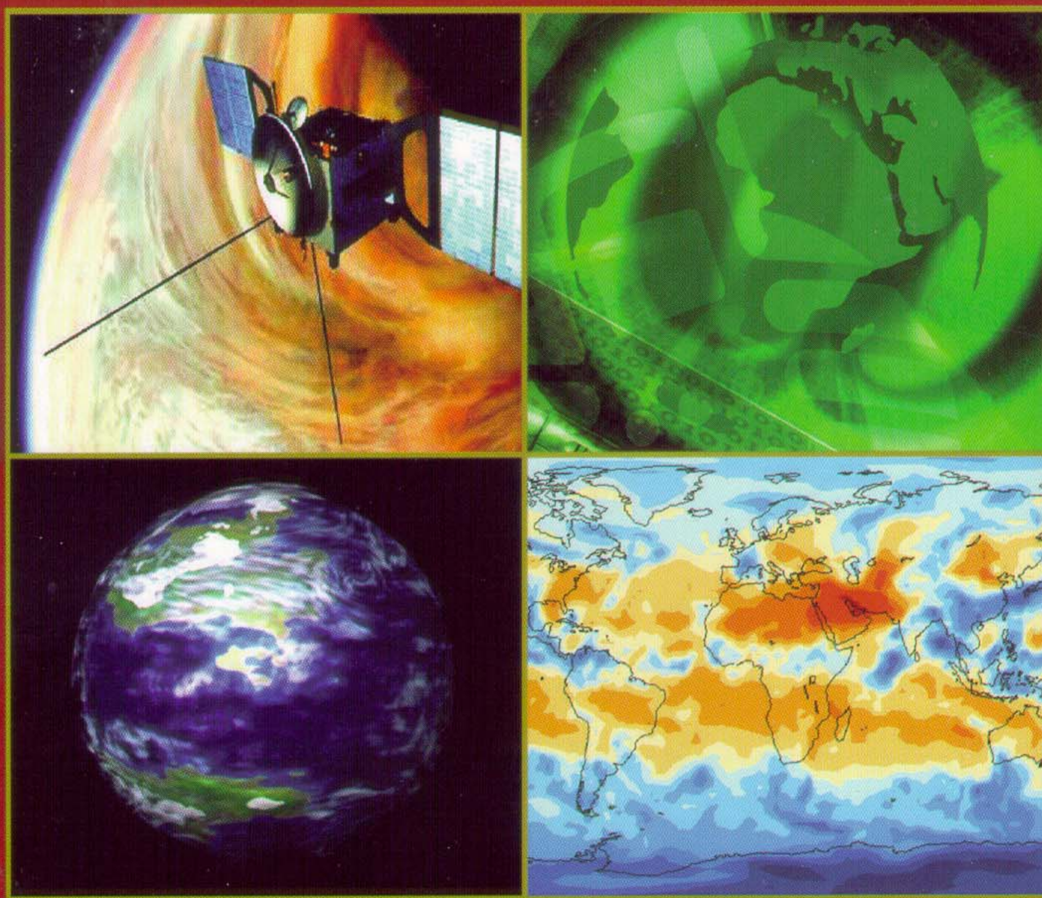

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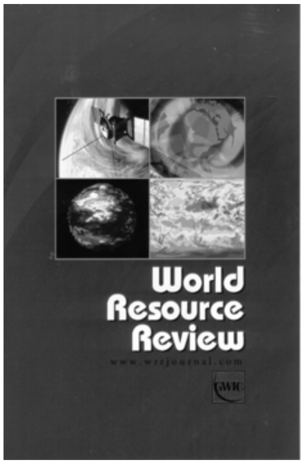

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VEGETATION FIRE IN THE SAVANNAS OF THE LLANOS ORIENTALES OF COLOMBIA

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Keywords: Vegetation fire, savannas, remote sensing, global change, Colombia

SUMMARY

Vegetation fires are widespread over the world but little attention has been paid to savanna fires in South America. Spatial distribution of savanna fires in Los Llanos Orientales of Colombia was investigated and estimates were made of the area burned as detected from satellite data in the dry season when most fires occur (December 2000 to March 2001). A number of 3639 burned scars (with an extension of 488,235 ha) were detected in the period analysed. This burned area accounted for 5.18% of the savanna area (9,419,741 ha) and 2.87% of the total study area (17,017,854 ha). The mean size of the fire scars was 134.17 ha and over 75% of the patches are smaller than 115 ha. This data is the first local estimate of burned area in the Colombian savannas and might be of importance for future calculations of greenhouse and atmospheric trace gas emissions to the atmosphere from Colombia.

