Fire Along the Transition Between the Amazon Forest and the Cerrado Ecosystems[1]

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ABSTRACT

Most of the fires in Amazonia happen along an arc of deforestation, which generally follows the transition between the Amazon evergreen forests and the savannas (cerrado). The evergreen primary forest acts as a giant fire break, while the cerrado has adapted to frequent fires. The transitional zone between these two ecosystems is a fragile boundary controlled by very dynamic ecosystem processes. It is also an area with heavy pressures from human settlements that use fire as a way to clear and manage the land. Canopy disturbance of the primary forest due to increased selective logging and deforestation, along with extended droughts, alters the hydrological equilibrium of this ecosystem and therefore, the ecotone. High temperatures and very low relative humidity in disturbed stands increase the flammability of the primary forest. The deep rooting systems have an important role in supplying water during the dry season. As precipitation decreases, the primary forest is able to tap deep soil water; however, if the water supply is interrupted during an exceptionally dry year, the vegetation can dry and suffer leaf loss. Light penetration then increases, fuel moisture decreases, and fuels become dangerously flammable. This paper presents the main ideas of a fire susceptibility model that is being developed for the region.

Key words: Fire, Forest Savanna Ecotone, Water Stress, Rooting Depth, GIS, Modeling, Tropics, Brazil.

I - INTRODUCTION

Fire and tropical rain forest are topics that seem unrelated; however today most of world's vegetation fires occur in the tropical and subtropical regions (Goldammer and Manan 1996). In 1987, approximately 20.5 million hectares of forests burned in the Brazilian Legal Amazon in more than 170,500 fire points (Setzer and Pereira 1991). In the following years this rate of fire was reduced, building again in 1995 with almost 40,000 fire points happening over Brazil by July, the beginning of the burning season (Annon 1995). The large number of fires in the Amazon has been related to regional and global problems, like carbon emissions, ozone production, and accumulation in the lower atmosphere (Chatfield and Delany 1990), and, more recently with economic and social

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problems caused by the smoke (Anon 1995). Fire is also very important in the definition of the savanna-forest ecotone in the Amazon, since the savanna has adapted to frequent burns (Ratter 1992), while the forest has adapted to avoid fire. Despite the importance of the issue, very little work has been done to understand the ecology of fire in the Amazon. This paper has two main objectives: 1) to present a general overview of fire in the Amazon forests with emphasis on the forest savanna transition zone, and based on those ideas, 2) present the main ideas of a fire susceptibility model that is currently being developed for the region by the senior author.

II - FIRE CONDITION IN THE AMAZON REGION

The international Amazon region, considered here as the Amazon and the Tocantins river basins, has almost 7 million square kilometers composed mostly of evergreen forests and cerrado, the Brazilian savanna (fig. 1). The savannas are more prevalent in the southern and eastern areas, with parts in the far north and southwest part of the region. The precipitation and the duration of the dry season in the region vary from more than 5,000 mm/year with no dry period in the west central and north part of the

