Please cite as:

Fearnside, P.M. 1985. Environmental Change and Deforestation in the Brazilian Amazon. pp. 70-89 In: J. Hemming (ed.) Change in the Amazon Basin: Man's Impact on Forests and Rivers. Manchester University Press, Manchester, UK.. 222 pp.

ENVIRONMENTAL CHANGE AND DEFORESTATION IN THE BRAZILIAN AMAZON

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September 2, 1982

Paper for presentation at the Symposium on Change in the Amazon Basin, 44th International Congress of Americanists, Manchester, U.K., 5-10 September 1982.

1.) BRAZIL'S SHRINKING RAINFOREST

Brazil's Amazon rinforests are rapidly shrinking. The form of the growth in cleared areas in the state of Rondonia indicated by LANDSAT images gives some indication that clearing may have been occurring in an exponential fashion between 1973 and 1978 (Fearnside, 1982). Although no such simple algebraic equation is adequate to predict the path of clearing, the nature of exponential growth would lead rapidly to complete deforestation of the region, assuming a constant exponential rate, even with the large areas of forest currently remaining. Along with the false impression of infinite size, another illusion engendered by Amazonian forests is that deforestation would have little environmental effect because secondary vegetation would reconstitute losses to effectively negate deforestation effects (*e.g.* Brown and Lugo, 1981, 1982; but see Myers, nd.). Unfortunately, many of the changes are not reversible (Gomez-Pompa *et al*., 1972).

Reliable information on clearing rates over time is scant for the Amazon. Estimates for Brazil's 5 X 10S06H kmS02H Legal Amazon from LANDSAT images taken in 1973 and 1978 indicated that 1.55% of the total area had been cleared by the latter date (Tardin, *et al*., 1980). Despite indications that the figure is somewhat underestimated, the conclusion that cleared area was small in relation to the total area of the region is sound. If the cleared area has increased exponentially at a constant rate since, it would have reached 5.8% of the Legal Amazon by 1982. Unfortunately, information more recent than 1978 is not available. Brazil's National Institute of Space Research (INPE) no longer monitors deforestation, having transferred the task to the Institute for Forestry Development (IBDF). A reorganization of IBDF has since resulted in all research activities being passed to the Brazilian Enterprise for Agriculture and Cattle Ranching Research (EMBRAPA). Meanwhile, no clearing estimates have been released.

The rate of deforestation is controlled by complex interactions among components in the region's ecological systems, including the area's human populations and their agricultural resources. Analytical expressions like the exponential cannot reflect the opposing forces influencing a process like deforestation, the study of such problems being more suited to computer simulation (Fearnside, nd-a). Work in progress at the National Institute for Research in the Amazon (INPA), in Manaus, may eventually supply information on this and related human ecological problems in a form that provides a framework for use in development planning.

The future course of deforestation depends on a network of interrelationships, some representing forces that speed the process and others that slow it. At present, forces leading to rapid clearing appear to dominate the process, but as felled areas and rates of clearing increase in the future, forces limiting the process can be expected to play an expanded role. One of the forces presently driving deforestation is a positive feedback relationship between road building and migration of settlers: building or improving roads encourages the entry of more settlers to a region, and the presence of more settlers justifies the construction of still more roads. As Brazil's Second National Development Plan states: "The occupation of new areas should continue .... in view of the fact that the gigantic highway system, already constructed, has placed at the disposition of the [agricultural] sector immense areas .... in Amazonia." (Brazil, Presidencia da Republica, 1974: 41). In addition to drawing new migrants, the arrival of access roads augments deforestation by spurring settlers already in place to dramatically increase their land clearing rates. Such increases are readily apparent in data being collected in the Ouro Preto colonization area in Rondonia. Another process linked to road improvement is the turnover of colonists in settlement areas. Original settlers sell their land or claims to land to new arrivals, especially when improved access causes land values to rise and potential buyers to appear. Newcomers bring greater material resources and plant larger areas of crops than do the original settlers they replace (Fearnside, 1980a). In their first four years after arrival, newcomers fell virgin forest at almost twice the annual rate of the original occupants (Fearnside, nd-b).

One of the primary forces driving deforestation is the rapid increase in the region's human population. A part of the increase is due to reproduction (Brazil's population grew by 2.4% annually between the 1970 and 1980 censuses), but far more is due to migration from other parts of Brazil, especially for migration focii like Rondonia. Rondonia's population grew at 14%/year during the 1970-1980 period. (data from Brazil, IBGE, 1981). Deforested area grew even faster, increasing at an exponential rate of 41%/year between 1975 and 1978 (data from Tardin *et al.*, 1980; see Fearnside, 1982). Clearly the relationships are more complex than simple population growth, although population is of central importance.

Rapid clearing is closely linked with land use choices. Cattle pasture is both a cause and a result of rapid deforestation. Pasture is the cheapest and quickest way of occupying felled land, which is important in establishing land tenure claims (Fearnside, 1979a). Establishing such claims for speculative purposes is a major motive for deforestation. Pasture also requires much less human labor to maintain than other non-forested land use choices, thus allowing settlers who specialize in ranching to clear much larger areas before limitations of available of available labor and economic resources inhibit further expansion.

Forces which can be expected to exert upward pressure on clearing rates in the future include the consequences of unsustainable land uses, such as pasture, now occupying most cleared areas. Unsustainable practices mean that land will have to be left fallow or in low-intensity uses in the future, thus freeing the settler's resources for further clearing in virgin forest.

Other probable factors fueling deforestation in the future in this century include increased timber exploitation once dwindling rainforest areas in Southeast Asia cease to supply world markets. Another is anticipated surges of economic development in parts of Amazonia favored by mineral and hydroelectric resources such as the development pole associated with the Grande Carajas Project, occupying approximately one-sixth of Brazil's Legal Amazon (Fearnside and Rankin, nd).

Forces which should act to decrease felling rates in the future include the progressive decline in quality of remaining land. The best agricultural land in the Amazon has already been cleared: the two major occurrences of the relatively fertile soil *terra roxa* (ALFISOL) at Altamira (Para) and Ouro Preto (Rondonia) are, for all practical purposes, fully occupied. By the same token, land with the easiest access has already been cleared. Areas with river access have long been settled, and land nearest the major trunk highways is also fully claimed. Distances which must be travelled on precarious lateral feeder roads to reach available land from major thoroughfares whould increase on average.

