 Fearnside, P. M. 1982. Deforestation in the Brazilian Amazon: How fast is it occurring? *Interciencia* 7 (2): 82-85.

DEFORESTATION IN THE BRAZILIAN AMAZON: HOW FAST IS IT OCCURRING?

PHILIP M. FEARNSIDE

Estimates of how much of the Brazilian Amazon's rainforest has been cleared, and how fast this process is presently occurring vary sharply. Even more striking are the differences in interpretation of how fast forest clearing is likely to be in the future, and whether present trends are a cause for concern. It is important to examine available information on present rates and likely trends for the region as a whole, and to examine in greater detail the deforestation process in one of the current foci of felling activity: the Federal Territory of Rondônia.

Officials of the Brazilian Institute for Forestry Development (IBDF), the Superintendency for Development of the Amazon (SUDAM) and others have offered estimates of forest clearing in the Amazon, summarized in Table I. In January 1980, Brazil's National Institute for Space Research (INPE) released the first estimates for the region as a whole based on interpreting LANDSAT satellite imagery (Table I). The INPE findings that only 1.55% of Brazil's Legal Amazon had been deforested by the time of the 1978 images used has led to a certain complacency in many quarters concerning deforestation in the region. A closer examination of state and regional trends indicated in the INPE data, as well as my own work with LANDSAT information on Rondônia, leave no room for such complacency.

Several problems with LANDSAT imagery lead to a tendency to underestimate deforestation. These include the exclusion of "very small" clearings (Tardin *et al.*, 1980). More importantly, distinguishing second growth more than a few years old from primary forest is difficult. Tracings of LANDSAT images for Rondônia, discussed later in this paper, indicate a number of clearings in 1976 reverting to classification as virgin forest by 1978. In the case of the INPE study (Tardin *et al.*, 1980) the discrepancy is clearest with respect to the known clearing of the Zona Bragantina. This approximately 30,000 km[2] area of Pará near the town of Bragança has been settled since the late nineteenth century, and has been virtually entirely cleared for many years (Penteado, 1967; Sioli, 1973: 327). My own visits to the area from 1975 onwards confirm the impression that none of the original high forest remains. The area of the Zona Bragantina alone is greater than the 28,595 km[2] indicated by the INPE study (Tardin *et al.*, 1980) as being cleared through 1975 in the entire Legal Amazon, and is almost four times the 8,654 km[2] area indicated as cleared by 1975 in the State of Pará.

Far more important than underestimates of cleared areas due to technical limitations of LANDSAT interpretation are the rate at which clearing has been increasing, and the forces in motion leading to further likely increases. The basic INPE finding, namely that cleared area through 1978 was small in relation to the area of the Legal Amazon, is quite correct, even allowing for any underestimation in area figures. Several indications suggest that recent deforestation trends may be exponential although available information is insufficient for firm conclusions. These trends collide with one of the Amazon's great illusions: the illusion of infinite size.

The Nature of Exponential Growth: Illusion of Size

The rate at which a small quantity can become a large one, when growing exponentially, has always been a source of surprise to people, from supermarket shoppers to government planners. The case of inflation is the best example. In Brazil, inflation has been in the double digit category for virtually all of living memory, and in the triple digit category in more recent years. Yet shoppers are still continually surprised by the magnitude of increases when they do their weekly marketing. The idea of an older person having bought a house for less than the current price of a bottle of Coca Cola still produces amazement, even after a lifetime of exposure to the exponential trend. The same difficulty hinders visualizing the growth of a relatively small cleared area to cover the vast expanse of Amazonia. An exponential trend can lead to just such an increase within a very few years. It is worth examining more closely some of the properties of exponential patterns in general. and how they relate to deforestation in Amazonia.

Quantities growing by amounts that depend on the amount already present increase exponentially. Such a pattern applies to a diverse variety of phenomena, from money in bank accounts to unrestrained populations of organisms, and may apply to current trends in deforestation in Amazonia. If a quantity grows by a constant fraction during each time interval, its size at any time would be described by:

$$N_t = N_o (1 + i)^t \qquad \text{Equation 1.}$$

where: N_t = the number at time "t"
N_o = the initial number (number at time "0")
i = the proportion by which the number increases in each time unit ($1 + i$ = the finite rate of increase)
t = the number of time units elapsed.

Equation 1 would describe, for example, growth of money in a bank account where interest is compounded once annually, if t = 1 year and i = the interest rate expressed as a proportion. Money in a bank account grows faster as the number of compoundings per year increases. Including the number of times interest is compounded (q times/time unit), gives the form of the equation familiar to bankers:

$$N_t = N_o \left(1 + \frac{i}{q}\right)^{tq} \qquad \text{Equation 2.}$$

As the number of compoundings approaches infinity, Equation 2 approaches the exponential equation in the form familiar to biologists (see Pielou, 1974: 360 for a derivation):

$$N_t = N_o e^{rt} \qquad \text{Equation 3.}$$

where:

r = the innate rate of increase (related to i of Equation 1 by $r = \ln (1 + i)$ or $i = e^r - 1$)
e = the base of natural logarithms (the constant 2.71828...)