INTRODUCTION

Vegetation fires and in particular, savanna fires, occurs all over the world

resulting in an important emission of greenhouse and atmospheric trace gases to the atmosphere (Ward et al., 1992; Hoffa et al., 1999; Barbosa and Fearnside, 2005). But fire also affects the maintenance of grassland ecosystems, in fact fire can help promote the spread of grasslands and savannas (Bond et al., 2003), limit tree formations in grasslands ecosystems (Silva et al., 2001; Eva and Lambin, 2000), is an important agent in maintaining a balance between forest advance and retreat in savannas (Hoffmann et al., 2003) and recurring fires and their frequency are one of the factors that can affect the physiognomic form of savanna formations (Santos et al., 2003) and modify the nutrient balance of soils (Crutzen and Andreae, 1990). Furthermore, current stationary savannas are formed partly as a consequence of the interrelation of the effects of human induced and natural fires (Sarmiento, 1990). There are some estimates regarding the origin of vegetation fires and the results suggest that fire set by humans in about 80% of the times while only 20% occurs by a natural event such as lighting (Levine, 1996)

In a global spatial distribution of vegetation fires study, Dwyer et al. (2000b) found that 38% of all fires were located in the Southern Hemisphere and most of them were detected within the tropical belt. The African continent is subject to most of the fires globally detected (50% of all detected in Dwyer study) mainly occurring in savanna regions. During 1997-2000, between 65% to 77% of biomass burned was in the tropics (Shultz, 2002) and between 16% to 27% of all biomass burned in the world was in South America. In this continent, south of equator most burning occurs in Brazil and north of equator burning takes place in Venezuela and Colombia savannas (Dwyer et al, 2000b).

The knowledge on global and spatial distribution of savannas fires has becoming increasingly important for policy makers due to the potential effects on global change. As much as 5 million km^2 of tropical and subtropical savannas are burned each year (Levine et al., 1999) and up to 40% of all biomass burned globally is due to savanna fires (Hao and Ward, 1993). Hao and Liu in 1994 estimated that about 50% of the fires in the tropics occur in savannas, even though in this region grasslands account for 14% less area than forests (White et al., 2000). The burning of savannas can destroy 3 times as much dry matter per year as forest burning and constitute 40% of the gross carbon emissions to the atmosphere (Andreae, 1991).

Most recent global fire vegetation estimates have been done using satellite data with global coverage, gross or medium spatial resolution and high temporal resolution like Advanced Very High Resolution Radiometer (AVHRR)(Dwyer et al., 2000a; Barbosa et al., 1999b; Barbosa and Fearnside, 2005), Systeme Pour lÓbservation de la Terre (SPOT)(Gregoire et al., 2003; Tansey et al., 2004), Moderate Resolution Imaging Spectroradiometer (MODIS) (Kauffman et al., 1998; Justice et al., 2002) or the Along Track Scanning

