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FIRE IN THE TROPICAL RAIN FOREST OF THE AMAZON BASIN

Philip M. Fearnside
National Institute for Research
in the Amazon (INPA)
C.P. 478
69011 Manaus-Amazonas
BRAZIL

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1.) ANCIENT AND "NATURAL" FIRES

Fire has long played an important role in the formation of vegetation types in Amazonia. During the Pleistocene, a large part of Amazonia was covered by grassland, with forest confined to small refugia (the number, size and evolutionary importance of which are the subject of controversy) (Prance, 1983). This period coincided with the arrival of the first humans in the area. Fires started by precolumbian human groups would have slowed the progress of recolonization of the grasslands by forest (e.g., Budowski, 1956). Human-initiated burning of grasslands could be expected to affect both the 165,000 km^2 of humid savannas of present-day Amazonia (such as those in Roraima in the Humaitá area of the state of Amazonas) and the limit between the forest and the cerrado or central Brazilian scrubland. Charcoal in the soil of the lavrados ("natural" grasslands) of Roraima indicate large-scale burning about 1000 years B.P. (Sternberg, 1968).

Fire in clearings for shifting cultivation within the forested area also affects the composition of the vegetation, although not to the extent of preventing woody vegetation from returning. The density of human population was formerly much higher than it is today, as indicated by the large number of anthropogenic "black soil" sites in the region (Smith, 1980). Charcoal has been found in soils under "virgin" Amazonian forest in Venezuela and Colombia (Sanford et al., 1985), in Altamira (Pará) (Fearnside, 1978) and at Manaus (Amazonas) and Ouro Preto do Oeste (Rondonia). Recent recovery and radiometric age determination of charcoal in the lowland tropical rain forest of East Kalimantan (Indonesia) is described by Goldammer and Seibert in this volume.

Fires can also be started by nonhuman agents such as lightning. Reasons for believing that the principal cause of precolumbian forest burning was human, however, include the very limited extent of lightning-caused fires in Amazonia today. Usually only a single tree or a very small patch is burned when lightning strikes. The forest normally has to be felled and the trees allowed to dry on the ground for a few weeks before they can be ignited.

2.) DEFORESTATION AND BURNING IN AMAZONIA TODAY

Burning in deforested areas in Amazonia today dwarfs the burning of past eras. By 1988 approximately 400,000 km^2, or 8% of Brazil's 5 x 10^6 km^2 Legal Amazon region had been cleared, and the cleared area was increasing at about 35,000 km^2 annually (Fearnside, in press). Of this cleared area, approximately 250,000 km^2 is in the 3.4 x 10^6 km^2 part of the Legal Amazon occupied by dense or "rain" forests (7% of the original area of these forests), while 170,000 km^2 is in the 1.3 x 10^6 km^2 portion occupied by cerrado (Mato Grosso and Tocantins, formerly northern Goiás) versus the remaining seven states, where dense forests predominate (Fearnside, unpublished a). In addition to clearing, the cerrado vegetation is regularly burned without being deforested--burning is an event to which the fire-resistant species of this vegetation type are adapted.