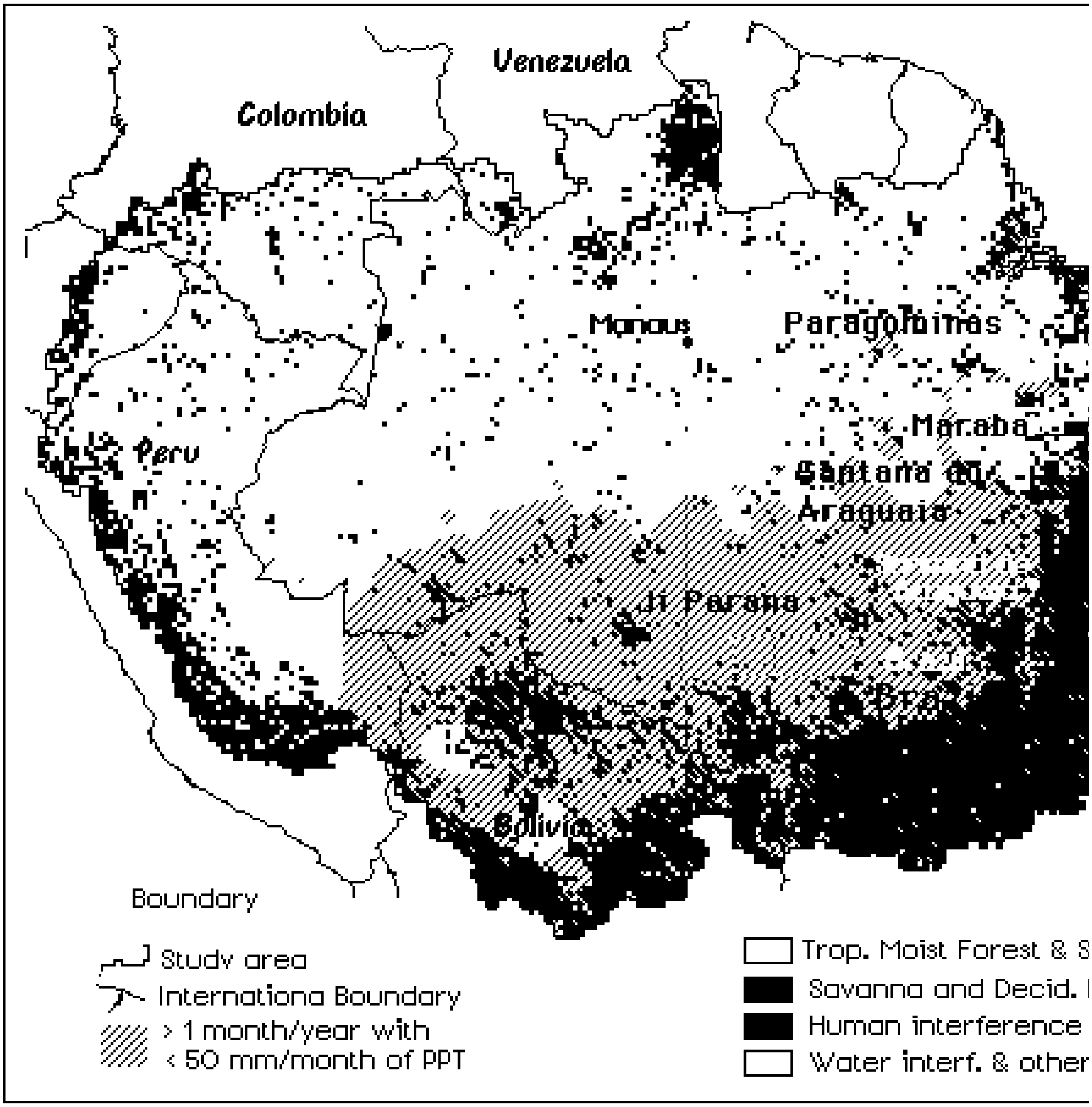

Figure Study area and vegetation distribution. The shaded areas show where the dry seasons are longer and drier. The study area is composed of the watersheds of the Amazon and Tocantins rivers and the political boundaries of the Brazilian states that are part of the Brazilian Legal Amazon. The vegetation classes are adapted from Stone and others (1994) and the climatic data used were obtained from the CAMREX Project at the University of Washington.

region, to areas dominated by cerrado with 1,100 or less mm/year with an intense dry period of five months or longer in the southern east part.[8] The human settlements in the Amazon generally follow the patterns of the roads that reach the region. By its shape it is usually referred to as "the arc of deforestation," as it generally follows the forest-savanna boundaries. In large areas close to the forest savanna ecotone, the evergreen forests are subjected to large and intense dry seasons in which the monthly precipitation does not meet the evapotranspiration needs of the vegetation. In these areas, some deciduous and semi-deciduous trees in the forests usually show a lower, and sometimes less constant canopy.

At the Savanna

Like most savannas in the world, the Brazilian savannas have adapted to seasonal fires. The frequency of fire in the savannas has an important role in the definition of its physiognomy. The higher the frequency of fires, the smaller the woody component in the vegetation, producing a savanna that tends toward grassland. The smaller the fire frequency, the larger the woody component of the savanna, producing a savanna that tends toward forest (Ratter 1992).

The savanna climate, a long dry season, high temperatures, and low precipitation is an ideal high fire frequency scenario. The precipitation in the savanna areas rarely exceeds 1,700 mm/year, most of which falls during the rainy season (southern summer). In the cerrado, the dry seasons are long (five or more months) with the precipitation below 50 mm/month. Periods of 100 or more days without precipitation are common in the savanna area. The daily temperatures in the savanna during the dry season are high (usually more than 30^{o}C), and the relative humidity of the air is low (usually less than 30%), conditions that contribute to seasonal burns.

At the Forest

The climate in Amazon tropical forests is generally more humid than in the savannas, making forest less susceptible to fire. However, as the forest approaches the ecotone region, the climatic conditions change. The dry season becomes longer and drier; causing the humidity equilibrium of the forest to become more sensitive. In these regions two factors play important roles in the flammability of the forests: the degree of human interference in the forest structure and the hydrological condition of the ecosystem. Both factors are linked with the flammability by the energy (sunlight) allowed to reach the forest floor and the water that the ecosystem can retain.