Radiometer (ATSR)(Kempeneers et al., 2002). One of the most recent global estimates of burned area indicates 8015 km^2 of burned area and 735 fire scars detected (Tansey et al., 2004) in grasslands and croplands for Colombia in the year 2000, much higher that the figures estimated for Brazil in the same study (5258 km^2, 1575 scars). However, there is a strong requirement for detailed information assessing the extent of vegetation fires using higher resolution sensors such as LANDSAT or SPOT that can detect the impact of fires after a fire event in the form of fire burn scars. The information on the geographic distribution of savanna fires in South America and in particular in Colombia is poor in comparison to other regions where several studies have been conducted in regions of Africa (Barbosa et al., 1999a; Hofa et al., 1999; Hudak et al., 2004; Korontzi et al., 2004), Asia (Streets et al., 2000; Liew, 1997) or in South America, mainly in Brazil (Fearnside, 1997; Dwyer et al., 2000ab; Barbosa and Fearnside, 2005). In the Colombian part of the Orinoco basin, fires are one of the most important natural and human factors associated to the expansion of the agriculture frontier. Savannas are being converted to agriculture and ranching at an unknown rate and despite the ecological benefits of fire the fact is that the possible loss of species that might be occurring due to recurrent burning is also unknown. Also biomass burning contribution of Colombian savannas to global change emissions is uncertain. This study has the objective of estimating the area burned, the percentage of area affected and the spatial distribution of burned areas in the savannas of Colombian Llanos Orientales. They will be of use not only to understand the global and regional geography of potential emissions due to biomass burning but also the role of fire in land use and land cover change in this part of the world.

STUDY AREA

The Orinoco savannas of Colombia also known as the Llanos Orientales, are located in the northeastern part of Colombia, western part of the Orinoco basin between 2° 30’ - 7° 0’N and 74°0`- 67°24W (Figure 1). The Colombian together with the Venezuelan savannas constitute the main tropical savannas in northern South America (Berrio et al., 2002) and form a continuous plain between 80-300 m of altitude covering 8.507.191 ha approximately. The climate in the study area has been classified as hot, tropical and humid to dry. Mean annual temperature is between 27-30°C in the dry months and 23-26°C in the rainy months. Annual average precipitation varies between 1000 and 3500 mm. The climate is seasonal with rains distributed with a dry period from 2 to 5 months (between November and March) depending in its longitudinal gradient (Etter, 1998).

Its complex geological history has 3 tectonic provinces (ORAM, 1999). The first one includes the small precambric rocky formations derived from the relicts of the Guiana shield, restricted to the boundary with Venezuela. The second one includes the extended tertiary formations of sandy soils from the limits of the shield that are sometimes filled with quaternary alluvial deposits. The third

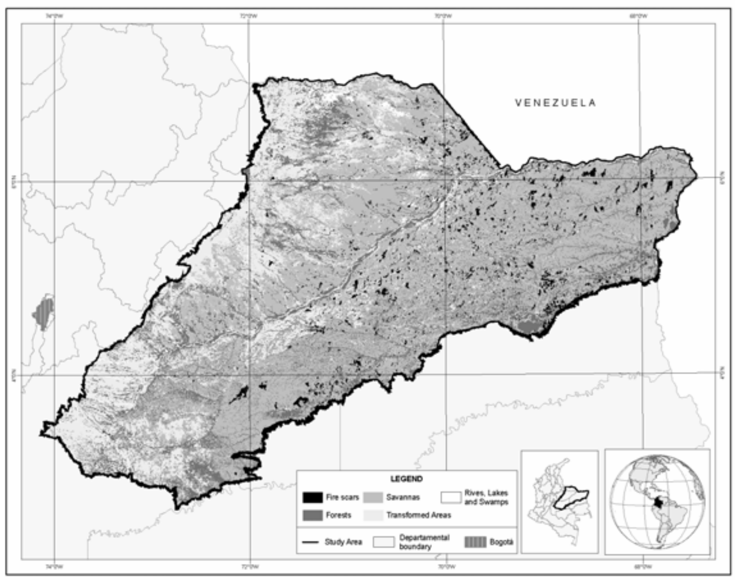

Figure 1 The study is of Los Llanos orientales of Colombia with the location of its forest, savanna, transformed areas and fire scars

province includes the alluvial savannas of the late quaternary, located in the northern part of the Meta River and affected by sediments from the Eastern face of the Andes. The soils of the Llanos Orientales, are chemically very poor and are the product of a long climatic and geological history. The most typical soils are Ultisols, Oxisols, Entisols and Inceptisols (Cochrane et al., 1985; IGAC, 1983; Proradam, 1979; Malagon, 1977).

