazilian Amazon and provided new directions in Brazilian conservation policy (Capobianco et al., 2001).

In our study, most of the 'lavrado' area within Indian lands and environmentally protected areas were covered only by high-resolution images. This fact illustrates one of the challenges associated with using remote sensing of natural covering and disturbed areas in open vegetation (savannas / scrublands): an inappropriate spatial resolution establishing similar patterns of reflectance between clearing areas and natural coverage of open areas (Sano et al., 2007). Whether the evaluation method is manual or digital vectorization, definition/detection of clearing areas remains difficult, resulting in inaccurate detection of land use categories that lack appropriate information about ground coverage (Mantovani and Amaral, 1998; Mantovani and Pereira, 1998). For example, Sokolonski et al. (2005) was unable to detect the land use patterns of the entire state of Roraima using Landsat images, due to differences in the scale of analysis and actual field data, especially in the 'lavrado' areas.

The "other disturbed areas" in the 'lavrado' represent various effects from use of heavy machinery, (that is, tractors), although details of these effects are not available. These "other disturbed areas" are very widespread in the very high and high resolution images and, in the same way, in the "Indigenous Lands" (10.6 %) and "unprotected areas" (89.4 %). The large area covered by permanent crops in non-forest systems represent fruit-tree plantations created by the State and Municipalities (mainly Boa Vista) in the 1990s, now partiality abandoned. Only ~0.15 % of these large fruit cultivations were detected on Indian lands, where fruit trees are commonly cultivated in small home gardens and co-occur with a diversity of species (Pinho et al., 2010). This type of cultivation is not possible to distinguish using images available on Google Earth (high and very-high resolution). Thus, home gardens with fruit trees, horticulture and cultivation of medicinal plants were included in the category 'rural edification'.

Finally, it is important to note that the presence of the 'lavrado' in the environmentally protected areas is restricted to small natural enclaves in Maracá Ecological Station and Monte Roraima National Park. Together, these two areas protect less than 0.5% of the whole 'lavrado' region (Barbosa et al., 2007). The Brazilian National Biological Diversity Program of the Ministry of Environment, through the Seminar on the Evaluation and Identification of Priority Actions for Conservation, Sustainable Use and Sharing of the Benefits of Biodiversity in the Brazilian Amazon, described the 'lavrado' of Roraima as an "Area of Extreme Biological Importance", with the intention of creating a federally protected area (MMA 2002). However, local political actions overrode the federal government's plans. Given the increasing pressure to generate jobs and income through large-scale agriculture in the 'lavrado', there is an urgent need for cooperation between the State and federal governments. This cooperation may promote a dialogue that emphasizes the importance of the 'lavrado' as a source of investment for biodiversity conservation, and opens up the possibility for providing subsidies to local landowners who protect this biodiversity.

## Conclusion

The 'lavrado' of Roraima represent the largest continuous area of savannas in the Brazilian Amazon and is currently undergoing rapid population growth and expanding agriculture. Our geographical data suggest that anthropogenic land use in the 'lavrado' has a pattern of distribution associated with areas closer to roads that cross along the capital of Roraima, Boa Vista. However, despite the

'lavrado' ecological role and growing anthropogenic pressure, the 'lavrado' still has no official area under full environmental protection.

The fact that more than half of the 'lavrado' of Roraima occurs on Indian Lands illustrates the important role Indigenous population play in the conservation of this large landscape. However, as population growth increases, the small and more densely populated indigenous territories pose an especially significant threat to the 'lavrado', highlighting the urgent need to implement participative management programs and environmental monitoring of these territories.

Updated information on trends and the current status of land use of the 'lavrado' are necessary to formulate land management policies that permit the expansion of agriculture without compromising the environmental services offered by the 'lavrado' of Roraima.

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