The flammability of forest ecosystems is highly dependent on the structure of the vegetation (height, density, and openness of the canopy and understory) which determines the microclimate of the stands (insulation, temperature, and relative humidity). In one region of the Amazon, the primary forest with undisturbed canopies does not reach flammable levels even in periods of more than 30 rainless days. The 15 year old secondary forests need a period of 8-10 rainless days to have flammable conditions, and a pasture needs only a 24 h rainless period. The selectively logged forest,

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8 Analysis of 22 years of precipitation data of more than 400 different weather stations over the study area.

with artificially open canopies, becomes flammable in 5-6 rainless days (Uhl and Kaufman 1990).

The hydrological conditions of the forests are also sensible to long-term variances in the climate. The tropical forests close to the ecotone with the savanna use deep soil water stocks as a strategy to keep their evergreen closed canopy during the longer and drier seasons when precipitation is inadequate (Nepstad and others 1994, 1995). Interannual variations in the regional climate that reduce annual precipitation can adversely modify the water stocks in the deep soil for years in those areas (Jipp and others, in press). Once under water stress, the trees start to drop their leaves, increasing the light penetration in the understory, fuel on the forest floor, and therefore the flammability of the whole forest.

The land use dynamic and intensity in the Amazon region can create more favorable conditions for fires. In a natural environment in the Amazon, even in the ecotone, a large patch of undisturbed forest can be under water stress and flammable conditions with some seasonality (within a year or through decades), but this same patch of forest will only burn with a source of fire. The ignition of a fire in the Amazon forests has never been related to natural activity. Even if a natural ignition happened, it will need to be coincident, in space and time, with a flammable patch of forest. Fire in the Amazon forests is always associated with land use dynamic. In the Amazon, fire is largely used as a technique to clear areas of forest (undisturbed, secondary, or selectively logged), to make pastures or cultures, and to manage the pasture. In the mosaic of altered ecosystems generated by the land use intensity, where the remaining primary forests are the least flammable ecosystem, human activity becomes a regular source of fire. Therefore, when a patch of forest becomes flammable, it is more likely to burn if it is under or close by any land use intensity.

In the exceptionally dry years of 1983 and 1991, large fires happened in the tropical forest of south Asia (Goldammer and Manam 1996, Saad and others 1996). In 1991 more than 1,000 km^2 of multiple ecosystems found near Paragominas in Brazil burned (T. Stone[9]). In Sanatana do Araguaia, right in the ecotone, a positive correlation of dates between fire scars and pasture formation 2 km inside untouched forests in exceptionally dry years were recently found (G. Negreiros, unpublished data). In summary, when natural water stress and intense land use are combined in time and space in the tropics, large, frequent