The savannas of the Llanos belong to the Pedobiomes (Breckle, 2002), with azonal vegetation and extreme soil types that play a more important role than climate conditions in vegetation composition. This biome can be broadly divided

into several subcategories according to their soil conditions:

a. *peinobiomes*, low fertility soils;

b. *helobiomes*, hidrologically determined;

c. *anfibiomes*, both edaphically and hidrologically determined, permanently flooded; and

d. *litobiomes,* where rocky soils are present.

These biomes form a forest and savanna complex that hold different vegetation formations such as the arboreus savannas, flooded and seasonally flooded savannas, dune savannas, high plain savannas, sandy savannas, gallery forests, palm forests (*Mauritia flexuosa)* and swamp vegetation (Romero et al., 2004). The predominant vegetation is composed of C4 grass especially from the Poaceae and Cyperaceae families in association with some dispersed woody plants. It's relevant to highlight species like *Andropogon bicornis, A. leucostachyus, A. selloanum, Axonopus aureus, A. purpusii, Imperata brasilensis, Leptocoryphium lanatum, Mesosetum loliiforme, Panicum camprestre, P. laxum, P. Rudgei, Paspalum carinatum, P. convexum, Trachypogon plumosus, T. vestitus and from the woody ones Mauritia flexuosa, Curatella Americana,Byrsonima americana, Syagrus sancona, Bactris guianensis, Eritrina fusca, Indigofera hirsuta, Acrocomia aculeta, between others.*

METHODOLOGY

A vegetation map was carried out after acquiring the necessary basic and thematic cartography and the satellite images. We used Landsat ETM and TM images corresponding to the following months: December, 2000, January, February and March, 2001 (Table 1). The images were georeferenced and processed using ERDAS Imagine. The anthropic and natural vegetation classes were discriminated by a combination of manual and digital interpretation and secondary information. An ecosystem map was created for the study area, the classification system is explained in Romero et al. (2004) and includes

Table 1 Landsat images used for mapping major vegetation types and fire scars

Sensor	Path Row	Date
ETM	456	9 Jan 2001
ETM	457	9 Jan 2001
ETM	555	22 Apr 2001
TM	556	8 Jan 2001
ETM	655	31Jan 2001
ETM	656	16 Feb 2001
ETM	657	16 Feb 2001
TM	658	12 Mar 2001
ETM	755	13 Dec 2000
ETM	756	13 Dec 2000
ETM	757	13 Dec 2000
ETM	758	3 March 2001

geomorphologic and bioclimatic information. Areas affected or transformed by fire were obtained using the different spectral gammas of the satellite images. Fires were not directly detected using this methodology, but burnt scars that fires left in the land.

Ground testing was done where accessibility conditions allowed the field work scale. We used Meindenger (2000, 2003) protocols to evaluate the precision and the quality of the data. The thematic content of the ecosystem classification was evaluated through a statistic analysis using aerial photographs. 92.3% of the polygons were well classified with confidence intervals between 84.6% and 94.9%. Arcinfo-ArcGIS was used for the interpretation and integration of the information into a geographic information system. From the fire scars map were used to analyse the size of the scars (Figures 3, 4, 5 and 6).