As Amazonia becomes more settled, the behavior patterns of farmers living in the area should gain in relative importance as compared to the annual count of new migrant families entering the region. Blocks of occupied lots exhibit markedly different trends in deforestation from larger geographic areas where the entry of new migrants dominates clearing statistics. In a ten-year time series for occupied lots in Ouro Preto, Rondonia, cumulative felled areas increase following a linear trend for the first six years, after which a plateau's reached (Fearnside, nd-a). The linear portion of this pattern has also been observed for data from the first four years of occupancy at Altamira (Fearnside, 1982). A linear/plateau trend for individual properties, without changes in ownership, would contribute to slowing regional trends in a future, more fully settled, Amazon.

Another factor that may impede continued felling at present explosive rates is the delay necessary for settlers to move from deforestation focii in Rondonia and Southern Para to new areas once the present areas of concentrated felling are deforested. Areas with slower clearing rates and more uncut forest, such as Amapa and Amazonas, are also farther from access routes to Amazonia for new migrants from Southern Brazil.

Future deforestation trends could not hold to an exponential pattern up to its logical end point of complete clearing, since factors other than the availablility of forest would slow the trend. Labor and capital availability would limit the very fast felling implied by the final years of an exponential trend. Migrant source areas in Southern Brazil, while supplying millions of new migrants to Brazilian cities and to Amazonia, can not be expected to product ever increasing fluxes of new entrants once the present process of agricultural mechanization and land tenure concentration have progressed further in the source regions. As the Amazon frontier "closes," its relative attractiveness to potential migrants in search of unclaimed land would also decrease. Infinite availability of resources needed for greatly increased felling, especially petroleum, can also not be assumed. All of this means that one cannot foresee with confidence how many decades would be needed to clear all or almost all the Amazon rainforest. More important, such a prediction would be of little utility as compared to the urgency of gaining better knowledge of the environmental consequences of deforestation. It matters little whether rainforests last a few decades more or less, given that ample evidence is available that probable trends, in the absence of swift changes in governmental policies and controls, would lead to a speedy end to the forest. Better understanding of the environmental effects of deforestataion could, or should, move decision makers to set more rational policies regulating development in rainforest areas.

II.) SOIL DEGRADATION CONCERNS

1.) Leaching and Fixation of Nutrients

Following clearing of rainforest, the soil loses through leaching and fixation many of the nutrients present in the soil or added from ash when the forest is burned. Some of the nutrients are retained in the system after uptake by crops or secondary vegetation, but a significant portion is lost irretrievably in the first years after clearing. Cations such as calcium, magnesium and potassium are leached by the heavy rains, many of the soils having low capacities to retain these ions due to the lack of appropriate sites on clay particles (Irion, 1978). Studies of soil changes following clearing (*e.g.* Nye and Greenland, 1960; Brinkmann and de Nascimento, 1973; North Carolina State

University, Soil Science Department, 1974-78). Available phosphorus, a limiting nutrient for plant growth in much of Amazonia, is removed from the soil by "fixation", or conversion to compounds that cannot be used by plants. Fixation rates are inversely related to the concentration of phosphorus, ranging from 26.8 to 51.6% in 6 hours at 100 ppm P in a variety of Amazonian soils (Fassbender, 1969) to 83% in 7 days at 53 ppm P in *terra roxa* (ALFISOL) of the Transamazon Highway (Dynia *et al.*, 1977). Available phosphorus soon falls below plant requirements in even the best of Amazonia's principal soil types, such as *terra roxa*.

Soil organic matter declines rapidly after soil is exposed by clearing (Cunningham, 1963; Nye and Greenland, 1960). Unlike soil cations, organic matter is not added to the soil at the time of burning, but rather begins its decline as soil temperature increases and shifts the equilibrium between accumulation and decomposition. In soils where a forest root mat is prominent (*e.g.* Herreira *et al.*, 1978), the decline in organic matter is steepest after the roots of forest trees have decomposed in the years following clearing.

2.) Soil Compaction and Clay Migration

Exposed soil in rainforest areas becomes compacted within a few years as spaces between soil particles collapse. The soil becomes hard (increasing, for example, resistance to a penetrometer), bulk density increases, and infiltration rate and porosity decrease. Mechanized clearing results in immediate soil compaction (Seubert *et al.*, 1977; Van der Weert, 1974), but fortunately this practice is rare in the region. Traditional clearing methods avoid the compression of the soil column under the weight of a bulldozer, but cannot prevent the ensuing compaction of the exposed soil. Compaction occurs even without agricultural use (Cunningham, 1963), and proceeds more quickly still with cropping or especially cattle pasture (Schubart *et al.*, 1976; Dantas, 1979). Loss of organic matter following clearing decreases pore volume and contributes to compaction. Compacted soil inhibits the growth of plant roots, thus contributing to low crop production and retarded or deflected successions. Compaction also increases the susceptibility of the soil to erosion, as rain is unable to infiltrate into the soil column, thereby increasing runoff.

Soil physical structure is also altered after clearing by migration of clay particles to deeper levels in the soil profile (Scott, 1975). The clay migration leaves a sandier soil surface. Since different Amazonian soil present a complete range of granulometric compositions, virtually from pure sand to pure clay, the clay migration may either represent an improvement or a form of degradation. Heavy clays have reduced porosity, with consequent susceptibility to erosion, and offer physical resistance to plant growth, while very sandy soils both have reduced water retention and reduced capacity to bind and hold needed cations.