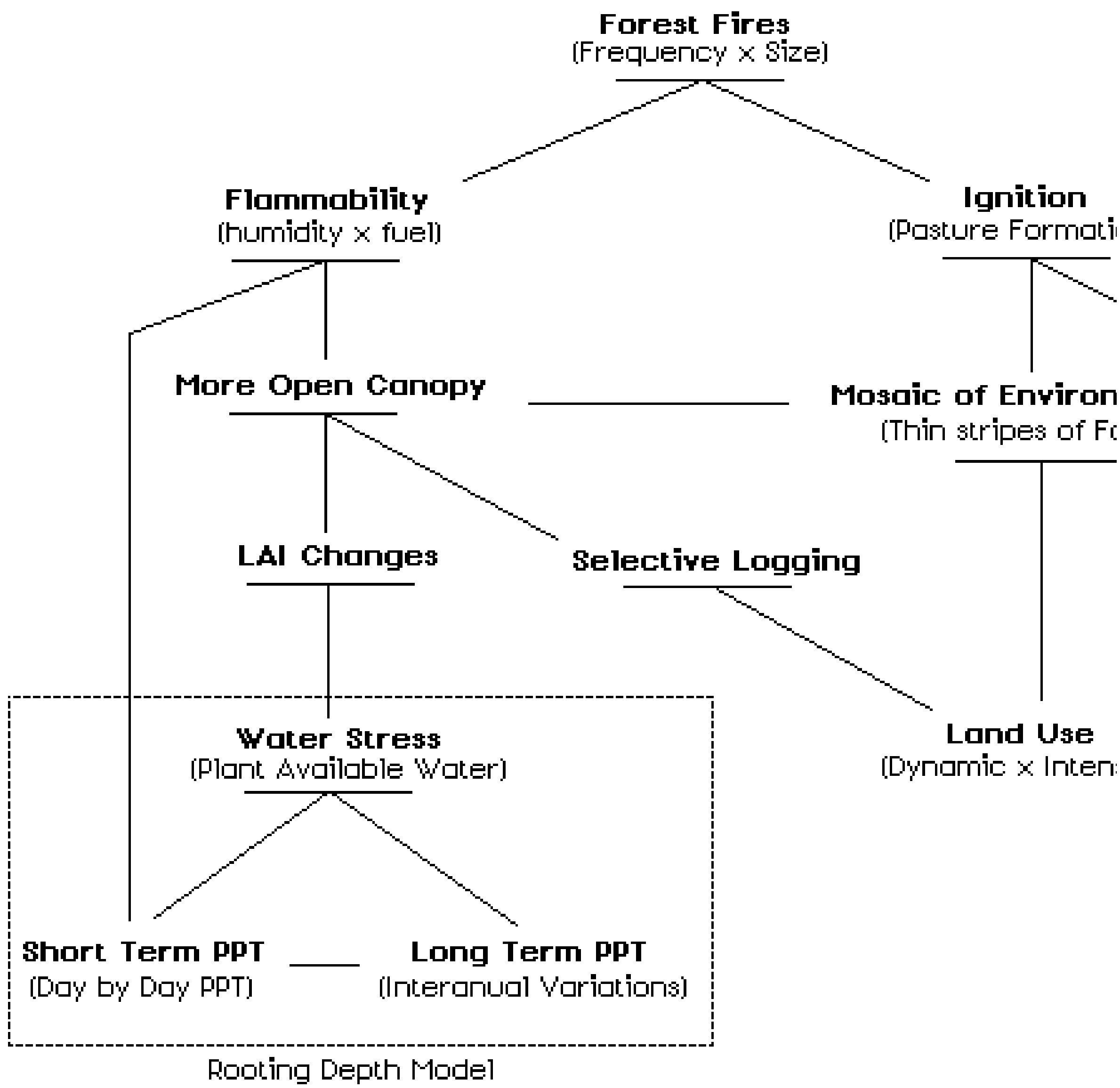

Figure Flux of the proposed model with the box representing the Rooting Depth Model. The two main columns (axes) represent: a) the ecological condition (flammability) driven by physical characteristics (climate and soils) and the condition of the ecosystem, and b) the exposure of this ecosystem to fire sources (ignition), driven by human activities in the region.

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9 Personal communication. 1996. T. Stone, Whoods Hole Research Center. Woods Hole, MA.

fires take place.

III - THE PROPOSED MODEL

Based on the ideas presented above, a framework of conditions that allow large and frequent fires to happen in the tropical forests of the forest savanna ecotone in the Amazon is proposed in fig. 2. This framework is being used as a basis to model the potential flammability of the forests in the forest savanna ecotone. The two main axes of this model are the water stress condition of the vegetation and the land use over the region.

The stress condition of the vegetation is obtained by interpreting the information generated in the rooting depth model (Negreiros and Nepstad 1994, Negreiros and others, in press, Negreiros and others, unpublished) in direct relation with the rooting depth. The rooting depth model is a mechanical model of the plant available water in the soil in different depths based on real precipitation and soil data, and evapotranspiration estimates over the forests of the entire Amazon Region. The stress condition is an indicator of the canopy openness, and by consequence, of flammability. This link between the plant available water in the soil and the flammability of the ecosystem is being tested in two different ways: intensive field work at different points on the Amazon Region and by remote sensing analyses of vegetation changes in multi-temporal AVHRR/NOAA images.

The land use information to be used is still an open question. The current plan is to use a combination of maps with statistical and GIS modeling techniques. The more recent land use map (Skole and Tucker 1993) will be used to define major areas of land use intensity and dynamic by spatial patterns. Statistical information about productivity of the land in different areas (seasonally generated by FIBGE in Brazil) will be combined with geographical information of roads and political borders. All this information will be gathered to generate an index of ignition rates to be combined with the flammability of the ecosystem.

The proposed model of potential fire frequency in the Amazon as a whole has already been tested. Since 1987, the frequencies of fire points have been directly measured by INPE using AVHRR/NOAA data. This tool is already being used to test the methodology and drive changes in the development of the model by direct comparisons between its results and the rooting depth model results.

IV -CONCLUSION

To control forest fires in the Amazon, one must understand its main cause: the combination of environmental conditions and human presence. The proposed model intends to produce information about the flammability of the forest ecosystems in the forest savanna ecotone and find possible high fire frequency areas based on the climatic and environmental information available. That information, modeled under past, present, and possible future scenarios can help us better understand the role of fire in the forest savanna ecotones in the Amazon, its dynamic, patterns, and future under the present trend or under the climate changes predicted by the current theories. The information that will be generated by the model can also lead, in the near future, to a better planning and a better policy of fire control in the region based on actual environmental, climatic, and land use data.

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