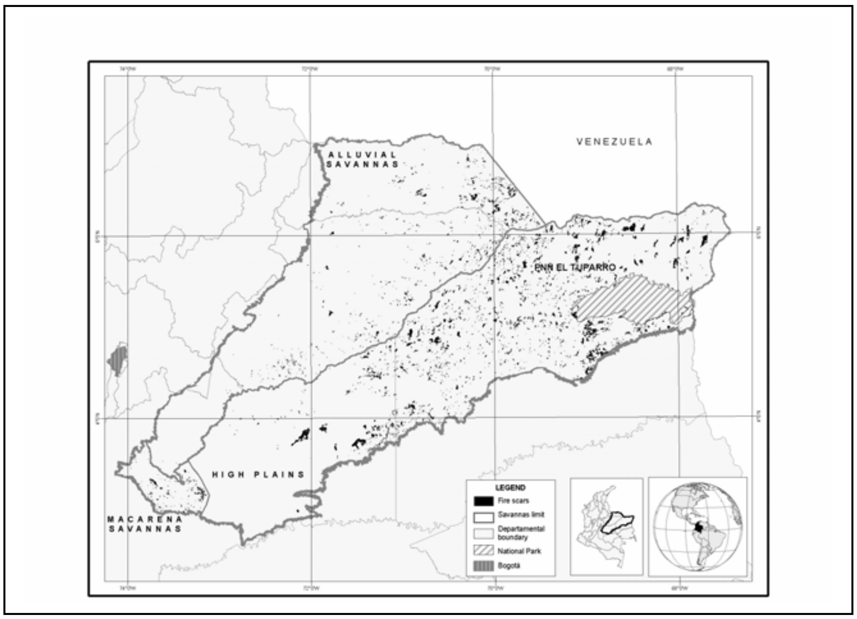

Figure 2 Location of fire scars in the three major savannas: alluvial, high plains and Macarena savannas

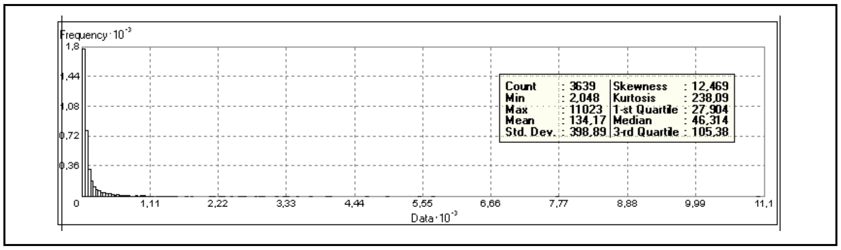

Figure 3 Frequency distribution of burnt scars patch sizes

RESULTS

The distribution of ecosystems and fire scars (Figure 1, Figure 2), estimates of area, number of burned scars and the percentage of the study area of each ecosystem and burned savanna within the study area are given in Table 1. 3639 different fire scars were detected in the savannas of Los Llanos Orientales of Colombia in the period analyzed (December 2000 - March 2001). The distribution of all fire scars can be appreciated both in 2, distribution shown separated according to the three major savanna types identified. Two major white areas where no fire scars are detected can be identified in the high plains savannas. One corresponds to the north eastern part of the study area where the national natural park El Tuparro is located. The other “fire gap” is located in the south western part and corresponds to an area where land use and land cover changed towards other agriculture systems and no more natural savannas are found but anthropogenic transformed ecosystems are present, mainly cattle grazing and mixed agricultural crops.

The total of savanna area burned in the period analyzed for the year 2000 are 488,235 ha (2.87% of the study area, Table 2). These figures are substantially lower in area and higher in number of scars than Tansey et al. (2004) estimates for Colombia in the year 2000 (8015 km^2 of burned area, 735 fire scars). Of all savannas fire scars detected 76.45% (373,270 ha) correspond to fire scars detected in high plain savannas, 19.52% (95,281 ha) are in alluvial savannas and the rest (19,682 ha) belong to the Macarena area.

Table 2 Extent, number of patches and percentage of the study area of each vegetation type and burned areas

Ecosystem type	Area (ha)	Number of Patches	Percentage of study area (%)
Forests	3,252,651	47118	19.11
Alluvian Savannas	2,980,277	12917	17.51
High plains Savannas	5,920,552	27322	34.79
Arboreous Savannas	30,677	475	0.18
Burn Scars in High plains Savannas	373,271	2400	2.19
Burn Scars in Macarena Savannas	19,683	280	0.12
Burn Scars in Alluvian Savannas	95,282	959	0.56
Transformed ecosystems	3,927,881	32138	23.08
Rivers, Lakes and Swamps	417,580	4191	2.45
Total	**17,017,854**	**127,800**	

The size of the fire scars has an average of 134.17ha and a standard deviation of 298.89 ha, minimum size of 2 ha and maximum of 11,023 ha (Figure 3). Over 75% of the patches are smaller than 115 ha. Figures 4, 5 and 6 illustrate the