3.) Erosion

Erosion is another problem that plagues agriculture in the Amazon. Many people not familiar with the region harbor the illusion that the Amazon is flat, an impression encouraged by the appearance of the forest from the air. Although some parts of the basin are indeed quite level, much of it is dissected into steep slopes. Erosion causes significant soil losses when the soil is exposed for cultivation, with soil surface often dropping one or two centimeters per year under annual crops

(Fearnside, l980b; see also McGregor, 1980; Scott, 1975). Erosion has a detrimental effect on soil fertility, since the soil quality on the Transamazon Highway is generally worse at lower depths than at the surface (soil profiles in: Brazil, Ministerio da Agricultura, IPEAN, 1967; Falesi, 1972a; Brazil, Ministerio da Agricultura, Divisao de Pesquisas Pedologicas, DNPEA, 1973a,b; Brasil, Ministerio de Minas e Energia, Departamento de Producao Mineral, Projeto RADAM, 1974: Vol. 5). This effect contrasts with the situation in some other parts of the world where erosion can improve soil quality by exposing less weathered material (Pendleton, 1956 cited by Popenoe, 1960; Sanchez and Buol, l975).

Erosion would be likely to constrain agricultural production most quickly in systems which leave soil exposed repeatedly. One such system is a proposed technology obtaining continuous production of annual crops (Sanchez *et al.*, 1982; Valverde and Bandy, 1982; Nicolaides *et al.*, 1982). Erosion is one of a number of potential problems making widespread use of the system difficult (see Fearnside, nd-c). The "flat ULTISOL" of Peru's Yurimaguas experiment station (Nicolaides *et al.*, 1982) differs from much of Amazonia expecially the areas undergoing intensive colonization in the Brazilian Amazon. A land use survey of the Amazon Basin indicating the half of that region has slopes of < 8% (Cochrane and Sanchez, 1982: 151) is often cited by proponents of continuous cultivation of annuals (*e.g.* Sanchez *et al.*, 1982), the 50 % figure is deceptive, however, due to the large scale maps used to classify topography and other contraints. For example, in a 23,600 ha area on the Transamazon Highway when a detailed slope map was made based on field measurements at 225 points, 49.3% of the tract has a slope of 10% or more (Fearnside 1978: 437; nd-d). The entire area was classified as < 8% slope by Cochrane and Sanchez (1982: 149).

4.) Laterization

"Laterization," or more properly the formation of plinthites, has been an overstated danger in many popular accounts of agricultural problems in the Amazon. The idea that this hardened material, largely composed of iron oxides, covers much of the tropics had its origin in early reports by nineteenth century temperate zone soil scientists visiting the tropics and emphasizing laterite due to its novelty (Sanchez, 1976: 52-54). More recently, fears that vast areas of the Amazon would turn to pavements of brick upon clearing have echoed through the popular press. Mary McNeil's (1964) widely read article on the subject in the *Scientific American* encouraged this impression. One text asserts that laterization on the Transamazon Highway will turn the Amazon into "the world's largest parking lot" (Ehrlich *et al.*, 1977: 627). The prospect of hardening of plinthite over large areas of rainforest with deforestation is remote (Bennema, 1975). The laterite problem can be a real one in some areas, but the extent of these areas is now thought to cover less than 7% of the tropics as a whole (Sanchez and Buol, l975) and 4% of the Amazon (Cochrane and Sanchez, 1982). Care must be taken in these areas; recommendations have occasionally been made that such soils be cleared in the Brazilian Amazon (*e.g.* Brazil, Ministerio da Agricultura, EMBRAPA-IPEAN, 1974: 46). It is important that the problem of laterite not be dismissed as an overreaction to the exaggerations of the past.

5.) Aerosol Nutrient Supply

Nutrient stocks in agricultural systems usually decline following forest clearing, unless replaced through fertilizer applications. The balance of losses and inputs may have a link, however, with the proximity of natural stands of vegetation. Recent studies of nutrient transport as aerosols indicate that significant quantities of sulfur, and possibly other nutrients may be transported in the air from forest edges into adjacent cleared areas (Stallard, 1981 from T.J. Goreau, pers. comm., 1982)). Such transport occurs at best over distances of a few hundred meters, so most of the cleared area are deprived of this nutrient source in the Brazilian Amazon due to the present pattern of clearing in vast expanses of cattle pasture.

III.) PRODUCTION SYSTEMS CONCERNS

1.) Upland Agriculture

Agriculture or the *terra firme*, or unflooded uplands, is linked in many ways to the amount and pattern of clearing that surrounds it. Forms of agriculture which require regeneration of second growth, as in the case of shifting cultivation, are likely to be modified when surrounding forest has been cleared. The modifications often involve shortening of the fallow period to a point where vegetation and soil quality are degraded, jeopardizing the system's sustainability. The process of succession on fallow land is affected by both the reduced fallow time and the long distance to rainforest seed sources. The principal danger is the sucessional path's switching from one leading to woody second growth to one leading to a grassland dysclimax. In Southeast Asia this has occurred over millions of hectares throughout the region forming low-value expanses of *Imperata cylindrica* grassland. In Indonesia alone, 16 million ha of *Imperata* have been formed in this way (UNESCO, 1978: 224); Return of primary forest dominantes has been observed to occur in that country only when clearing are < 1000 m^2 in area (Kramer, 1933 cited by Richards, 1966: 42). Very fortunately for the Amazon, this highly aggressive grass species has not arrived, but a somewhat less implacable relative, *Imperata brasiliensis*, does occur (Scott, 1978: 49-50). Other grass genera, such as *Andropogon*, tend to dominate new-world savannas. Many present savanna areas are believed to have resulted from human agricultural activities (Budowski, 1956; Sternberg, 1968). The trend to large cattle pastures can be expected to discourage woody regrowth due to soil compaction, depletion of soil seed stocks, and removal of seed sources, as has been suggested in the case of Volkswagen's Vale do Rio Cristalino Ranch (Uhl, Univ. of Florida seminar, 1982; see Uhl, 1982). Elimination of mycorrhizal associates of rainforest species is another factor inhibiting the return to forest vegetation (Janos, l975). Both the rapid rate and the frequent speculative motivation of rainforest clearing in Amazonia lead to pasture as the land use choice (Fearnside, 1979a). This choice has poor chances of sustainable production (Hecht, 1981; Fearnside, 1979d, 1980c), as well as increasing the liklihood of an eventual non-woody dysclimax.