The above estimates of areas deforested are based on linear projections to 1988 from the most recent two years of satellite data within each of the Brazilian Legal Amazon's nine states (Fearnside, in press). These estimates are substantially lower than an estimate produced from AVHRR images of fires interpreted by the National Institute for Space Studies (INPE), indicating that in 1987 204,608 km^2 was burned, of which approximately 80,000 km^2 was considered to be deforestation in the dense forest area (Setzer et al., 1988: 28). Reasons for the much higher value for burning include the fact that burning is not the same thing as deforestation: pastures, secondary forests, and cerrado are burned without contributing to deforestation. The area covered by the AVHRR image included substantial areas of pasture and cerrado outside of the Legal Amazon, having included the full area of two states (MaranhÔo and Goiás) that are only partially within the Legal Amazon. The discrepancy between the 80,000 km^2 area considered new deforestation in the AVHRR estimate and the 35,000 km^2 figure derived from linear projections is due to saturation of the AVHRR sensor when recording the heat emanating directly from the fires. The AVHRR images are composed of picture elements or pixels of 120 ha each; only a small area burning within one of these pixels is sufficient to trigger the sensor to indicate the entire pixel as burning. As little as 30 m^2 on fire can saturate the sensor (Robinson, in press). A constant correction factor of 70% was applied in the INPE study to adjust for partially burning pixels, but an adequate constant is difficult to derive for making this correction because of the great sensitivity to fire temperature, which varies depending on meteorological conditions, fuel moisture, time of day, etc. The explanation of the discrepancy in saturation of the AVHRR sensor is indicated by the results of an AVHRR image for Rondônia in the same year (1987) interpreted by Jean-Paul Malingreau (personal communication, 1988). Using reflected light from deforested areas, this indicated 15.1% of Rondônia as deforested by that year, whereas the INPE study of burning indicated 18.7% as actually on fire. Since any given hectare in the deforested area can only be re-burned once every 2-3 years, the INPE result implies an area on the order of 40% deforested, which represents the same level of discrepancy as that between the 35,000 km^2 indicated as the rate of deforestation in the Legal Amazon by linear projections, versus the 80,000 km^2 indicated by AVHRR sensing of burning.

The above results from linear projections also differ from an estimate for 1988 deforestation made by a different sector of INPE using LANDSAT imagery (Brazil, INPE, 1989). This study, released on 6 April 1989 in conjunction with President Sarney's Nossa Natureza ("Our Nature") Program, calculates that a total of only 5% of the Legal Amazon had been cleared, and implied an annual rate of increase of only 16,674 km^2. However, the data for several states conflict with other LANDSAT studies carried out by the Brazilian Institute for Forestry Development (IBDF). The INPE results would imply decreases in deforested areas for Acre, Pará, and Mato Grosso based on previous LANDSAT studies, and in Rondônia based on AVHRR studies. In Roraima, although a decrease is not implied, the increase would be so slight as to be highly improbable. The discrepancy between the linear projection estimate of 8% and the Nossa Natureza Program estimate of 5% is not due to out-of-date data in the linear projection study: the states with the most out-of-date data sets (Amazonas and Amapá) do not result in positive discrepancies, whereas states such as Pará and Acre where recent LANDSAT data are available are precisely those where the greatest discrepancies with the Nossa Natureza study are found. Combining the two estimates to arrive at a "best estimate" for deforested area through 1988 in the Legal Amazon, a figure of 8.4% results if the linear projection estimates are used for all states for which the Nossa Natureza estimates conflict with other data, and 8.1% if Nossa Natureza data are used for Rondônia, where differences between the AVHRR and LANDSAT-TM sensors could provide an explanation for the discrepancies (Fearnside, unpublished b). These figures tend to reinforce the 8% estimate as the most likely approximation of deforestation through 1988. Regardless of which estimates are correct, all show rapid increases in cleared areas and suggest that immediate measures must be taken to slow forest loss.

3.) TYPES AND QUALITIES OF BURNING

Burning in Amazonia has been classified into categories for virgin forest (forest not previously cleared by non-indigenous immigrants), secondary forest (in the case of slash-and-burn sites: abandoned areas at least eight months uncultivated), weeds (areas eight or fewer months uncultivated) and pasture. Small amounts of burning also take place in sugar cane, but this land use occupies only an insignificant portion of Amazonia.

Virgin forest is felled prior to burning, in such a way as to maximize the thoroughness of the burn. First the broca or underclearing is performed, cutting vines, understory plants, and saplings or poles that can be cut with a machete or brush hook. Valuable tree species may also be cut selectively prior to felling. The large trees are then cut in the derrubada (felling) phase. Most is done with chainsaws, although some small farmers use axes. Because of the onerous labor of cutting trees with axes, small farmers clearing their own land with axes are more likely to leave scattered trees standing in the cleared areas. Large ranchers, which contract third parties to clear the forest, generally have the least standing trees unfelled.