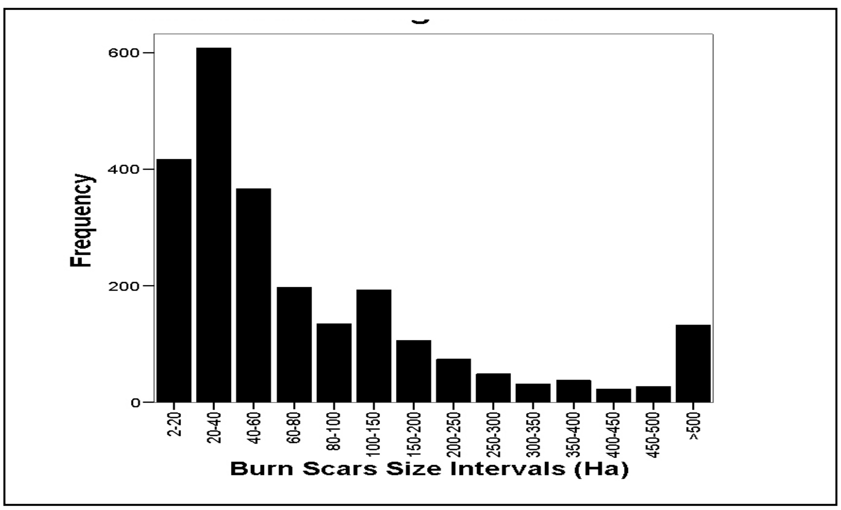

Figure 4 Distribution of burn scars size for the high plain Savannas of Los Llanos Orientales

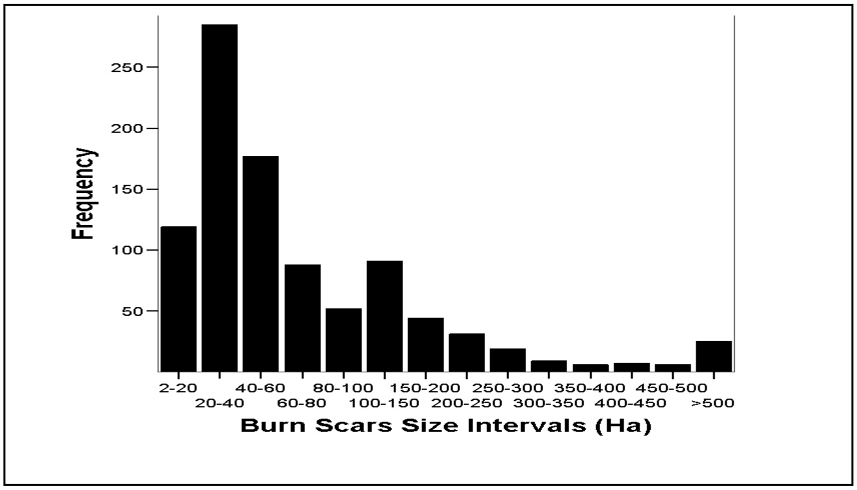

Figure 5 Distribution of burn scars size for the alluvian Savannas of Los Llanos Orientales