The present pattern of deforestation, which discourages small farmers and the production systems they employ, nevertheless allows substantial tracts to be occupied by small farms. This situation may change with the eventual elimination of significant areas of uncleared land. The closing of the frontier can be expected to be followed by continued consolidation of small holdings into larger properties has been the repeated pattern in Brazil (see Wood and Wilson, 1982 for current trends). Such large holdings frequently opt for nonsustainable land uses, especially pasture, as the primary exploitation pattern. At the same time, areas secured by small farmers are subdivided into uneconomic *minifundios*, as has occurred in the *Zona Bragantina* near Belem (Hebette and

Acevedo, 1979: 117-21), contributing to unsustainable increases in agricultural intensity and consequent failure of these areas to "fix the man to the land" (Penteado, 1967).

2.) Floodplain Agriculture

Deforestation can be expected to have its most direct effects on agriculture in the annually flooded *varzea* by alteration of the flooding cycle. Watershed deforestation invariably results in faster runoff after a rain, as less water is retained by the vegetation and its associated porous soil.

Measurements of changes in the flooding cycle from deforestation so far have been inconclusive. One report of increased flooding in the Peruvian Amazon (Gentry and Lopez-Parodi, 1980) has been criticized for ignoring alternative explanations of increased flood stage at Iquitos, including a probable unstable discharge/stage relation due to shifts in the river bed, and the possibility of superannual cycles such as those on the order of 12 years observed on the Rio Negro at Manaus (Nordin and Meade, 1982).

High variability in flooding behavior even without deforestation makes detection of changes difficult, as in the case of changes in rainfall. Nevertheless, the higher floods from 1970-78 as compared with 1962-69 are suggestive, and the logic linking higher floods with deforestation is impeccable. The unpredictable occurrence of higher than normal floods has long been the principal drawback of farming this fertile habitat, as many riverside inhabitants discovered when they lost their jute crops in 1982's unusually high flood. The variable timing and duration of the flood peak assumes an importance on a par with the flood height, while the variable time that farmable land remains exposed during the low water period is of ever greater importance (J.G. Gunn, pers. comm. l982). One hotly debated anthropological theory even hypothesized the evolution of a variety of cultural characteristics as adaptations to the "risky" nature of *varzea* agriculture which "set a ceiling on cultural development" (Meggers, 1971: 149; see critique by Roosevelt, 1980: 13-24). *Varzea* agriculture is likely to become more risky with continued deforestation of river watersheds.

3.) Inland Fisheries

Deforestation can be expected to negatively affect fisheries of many of the most important commercial fish species in the Amazon. Fish are essential in providing a relatively inexpensive source of protein to the population of the region. Among the poorest residents of Manaus, fish supply 37% of the total protein in the diet (Amoroso, 1981: 28). Fish species such as the tambaqui (*Colossoma macropomum*) spend part of the year inundated *varzea* forests of whitewater rivers consuming the fruit produced by a variety of tree species. Goulding (1980) has shown how the tambaqui and 34 other fish species utilize fruits of 40 plant species in flooded forests in Rondonia. Tambaqui alone supplied approximately 20 % of the total protein consumed in Amazonian cities such as Manaus in l973-74 (Giugliano *et al.*, 1978: 40), although over fishing since that time has caused a dramatic reduction in the size and quantity of this species caught. The removal of these forests could be expected to eliminate one of the most important links in the human food chain in the region. Flooded forests provide food directly or indirectly to an estimated 75% of the commercial catch reaching Manaus (Goulding, 1980: 253).

4.) Forest Production

Deforestation eliminates production of forest products such as Brazilnuts (*Bertholletia excelsa*), natural rubber (*Hevea brasiliensis*), rosewood oil (*Aniba duckei*) and timber. Areas with concentrations of such potentially renewable natural resources are, in many cases, deforested preferentially for conversion to cattle pasture. Brazilnut stands in the State of Para, for example, often have a sort of title dating from the nineteenth century, granting the land to *castanhalistas* (Brazilnut barons), which raises the value of the land for sale to speculators (Bunker, 1982). The same is true for land documented for *seringalistas* (rubber barons) in Rondonia and Acre.

Clearing rainforest closes forever the option of sustainable management of forest resources (Fearnside, nd-e). Many pharmaceutical uses of these products have barely begun to be tapped. Loss of rainforests, for example, is considered a major setback in the effort to find anti-cancer drugs (Myers, 1976).

IV.) MACRO-ECOLOGICAL CONCERNS

1.) Oxygen: A Straw Man

The purported threat to the world's oxygen supply from tropical deforestation is one of the more unfortunate misconceptions related to rainforest use, especially in Brazil. Oxygen levels are actually quite stable (Van Valen, 1971), and are not dependant on rainforests, which use up as much oxygen as they produce (Farnworth and Golley, 1973: 83-84). The idea that the Amazon rainforest is responsible for the world's oxygen supply has gained particular force among the popular press in Brazil, where the Amazon is called the "lung of the world." This belief came into prominence after a popular Brazilian periodical conducted a transoceanic telephone interview with Dr. Harald Sioli, and later misquoted this distinguished figure in Amazonian research (Sioli, 1980). After exposing the oxygen argument as fallacious, it is usual to imply that all arguments linking deforestation with climatic change, including the important questions of carbon dioxide and rainfall, are "alarmist" and unworthy of serious attention.

2.) Carbon Dioxide: "Greenhouse Effect"

Carbon dioxide is an item of worldwide concern due to its role in the balance controling global temperature. Atmospheric carbon dioxide classically is considered the cause of a "greenhouse effect," where energy in the form of visible and ultraviolet rays from the sun passes through the atmosphere freely but is unable to escape when re-radiated in the form of infrared radiation. (Note: the analogy of carbon dioxide with a greenhouse is somewhat misleading as the latter has most of its effect as a barrier to convection rather that as long wave radiation). An increase in carbon dioxide would result in the earth's climate warming as more energy was trapped by the atmosphere. Atmospheric carbon dioxide increased linearly from 1850 to 1960, but has since been increasing exponentially. By 1978, CO_2 levels had only increased by 18% over the levels of 1850, but they are now expected to have doubled by early in the next century.