The time available during the dry season limits the area that small farmers can clear with the labor available to them (Fearnside, 1980). If burning is delayed too long (usually with the intention of felling more area), then the always-unpredictable rainy season may begin, leaving the farmer with no land suitable for planting. In order to maximize the area cleared and the quality of the burn, clearing is often done in a circular pattern, leaving to be felled last an island of vegetation in the center of the field; the fire can then converge on the center of the clearing to consume this last-felled area despite its still being relatively green. The felled trees cannot be left too long before burning because resprouting green vegetation will shade the fuel bed, keeping it moist, and because the dry leaves will fall off the downed trees (making them more difficult to ignite). Variation in the dryness of the vegetation, nearness to the forest edge, topography, wind, and other conditions result in a large amount of variability in burn quality over short distances within the clearing. In one study of a 200-ha burn near Manaus (Amazonas), a visual assessment of 200 sampling stations classed burns into five categories: 22.0% of the points were classed as "excellent" (at least some trunks burned to ash), 45.5% were classed as "good" (burned vines and thick branches), 17.0% were "medium" (burned leaves and thin branches), 12.0% were "poor" (only leaves burned), and 3.5% were classed as "none" (not even dry leaves on the ground burned) (Fearnside et al., unpublished). This burn had consumed 29% of the pre-burn aboveground dry weight biomass, based on comparison of six pre-burn with ten post-burn destructive quadrats of 10 x 10 m each.

The percentage of biomass in the trunks, as opposed to vines and other finer material, appears to have a strong influence on the proportion of the biomass combusted. Finer material burns much more thoroughly: in the study near Manaus, 100% of the leaves burned, 75.8% of the vines, 49.1% of the branches, and 20.9% of the trunks. In a study of burns near Altamira (Pará), where a higher percentage of the forest biomass is composed of vines, a higher percentage of the biomass disappeared in the burn than was the case at Manaus.

Great variability in burn quality exists between farmers and between years. In a study among colonists on the Transamazon Highway near Altamira, burns were classified on a six-level scale: "none" (no burn attempted); "0" (burn attempted but did not burn); "1" (bad burn: only leaves and small twigs combusted); "2" (patchy burn: a mixture of class 1 and 3 burns); "3" (good burn: burned some wood as well as leaves and twigs); "4" (overburned: large logs burned completely to ashes) (Fearnside, 1986a; 1989). Grouping qualities "0" and "1" as "bad" burns and qualities "2" and "3" as "good" burns, of 247 virgin burns, 76 (30.8%) were "bad" while 171 (69.2%) were "good." Burn quality is a critical factor affecting soil fertility and agricultural productivity on the Transamazon Highway, and thereby plays a key role in limiting the human carrying capacity of the area. A good burn is necessary to remove the physical encumbrance of downed vegetation, to deposit nutrients in the form of ashes, to reduce competition from weeds, and to reduce the acidity of the soil. Burn quality is significantly associated with raising soil pH, lowering the concentration of toxic aluminum ions, and raising the levels of soil phosphorus (Fearnside, 1986a: 188-191). A poor soil with a good burn often produces a greater agricultural yield than a good soil with a poor burn. The quality of the burn depends partly on luck in having little or no rain during the period when the cut vegetation is drying, and partly on the skill of the farmer in judging when to set the fire. The range of behavior is very great: of 138 virgin burns performed by Transamazon Highway colonists, an average of 44 days elapsed between felling and burning with a standard deviation of 65 (CV = 148%). Felling dates ranged from May through December, with the most popular months being September (49.5%), October (22.6%), November (10.2%) and August (8.5%). The quality of the burn could be correctly predicted in 74% of 247 cases from meteorological factors: rain, evaporation, and insolation between felling and burning and in the 15 days prior to burning (Fearnside, 1986a: 186; 1989). Very high variability in meteorological parameters in the area guarantees high variability in burn quality from year to year (Fearnside, 1984).

Second growth burns can be predicted from meteorological factors in a way similar to that for virgin burns. Of 54 second growth burns surveyed in Altamira, 31 (57.4%) were "bad" (classes 0 and 1) and 23 (42.6%) were good (classes 2 and 3). Mean time elapsed between cutting and burning was 53 days (SD = 96, N = 79), with a coefficient of variation of 183%. The tremendous variability in clearing behavior explains some of the high variation in burn quality. The range of cutting dates is greater than for virgin burns, extending from June to January. It is possible to get away with cutting secondary forest closer to the beginning of the rainy season than is the case for primary forest. The most popular month for cutting secondary forest on the Transamazon Highway is September (21.6% of 111 cases), followed by October (21.6%), November (18.0%) and December (9.0%). The dates for burning in other parts of the region vary with the annual seasonal cycle. In Rondônia and Acre the most popular month is August, while in Amazonas it is September or October.