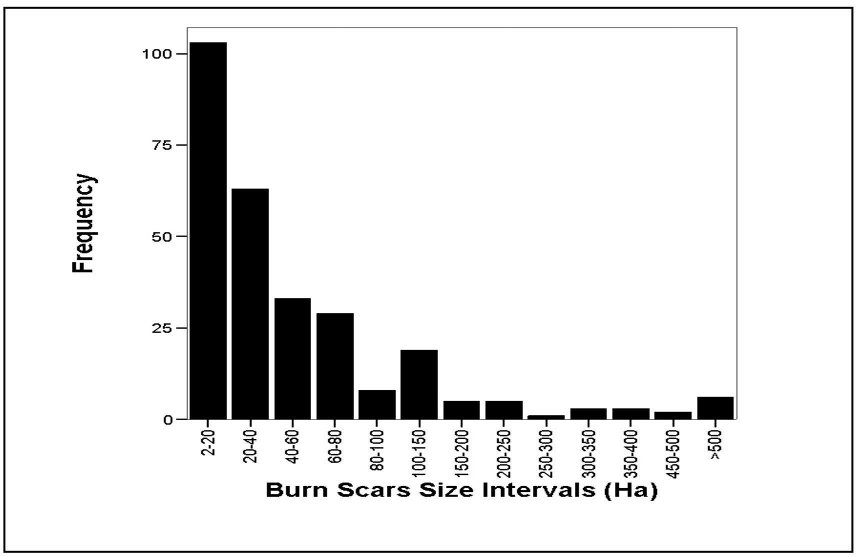

Figure 6 Distribution of burn scars size for the Macarena Savannas of Los Llanos Orientales

distribution of fire burn scars for each type of savannas. For high plain savannas,

the average burn scar is 155.52 ha (min. 2.048ha, max. 11,023ha), for alluvian savanna the average size is 99.35 ha (min. 2.048 ha, max. 3,304ha) and for Macarena savannas the mean fire scar has a size of 70.29 ha (min 2.048 ha, max 2,286.9 ha).

DISCUSSION AND CONCLUSIONS

Most of the fires in the savannas of Los Llanos Orientales of Colombia area caused by humans, mainly farmers that use fire for slash-and-burn practices. Usually people burn during the dry season (December to March) as a way of obtaining fresh grass for their cattle and to clear fields for cultivation later in the year. The spatial distribution of fire scars and an inventory of the extent of savanna burning with reference to Colombia is presented in this paper and clearly values for burned area depend on the savanna types. The total figures differ from the global burned area products developed under the GBA-Initiative (Gregoire et al., 2003, Tansey et al., 2004) from medium resolution imagery and at a coarse resolution of 1 km. A comparison of our results with the available through internet from the GBA-Initiative seem to indicate that the global estimates misclassified flooded areas as fire scars, probably overestimating burnt areas due to this effect. Also important is the detection of small fires, very frequent in the Colombian savannas and undetected in global estimates.

The spatial and size distribution of burn scars are influenced by the savanna's geomorphology, the climatic seasonality and the intensity of human pressure. The high plain savannas are not permanently flooded over the year and soils are mainly sandy soils, this fact facilitates the fire dispersion and gallery forests are usually the natural barrier to fire. On the other hand, in the alluvian savannas, the dry season is the period of the year where most fires occur but are also affected by the geomorphology, floods and humidity conditions. In the Macarena region, most natural ecosystems have already been transformed to agricultural systems, not much natural savannas are left and the few patches are smaller than those from other areas and so are the fire scars detected.

The information presented in this paper provides a detailed and direct spatial estimate of savanna burning in Colombia and uncertainties are less than those from global estimates. However is very important to take into account that scars from fires in savanna vegetation are visible for only a short period and frequency of fires is also unknown. Also important is to know more about the ecology of savannas in Colombia. Knowing these figures together with the data presented in this study will potentially help improved future estimates of greenhouse emissions from Colombia. Information is urgently needed on the

frequency of fires, the amount of biomass burnt and consumed by fire (above ground) and burning efficiency in each savanna type in Los Llanos Orientales of Colombia.

Acknowledgements: This work was the result of the project "Biodiversity and development in strategic ecoregions of Colombia: Orinoquia", partially funded by GTZ-Germany. Our thanks to Fernando Gast, General Director of Instituto de Investigacion de Recursos Biológicos Alexander von Humboldt in Colombia. We want to specially thank Javier Otero, Patricia Falla and Herbert Froemberg for their work in this project and all the member of the GIS Unit of Humboldt Institute. We also want to thank the following participant institutions: CDA, Corpoorinoquia, Cormacarena, Instituto Geográfico Agustín Codazzi, Unillanos, Unitropico, Universidad Javeriana, WWF-Colombia, Fundación Horizonte Verde and the Ministry of Environment. Finally, we want to thank all those that somehow contributed to the completion of this preliminary study.

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