Predicting future COS12H levels and their effects is complicated by other climatic factors that could act to cancel some of the global warming, as they have done since 1940. One of the several existing simulations for modeling global climate finds the net result of deforestation to be overall global cooling, mainly due to increased albedo, or reflectivity, of cleared land as compared with forest (Potter *et al.*, 1975; see also Sagan *et al.*, 1979). The rash of contradictory predictions with respect to future climate under different scenarios should not obscure recognition of the delicate balances on which these processes depend, and the woeful lack of data on some of the most important parameters, especially in the tropics. In addition to lack of reliable data on deforestation rates, biomass, and nonliving carbon pools such as charcoal, climate models have shown themselves to be particularly sensitive to such poorly quantified parameters as atmospheric CO_2 levels before the industrial revolution (Bjorkstein, 1979: 446-52) and the rate of mixing of the ocean layers seeming as sinks for both carbon (Bjorkstrom, 1979) and heat (Dickenson, 1981: 433).

Much of the carbon dioxide increase has historically resulted from burning fossil fuels. The biosphere has been singled out as a key factor by several studies (Bolin, 1977; Woodwell, 1978; Woodwell *et al.*, 1978). Marked seasonal oscillations in COS12H levels, especially in temperate zones, testify to the importance of the biosphere in maintaining this delicate balance. Since tropical rainforests are estimated to contain 41.5% of the world's plant mass of carbon, and tropical seasonal forests another 14.1% (calculated from data of Whittaker and Likens, 1973: 358), the future development of the world carbon problem could be affected by the fate of tropical forest.

The incomplete burning of forest biomass, a substantial amount of which remains as charcoal, moderates the effect of forest burning (Crutzen *et al.*, 1979). Lacking data from the tropics, Seiler and Crutzen (l980) used an estimate of unburned biomass based on observations following a wildfire in a temperate stand of ponderosa pine (*Pinus ponderosa*) to estimate the size of the world carbon sink in elemental carbon remaining in burned areas. This sink, estimated at 0.4-1.7 billion metric tons, together with estimates of the rate of deforestation lower than those used by other modelers, plus a substantial sink in afforestation, led Seiler and Crutzen (1980) to conclude that the land biota could be either losing or gaining 2 billion metric tons of carbon per year (Table 1). This figure is much lower than the loss estimates of 4-8 billion metric tons per year calculated by Woodwell *et al*. (1978). The root cause of such sharp discrepancies is the rudimentary nature of data available, especially on tropical deforestation, forest biomass and carbon content, growth rates of tropical second growth, and burning efficiencies. Research to fill these gaps in knowledge should be a top priority, especially in the Amazon where rainforests represent an estimated 20% of the planet's carbon reservoir in living biomass (Salati, 1979; Salati and Ribeiro, 1979).

The amount of warming that would result from a doubling of atmospheric carbon dioxide is not known with certainty. One simulation predicts global temperature increases of 2S0oH to 3S0oHC to result from this development (Stuiver, 1978). A United States National Academy of Sciences expert committee has estimated an effect of 3S0oHC \+\ 1.5S0oHC (cited by Wade, 1979). The Academy estimated that current trends would lead to a doubling of 1979 COS12H levels by 2030, with a "few decades" more needed for saturation of the heat absorbing capacity of deep oceans before uncontrollable temperature rises take place (Wade, 1979). Other estimates for the mean effect of doubling CO_2 vary from 4°C (Goodland and Irwin, 1975a: 35) to 2°C (Manabe and Wetherald, 1967). Models of Manabe and Stouffer (1979), which include seasonal insolation fluctuation and a less idealized modeling of geography than earlier models (Manabe and Wetherald,

1975) show a mean warming of 2°C, but with significant regional and seasonal asymmetries. Regional differences can have a much greater potential effect than the value for the mean warming itself. Woodwell (INPA seminar, 1980), who expects a 1.2°C mean warming from a doubling of CO_2, predicts virtually no temperature change at the equator as compared to 5-10°C at the poles. Greater effects at the poles results from a positive feedback relationship between temperature and albedo, which is decreased by melting snow and ice or *vice versa*. Some controversy surrounds the amount by which polar effects are enhanced in relation to global means. The more than doubling of sensitivity to climatic change at the poles suggested by Budyko (1969) has been reexamined by Lian and Cess (1977), who expect enhancement of sensitivity by only about 25%.(1)

Using the U.S. National Academy of Sciences estimate of 3°C ± 1.5°C, the possibility that a mean warming by even 1.5°C could result in melting of polar ice caps has concerned a number of meteorologists. The disproportionately higher temperature increases at the poles are especially worrisome.

According to most of the recent research, the Arctic ice sheet can just maintain itself under present climatic conditions. Therefore, significant further warming would cause a complete transformation by the creation of an open sea in place of the Arctic ice sheet; an open Arctic Ocean should result in the drastic movement of all climatic zones several hundred kilometers northward......The effect of such a shift would be especially noticeable in the belt which presently has a sub-tropical climate with winter rains (California, Mediterranean, Near East and Punjab), which would then become arid *steppe* (Flohn, 1974: 103).

Some uncertainty exists as to the rapidity and magnitude of the rise in sea levels that would result were polar ice to begin melting. The contribution of Antarctic ice is particularly uncertain, as much of it is poorly mapped and lies below sea level (Thomas *et al*., 1979). Typical estimates of the potential rise in ocean levels range from 4-8 m (United States, Council of Environmental Quality 1980 cited by Marshall, 1981) to 5-6 m (G. Woodwell, INPA seminar 1980) to 10 m (Salati, 1979). Goodland and Irwin's (1974: 35) figure of 35 m appears high. Mean sea levels have risen by 12 cm over the past centry (Gormity *et al*., 1982), and floating sea ice has been decreasing for the past several decades (Kukla and Gavin, 1981), presumably primarily as a result of CO_2 increase (Etkins and Epstein, 1982).

Although more reliable and detailed data, especially from the tropics, are needed before firm conclusions can be drawn on the future of world temperatures, the simple doubt that major and irreparable meteorological changes could occur should give pause to planners intent on promoting massive deforestation.