The fires are usually set at about 13:00 h, and burn throughout the afternoon and into the night. By the next morning one can normally walk through the burned areas, although large trunks may smolder for several days. The different species of trees burn with varying thoroughness. A few, such as samaúma (Ceiba pentandra) commonly burn completely to ashes.

Trunks of many species are reduced to ashes in the relatively rare cases where, under unusually favorable burning conditions, an "overburn" (class 4 burn) occurs. This "burns the earth," and results in stunted crop growth. Secondary succession is also altered: in the Altamira area, overburned sites sometimes develop a cover of bracken ferns that delays entry of woody secondary forest species for several years.

Following either a virgin or a second growth burn, the farmer may cut unburned branches and small trunks and pile them in mounds where they can be burned in a second burn prior to planting. The piling and re-burning operation, known as coivara, is usually done if upland rice is to be the crop planted; it is occasionally done for maize and never for pasture. The task is a laborious one, but varies greatly depending on the quality of the burn and the thoroughness with which the coivara is done. For virgin burns, a mean of 6.3 man-days/ha of labor are spent on coivara (SD = 8.9, N = 200); for second-growth burns the mean is 1.7 man-days/ha (SD = 2.3, N = 12) (Fearnside, 1986a: 179). Coivara is most frequent when the burn is of intermediate quality: if the burn is good then coivara is unnecessary, while if it is very poor then it is impractical except perhaps for a very small patch to be used for subsistence production. The time between burning and planting (about 3 months) and the amount of labor available to the colonist usually limit the area to which coivara is done to a portion of the area felled.

Weed burns are done when preparing for a second year of planting on a slash-and-burn site. The residues from the previous crop plus any weeds that have grown up in the field are cut; often they are piled up in mounds prior to burning. Weed burn quality can be predicted from weather parameters, but the quality of weed burns is not significantly associated with the magnitude of soil fertility changes.

Pasture burns are done every 2-3 years in cattle pasture that is being maintained for grazing. All of the pasture in a given property cannot be burned in the same year, as the colonist or rancher must have somewhere to put the cattle when a part of the lot is burned. Usually the woody secondary forest species invading the pastures are cut prior to burning, although occasionally burns are attempted without this step. The logs left in the pasture from the original forest felling are often reduced to ashes when the pasture is burned; after about a decade the pastures are mostly free of the downed timber that is so evident in younger pastures.

4.) IMPACTS OF BURNING ON AMAZONIAN VEGETATION

Repeated burnings in deforested areas have a strong effect on the course of secondary succession. Burning eliminates most of the stock of seeds in the soil from the original forest

(Brinkmann and Vieira, 1971). Fields recently cleared from primary forest also have a strong contribution to regeneration from stump sprouts (Uhl, 1987), which is also eliminated by repeated burnings. In Brazilian Amazonia most of the deforested areas are maintained in cattle pasture, beginning either directly after the clearing of primary forest (in the case of the large ranchers, who account for about 75% of the clearing) or after a year or two under annual crops (in the case of the small farmers, who account for about 25% of the clearing). In abandoned pastures the secondary vegetation grows much more slowly than it does in shifting cultivation fallows. Intensity of pasture use also has a strong effect. In Paragominas (Pará), Uhl et al. (1988) found that eight years after abandonment, lightly used pastures averaged twice the biomass accumulation of moderately used pastures and 17 times more than heavily used pastures. "Lightly used" pastures are defined as those never weeded, with no or little grazing, and "abandoned" (i.e., no longer weeded or burned) shortly after formation; "moderate" use refers to areas abandoned 6-12 years after formation, with grazing, and with weed cutting and burning every 2-3 years; "heavy use" refers to bulldozing and windrowing after several years under "moderate" use.