3.) Nitrous Oxide: Ozone Depletion

Rainforest clearing appears to be one of the contributors to a global increase in atmospheric nitrous oxide (NS12HO). This gas is known to react in the stratosphere to produce NO, which in turn serves as a catalyst in the breaking of ozone (OS13H) molecules. Evidence for a strong catalytic effect comes from observations in nature (Fox *et al*., 1975), although rates for these reactions are quite low (Ruderman *et al*., 1976: note 6). Stratospheric ozone acts to absorb incoming ultraviolet radiation, shielding the biosphere from intense UV radiation.

The injection of NS12HO into the stratosphere by proposed supersonic transport (SST) aircraft was a subject of heated debate during the mid 1970's. Ozone depletion effects of flurocarbons from aerosol propellants and refrigerants became a public issue during the same period. Unfortunately, the potential ill-effects claimed were occasionally exaggerated, causing many to cease worrying about ozone depletion in subsequent years. Loss of public interest in stratospheric ozone was also partly the result of a widely publicized summary of a report by the US government's Climatic Impact Assessment Program (CIAP) which "conceals the logical conclusions of the study" (Donahue, 1975). The understatement of effects identified during the course of the original study was later bitterly pointed out by the atmospheric scientists involved (see exchange of letters in *Science*, 187: 1145-46, March 28, 1975), but could not undo the effect on public perceptions stemming from wide press coverage of the CIAP report's "Executive Summary" (Grobecker *et al.*, 1974). Even more unfortunately, the realities of nitrous oxide and ozone depletion are still with us and are likely to increase.

Increased UV radiation could be expected to increase substantially the insidence of skin cancer (basal cell carcinoma, squamous cell carcinoma, and melanoma) in humans (a 10-20% reduction in ozone could be expected for example to increase UV by 20-40% raising skin cancer incidence by about 20% among the Caucasian population of the world (Donahue, 1975). Any possible behavioral changes in UV oriented insects should be determined by actual testing before making claims to that effect. Effects on aquatic ecosystems are numerous, and deserve close scrutiny due to the key role of aquatic organisms in many food chains and biogeochemical cycles (Calkins, l982).

Possible effects in agriculture due to increased rates of mutation cannot be predicted with confidence with available knowledge, but the disastrous consequence of negative impact on any of the staple grain species is ample cause for avoiding exposure. DNA's absorption maximum is at 260 nanometers, only slightly below the 286 nanometer present lower limit of solar radiation reaching the earth's surface (Eigner, 1975: 17). One of the principal concerns is the expected deleterious effect on agriculture from increased mutation rates.

The impact of rainforest burning on nitrous oxide flux to the atmosphere, as well as the seriousness of expected changes, are areas of current debate. The debate illustrates both the minimal level of our present understanding of many fundamental global processes, and the near total absence of relevant data, especially from the tropics.

The concentration of NS12HO in the troposphere has been increasing at about 0.2%/year (0.5 ppbv/year) over the past 20 years (Weiss, 1981). All known sources of N_2O are at ground level, and many are linked to human activities. One source is the decomposition of organic materials in low oxygen enviromnents, such as much human waste deposited in the anoxic conditions of dumping sites or sewage water (McElroy *et al.*, l976). In addition to wastes and compost, agriculture produces nitrous oxide through aerobic nitrification of fertilizer nitrogen (Bremner and Blackmer, 1978). Combustion of fossil fuel is a major source, believed to account for about half of the total 1.1×10^{11} moles N_2O annual anthropogenic input (Weiss, 1981; Weiss and Craig, 1976).

Nitrous oxide production from deforestation is believed to be significant from two sources: combustion of the felled biomass (Crutzen *et al*., 1979) and increased production in bare soil as compared to forest (Goreau, 1981). Forest soils have been found to produce significant fluxes of N_2O through oxidation of ammonia by nitrifying bacteria, with rates increasing at low oxygen levels (Goreau *et al*., 1980; Goreau, 1981). cleared land, however, produces much more N_2O than does the same area under forest cover.

The contribution of fertilizer to global N_2O flux needs to be better understood as a check on the share attributed to deforestation. The importance of oxygen concentration gradients in nitrifying environments has recently been demonstrated by Goreau (1981). Much of the NS12HO produced through denitrification at deeper (less well oxygenated) layers in the soil is never relaesed to the atmosphere, but rather is consumed within the soil as an electron acceptor in respiration reactions (Goreau, 1981: 78). Much of the work done with fertilized agricultural soils has not taken this uptake into account (T.J.Goreau, pers. comm., July 1982). The implication of this is that estimates of NS12HO production in fertilized soils probably exaggerate the NS12HO derived from fertilizers -- and a larger share of the observed atmospheric increases must therfore be explained by other sources, such as deforestation.(2)

Nitrous oxide flux measurements from the tropics are nonexistent. Several indirect indications, however, suggest the conclusion that deforestation in tropical forests results in larger N_2O fluxes than temperate equivalents. Low counts of nitrifying bacteria are characteristic of acid soils under tropical forests (Nye and Greenland, 1960; Jordan *et al*., 1979), but the nitrifiers greatly increase in numbers when clearing and burning raises soil pH (Nye and Greenland, 1960). When the humus, root mat, and detritus are oxidized in the exposed soil, increased nitrification would release corresponding amounts of N_2O.

The long term contributions of rainforest felling are unclear. One reason is the large amount of rainforest converted to cattle pasture. Initial conversion to pastures would result in release of N_2O as with all clearing. The lower equilibrium organic matter content of soils under pastures as compared with tropical forests (see Fearnside, 1980c) would contribute to this, as soil nitrogen is approximately 98% organic (Russell, 1973). Grasslands are known for low nitrification rates (Nye and Greenland, 1960; Russell, 1973), which would mean that further releases of N_2O from the soil should be relatively small once the initial conversion had taken place. Nitrous oxide would continue to be released from combustion, however pasture is burned frequently while it lasts, and after invaded by second growth can be expected to undergo cutting and burning at intervals of a few years until weeds, compaction, and soil fertility degradation force abandonment of stock raising. Savannas are often burned as a matter of cultural tradition in Brazil, even when no immediate economic use is intended.

5.) Hydrological Cycle: Desertification

The issue of "desertification" is an emotional one, especially in Brazil with reference to the Amazon. A tendency toward decrease in rainfall in the region, even if not crossing the threshold of annual precipitation that defines a desert in climatological terms, is a possibility which cannot be dismissed as a consequence of deforestation (Fearnside, 1979c). One reason is that in the Amazon, far more than in other parts of the earth, rainfall is derived from water recycled into the atmosphere through evapotranspiration, rather than being blown into the region directly as clouds from the Atlantic Ocean.

Estimates for the contribution of evapotranspiration to the precipitation in the Amazon Basin as a whole range from 54% based on an estimated annual total precipitation of 12.0 X 10^{12} m^3 and river discharge of 5.5 X 10^{12} m^3 (Villa Nova, *et al*., 1976) to 56% based on water and energy balances derived from average charts of wind and humidity (Molion, 1975). More detailed studies of the area between Belem and Manaus have produced estimates of the evapotranspiration component in rainfall in this part of the Basin ranging from 48%, based on calculations of precipitable water and water vapor flux (Marques *et al*., 1977), to up to 50% (depending on the month), based on isotope ratioing (Salati *et al*., 1978).

Hydrological work near Manaus has shown that the vast majority of evapotranspiration is transpiration rather than evaporation (W. Franken, INPA seminar, 1980). Clearly the much greater leaf area of rainforest as compared with pasture crops or second growth indicates deforestation will lead to decreased evapotranspiration and consequently decreased rainfall in the region. Western parts of Amazonia, such as Rondonia and Acre, depend on evapotranspiration for a greater portion of their rainfall than does the Belem - Manaus area where estimates were made, and therefore would be expected to suffer greater decreases when forest is felled.

Other consequences of deforestation, such as increased albedo, also affect rainfall. Some models predict decreases in rainfall in temperate regions as a result of increased albedo with tropical deforestation which leads to lowered heat absorption, reduced evapotranspiration and heat flux, weakening global air circulation patterns and reducing rainfall in the 45° 85°N and 40 60°S latitude ranges (Potter *et al*., 1975).

However, the magnitude of changes in albedo resulting from deforestation is a matter of debate. Problems arise from differing definitions of albedo (the ratio of reflected to incident light), and from use of unrealistic values for forest albedos prior to clearing. Forest vegetation reflects only a small amount of visible light, as indicated by its dark appearance. However, a large amount of reflectance occurs in the near infrared region of the spectrum, making forest albedos much higher if infrared radiation is included in the measurement. Dickenson (1981) has criticized studies such as that of Potter *et al*. (1975) for using visible spectrum albedo values (Posey and Clapp, 1964) derived from measurements made in the temperate zone between 1919 and 1947 (List, 1958: 442-43). Widening the spectrum included in albedo measurements, and suing a suitable average of more recent values from the tropics, approximately doubles the albedo of forest from 0.07 to between 0.12 and 0.14 (Dickenson, 1981: 421). Combined with the assumption that forest is replaced by green secondary vegatation, albedos of these areas increase by only 0.02 to 0.04, or one half to one fourth the increases assumed by Potter *et al*. (1975) and others. The assumption is critical that evergreen vegetation replaces primary forest, however, as open savanna or grassland resulting from decreased rainfall in dry periods (*e.g.* Salati *et al*., 1978) and repeated burnings by humans (Budowski, 1956) could well be a more likely future for these areas.

The illusion must be dispelled that, because annual rainfall totals in the Amazon are quite high, a significant amount of drying could be tolerated. The dry season in the Amazon already poses severe limits on many agricultural activities. During the dry season of 1979, Manaus went for 73 days without a single drop of rain. Soil water levels fell to very low levels both in the open and under forest cover, where trees continued to transpire from large leaf areas. Since plants react to water levels in their root zones on a day-to-day basis, and not to the abstraction of annual rainfall statistics, effects of even small increases in the severity of the dry season could be dramatic. Natural vegetation which does not tolerate severe water stress and could be expected to gradually give way to more xerophytic *cerrado* (scrubland) vegetation over time. Such a change would have the potential for becoming a positive feedback process, where the resulting further reduction in evapotranspiration would increase dryness and accelerate vegetational changes (Table 2).

5.) Genetic Diversity: Extinction of Species and Ecosystems

The genetic diversity of the Amazon rainforest is legend. One hectare inventories 30 km from Manaus had 235 species of woody plants over 5 cm in diameter (Prance *et al*., 1976). Many of the Amazon's species of plants and animals have never been collected or described, and each new collecting expedition reveals several new species (Prance, 1975; Pires and Prance, 1977). A high degree of endemism exists among Amazonian species: many species occur in limited ranges. This endemism means large deforestations automatically insure extinction of many species. The potential loss of genetic diversitty from deforestation in the Amazon has been a major concern of biologists worldwide (Lovejoy, 1973; Myers, 1976, 1979, 1980; Oldfield, 1981, Eckholm, 1978; Ehrlich, l982; Ehrlich and Ehrlich, 1981). Whether or not this fact represents a reason for restraint is a question dividing many people concerned with Amazonian development. Some reasons for conserving genetic diversity include potential for discovery of new organisms of economic value, or new uses for already known organisms, these include new crop plants, and varieties. The continuing evolution and dispersal to new areas of crop pests and diseases means that need for new germplasm will never cease. A good example is the vital input of coffee germplasm from the remnants of forest in Ethiopia as a means of obtaining resistance to leaf rust (*Hemeleia vasatrix*) in *Coffea arabica* (Oldfield, 1981). Destruction of stands of disease-tolerant, if low-yielding, natural rubber trees in Acre and Rondonia is one of many such losses occurring due to Amazonian deforestation. The same applies to need for new pharmaceutical chemicals in the face of continuing evolution of human disease organisms. The rush to obtain natural quinine when malarial parasites evolved resistance to chloroquine is a case in point (Oldfield, 1981). The value of rainforest as a resource for fundamental scientific research has also been argued (Budowski, 1976; Poole, 1976; Jacobs, 1980).

Ecological diversity, as well as genetic diversity in the strict sense, is quickly destroyed by deforestation. Often complex coevolved associations go extinct long before the last individuals of the species involved disappear (Janzen, 1972, 1974, 1976).