In certain parts of the Amazon region, repeated burning leads to dominance of the vegetation by fire-resistant palm species. This is true in MaranhÔo and southern Pará, where the babaçu palm (Attalea speciosa or Orbignya phalerata) forms solid stands completely eliminating both pasture grasses and other woody species. In areas cleared from dense forest in Roraima, the related inajá palm (Attalea regia) forms stands similar to those of babaçu.

Repeated burnings, combined with pasture degradation through soil compaction and nutrient depletion, can also contribute to deflecting ecological succession to a dysclimax of inedible grasses rather than the normal route to woody secondary vegetation. Tree dispersal and seedling establishment are impeded by the harsh site conditions and repeated burnings in the pasture (Nepstad et al., in press). In some highly-degraded pastures in Acre the grass known as rabo de cavalo (Andropogon spp.) dominates, while in some other areas the sapé grass (Imperata brasiliensis) takes over; this also occurs in some shifting cultivation fallows (e.g., in the Gran Pajonal of Peru: Scott, 1978). Amazonian successions are not presently subject to dominance by very aggressive grass species like the Imperata cylindrica, that outcompetes woody second growth in Southeast Asia (see UNESCO/UNEP/UN-FAO, 1978: 224). It is not a God-given dictum that Amazonian successions will always tend to woody regrowth rather than grass, and the degradation of vast areas of cattle pastures in the region increases the danger that grass will become the predominant successional route in Amazonia as well.

The tendency to favor grasses over trees would be reinforced by changes in precipitation patterns that are expected to accompany large-scale deforestation in Amazonia. Approximately half of the rainfall in the region is the result of water that is recycled through the forest and returned to the air via evapotranspiration. Deforestation would reduce precipitation most during the dry season (Salati et al., 1979; Salati and Vose, 1984). This is when rainfall is needed most to maintain the forest, which already suffers from drought stress approaching the limits of tolerance of the rain forest tree species during the occasional extended dry seasons that occur naturally even in the absence of massive deforestation. Grass is a particularly poor contributor to evapotranspiration during the dry season because the grass leaves are either eaten by the cattle or die, whereas the leaves of the forest remain green all year round and continue to transpire water. Deforestation could initiate a positive feedback loop leading to thinner, more xerophytic forests and more frequent and severe droughts (Fearnside, 1985a).

Fire is likely to be an increasing threat to the remaining forest as the climate of the region becomes dryer. Occasional droughts of unprecedented severity, rather than a gradual reduction of the mean precipitation, is the most likely and most dangerous result of reduced evapotranspiration. During these droughts, fires could escape into the standing forest without the trees having been felled and allowed to dry beforehand. This has already occurred in Borneo under similar circumstances during the 1982-1983 drought provoked by the Southern oscillation-El Nio phenomenon (Malingreau et al., 1985).

Logging disturbance greatly increased the danger of fires escaping into the standing forest burned in Borneo in 1982-1983 (although a large area of undisturbed forest was also burned). In Brazil, Uhl and Buschbacher (1985) have documented the increased probability of fire spreading from cattle pastures into surrounding forest where selective logging has occurred. Logging activity in Amazonia can be expected to increase in the future as the remaining stocks of South East Asian timber dwindle (Fearnside, 1987a).

5.) INDIRECT EFFECTS OF BURNING

Burning of Amazonian forest has a variety of indirect effects, and these can be expected to increase as deforestation spreads. Burning has undoubtedly already altered the nutrient balance of the remaining forest through the deposition of nutrients in the form of aerosols. Smoke from Amazonian fires now blankets the entire Amazon Basin during the dry season, often resulting in closure of airports for extended periods. The smoke remains in the lower part of the troposphere where it can be removed by rainfall and deposited in the surrounding forest. In fact, burning often provokes localized rainfall events by supplying condensation nucleii and by the effect of rising air currents above the burn. Elements, such as phosphorus, which is present in limited quantities in Amazonian soils and ecosystems, are likely to be scavenged from the solid and liquid deposition falling on the forest downwind of the fire. Amazonian forests are highly efficient in removing nutrients that are contributed through such deposition (Herrera et al., 1978).

One of the furthest-reaching effects of large-scale burning of Amazonian forest is the contribution to global warming through the greenhouse effect. Using an admittedly crude seven-category classification for Amazonian vegetation (based on Braga, 1979), and existing information on the biomass and soil carbon between the natural vegetation and cattle pasture, conversion of the entire Legal Amazon to pasture would release approximately 50 billion metric tons (Gigatons = G tons) of carbon (Fearnside, 1985b, 1986b, 1987b). Were this transformation to take place over a span of 50 years, then an average of one G ton of carbon would be released per year, or about 20% of the 5-6 G tons presently released from burning fossil fuels throughout the world. The present rate of deforestation in Brazilian Amazonia would represent a contribution of about 5-7% of the global fossil fuel total. The contribution to the greenhouse effect would be greater than the percentage of carbon release would indicate, however, because part of the carbon is released in the form of methane, which is far more potent in provoking the greenhouse effect per ton of carbon than is carbon dioxide. Fossil fuel combustion is more efficient and releases only an insignificant amount of methane. Reburning of cattle pastures produces a net release of methane because, unlike carbon dioxide which is absorbed by vegetation through photosynthesis, methane continues to build up in the atmosphere without biological sinks. Although far from the entire problem, this represents a significant contribution to a major environmental concern. On a per-capita basis, a single deforester in Amazonia can make a contribution to the greenhouse effect equivalent to hundreds, and in the case of large ranchers to hundreds of thousands, of people living in cities burning fossil fuels. Because the cattle pastures in the region produce very little beef, this and other environmental costs are being borne by society in exchange for almost no benefit.

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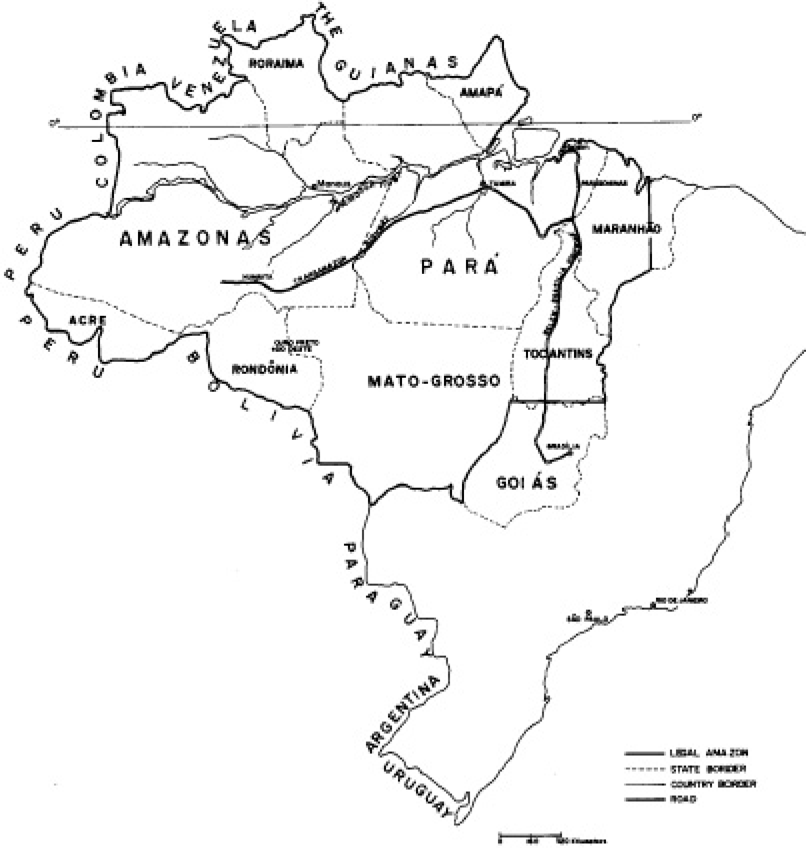
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RONDÔNIA
BOLIVIA
MATO-GROSSO
TOCANTINS
BRASILIA
GOIÁS
PARAGUAY
ARGENTINA
URUGUAY
RIO DE JANEIRO
SÃO PAULO
LEGAL AMAZON
STATE BORDER
COUNTRY BORDER
ROAD