6.) Indigenous Peoples: Disappearance of Human Cultures and Population

When the Transamazon Highway was announced as a way to bring "people without land to a land without people" the statement was tragically in error. Virtually all of the Amazon was already occupied when the highway construction program was launched. The large areas not settled by Portuguese-speaking "Luso-Brazilians" were occupied by Amerindians (Davis, 1977). The incompatibility of colonization with the maintenance of indigenous populations in these areas is obvious. Locations of Amerindian tribes with relation to proposed highway routes are described in a chapter of Robert Goodland and Howard Irwin's (1975a: chapter 5) book *Amazon Jungle: Green Hell to Red Desert?* The resolution of conflicts of interest between highway construction and indigenous populations has rarely been nondestructive one for the Amerindians (Davis, 1977; Bodard, 1972; Ramos, 1980; Hanbury-Tenison, 1973; Brooks *et al.*, 1973; Bourne, 1978; de Oliveira *et al.*, 1979).

Most are agreed that since indigenous cultures are not compatible with "development," the solution is to separate Amerindian groups from settlement areas through provision of adequately sized, located, and protected reserves. It is a question of bitter debate as to where reserves should be places, how large they should be and whether reserves should be respected when land is desired for highway routes, mineral deposits, ranching, agriculture and land speculation.

The tropical rainforest is regarded as a resource for pioneer farming by the Brazilian government, as well as by the thousands of individuals and groups that have set out to replace rainforest with agriculture in the Amazon. Characteristics of the rainforest ecosystem, changes that occur after it is cleared and planted, and environmental and other considerations tied to the massive scale of these alterations, all must be considered in planning colonization programs and other forms of development.

V.) CONCLUSION

Most changes resulting from deforestation in the Amazon are bad from the human point of view, especially if the wellbeing of future generations in the region is given the weight that it deserves. Although not all of the ill-effects ever attributed to deforestation are likely, effects for which reasonable scientific grounds exist are numerous and severe. Exaggerated or unfounded claims of deleterious effects are to be deplored, as is the frequent oratorical use made of such statements by persons anxious to discredit by association the many valid concerns related to rainforest destruction. Soil degradation concerns include nutrient leaching and fixation, organic matter decomposition, compaction, and erosion. Production systems in upland and floodplain agriculture, inland fisheries, and forest extraction depend on rainforest. Macro-ecological effects include logical expectations of changes in the regional hydrological cycle. Global hydrological changes are more debated, but the severity of any consequences to the planet's major agricultural production systems justifies both caution and intensive study. Contributions, by amounts not well determined, are also made by deforestation to global carbon dioxide and nitrous oxide problems, both of which, when considered along with the contributions of humanity's industrial activities, imply disastrous potential environmental effects. Climatic concerns are especially dangerous since delays inherent in the natural systems mean that many of the effects may not be detectable before irreversible processes have been set in motion. The extinction of species and ecosystems and the disappearance of human cultures and populations associated with the rainforest are no less important and irreversible. The weight of evidence indicating unfavorable environmental changes as the result of deforestation should provide ample ground for decision makers to take immediate and far-reaching steps to slow the process and prevent its occurrence in significant areas of the region. The fact that many consequences are poorly understood should, in no way, justify postponing or diminishing such actions. Such uncertainty, combined with the magnitude of some of the potential changes, should motivate an even more cautious approach to developments involving deforestation.

NOTES

1.) Some investigators have reported findings implying a substantially lower effect on global temperatures from a given increase in atmospheric CO_2. Using meteorological observations accompanying a volcanic eruption as a natural experiment rather than computer simulations used in other studies, Newell and Dopplick (1979) estimate that temperature increases resulting from a doubling of atmospheric CO_2 would be no more that 0.25°c in tropical latitudes. Another experimental study (Idso, 1980a,b) calculates a value for global mean warming of up to 0.26°C. A number of investigators regard these estimates as low (G. Woodwell, INPA seminar, l980; P. Crutzen, pers. comm., 1980; Schneider *et al*., 1980; Leovy, 1980), differences in results apparently being due to assumptions regarding humidity and altitude of cloud cover. Two much higher estimates, 10°C (Muller, 1963) and 5.3°C (Bryson and Dittberner, 1976), have mistakenly ignored latent heat exchange with the surface (Manabe and Wetherald, 1967; Watts, 1980a,b).

2.) The insignificant role of denitrification means that only about 0.3% of N applied would be released as atmospheric N_2O (Goreau, 1981: 126); this corresponds to 5% of the total global flux, whereas a higher 1% yield would account for 20% of the annual flux (Keller, l982: 30).

3.) This chapter is not included in the Portuguese language edition (Goodland and Irwin, 1975b).

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TABLE 1
ESTIMATES OF ANNUAL CARBON RELEASE

Authors	Tropical Deforestation	All Terrestrial Ecosystems
Woodwell *et al*. 1978	3.5 (1-7)	4-8
Dickenson, 1981	1.0	
Loucks, 1980	1.5	
Hampicke, 1979: 230	3.6	1.5-4.5
Hampicke, 1980, cited by Henderson-Sellers, 1981: 456		
Based on Historical evidence	1.8-4.0	
Based on socio-economic development	1.3-2.3	
Based on remote sensing measures of forest decreases	1.5-2.5	
Adams *et al*, 1977		0.4-4
Bolin, 1977	1.5	0.4-1.6
Wong, 1978		1.9
Moore *et al*., 1981		2.2-4.7

Seiler and Crutzen, l980	-2-2

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*in billions of metric tons (gigatons)

TABLE 2: POSSIBLE MACRO-CLIMATIC EFFECTS OF AMAZONIAN DEFORESTATION

Item	Change	Effect
Oxygen	not significant	not significant
Carbon dioxide	increase	global temperature increase (note: contribution of rainforest is subject of controversy)
Nitrous oxide	increase	global temperatures increase (slightly) ultraviolet radiation increases at ground level
Albedo (reflectivity)	increase	decreased rainfall in temperate zones
Evapo-transpiration	decrease	decreased rainfall neighboring regions; temperature increase due to decrease of heat absorbing function of evapo-transpiration.
Rainfall	1) decrease in total	vegetation changes: climatic regime

2) increased length of dry season (more important)	becomes unfavorable for rainforest. Reinforces trend toward still drier climate.