Equation 3 is the best representation for such phenomena as population growth and deforestation, due to its representation of exponential growth as a continuous process rather than a series of discrete events such as compounding interest at the end of each time interval (as in Equations 1 or 2). The difference in results obtained using a discrete representation (Equations 1 or 2) rather than a continuous one (Equation 3) can be relatively small at low values of "i" or "r", but become larger as the rates increase. The proper choice of equations depends on the nature of the phenomenon and how the value employed for the rate of increase is derived.

The rate of exponential increase (r) can be obtained by rearranging Equation 3:

$$r = \frac{\ln\left(\frac{N_t}{N_o}\right)}{t}$$

Equation 4.

For calculating the rate from information on a particular interval, the values of "No" and "Nt" used would represent the amounts at the beginning and end of the interval, and "t" the time elapsed.

The time needed to destroy a resource, for example to deforest a given area such as Brazil's Legal Amazon, would be obtained by rearranging Equation 4:

$$t = \frac{\ln\left(\frac{N_t}{N_o}\right)}{r}$$

Equation 5.

The time from the present to deforest a region, for example, would be given by "t" in Equation 5 if "Nt" were the region's total area and "No" the amount cleared up to the present.

Difficulty in visualizing large results of exponential changes from seemingly small values of the exponential rate of increase (r) often makes it convenient to convert these rates to doubling times. The time needed to double an amount can be obtained from Equation 5 by substituting the value 2 for the ratio Nt/No. The doubling time is therefore equal to In 2 / r, or 0.6931 / r. For quick mental calculations, it is easiest to estimate doubling time in years by dividing the value 70 (as an approximation of 69.31) by the annual percentage increase.

Rainforest Clearing: Implications of Exponential Trends

Recent deforestation trends appear to be exponential, although available information cannot be considered conclusive. If one assumes that such a trend continues into the future at a constant rate ("r" of Equation 3), one can observe the consequences of the trend. Strengths and weaknesses of the assumption of a constant growth rate will be discussed later.

The INPE study (Tardin *et al.*, 1980) indicates that 28,595.25 km[2] of the Legal Amazon had been cleared by 1975, increasing to 77,171.75 km[2] by 1978. Using these figures for "No" and "Nt" respectively in Equation 4, and the 3 year observation interval for "t", one can calculate a value for the annual rate of increase "r" of 0.33093. Note that this corresponds to a doubling time of only 2.09 years. The time needed to clear the entire Legal Amazon at this rate can be obtained from Equation 5, by substituting the above value for "r", the 4,975,527 km[2] area of the Legal Amazon for "N,", and the 1978 clearing estimate of 77,171.75 km[2] for "No" The resulting time to clear the area is 12.6 years, meaning that the process would be completed by the year 1991.

Concentration of felling activity in certain regions has been an important feature of the clearing pattern. The most

intense clearing has been in Rondônia, Acre, and in the cattle ranching areas in southern Pará, western Maranhão, northern Goiás, and northern Mato Grosso. Table II shows the implications of an exponential growth pattern by state or territory, calculated from INPE data (Tardin *et al.*, 1980: 12).

It is worth repeating that the times to complete clearing shown in table II assume a constant "r" in the exponential equation. The value of "r" is undoubtedly not constant: it can change, either up or down. The table therefore does not represent a forecast of what will actually occur, but does show the consequences of sustained exponential trends. Facing the consequences of those trends could, itself, motivate government leaders to take steps to restrain the forces underlying deforestation (Fearnside, 1979).

Rondônia: A Laboratory for Studying Deforestation

Rondônia, as can be seen from Table II, is the state--or territory-sized unit with the fastest clearing rate in the Legal Amazon, an exponential trend at the current rate leading to complete clearing by 1988[*(1)*]. Within Rondônia, certain areas have undergone truely explosive clearing. The Municipio of Cacoal, for example, had a cleared area of 2,150 ha in 1975, increasing to 66,950 ha in 1978 (Brazil CNPqINPE, Departamento de Sensoriamento Remoto, Divisão de Aquisição de Dados, Seção de Aeronave e Apoio Cartográfico, 1980. Cited by Calvente, 1980: 27). An exponential increase at this rate would have an "r" value of 1.14616, or a doubling time of 0.6 years! The 80,000 ha total area of the Município (Brazil, Território Federal de Rondônia, Secretaria de Agricultura, 1980: Vol. 2, p. 37) would be completely cleared by the end of 1981 were the rate to remain unchanged. Within the Município, the cleared area southwest of the BR-364 highway grew even faster, from 550 ha in 1975 to 24,875 ha in 1978 (Brazil, CNPqINPE, Departamento de Sensoriamento Remoto, Divisão de Aquisição de Dados, Seção de Aeronave e Apoio Cartográfico, 1980 cited by Calvente, 1980: 27), corresponding to an "r" of 1.27786, and a doubling time of only 0.54 years. Clearly Rondônia is an area where the processes of deforestation can be expected to reveal themselves most sharply, with areas presently undergoing rapid changes at all stages in the process: from areas as yet unoccupied by Luso-Brazilians (as distinguished from Amerindians), to areas where all land is claimed by settlers and clearing is well advanced.

Increase in Cleared Areas

Examination of a more complete time series of clearing information from an area in Rondônia will give a better idea of the nature of the growth pattern of cleared areas, although data available are few. Information comes from tracings of LANDSAT images taken in 1973, 1975, 1976, and 1978 of the area shown in Figure 1. The maps were on a scale of 1:250,000, with some slight variation (CV = 0.59%). Deforested areas were estimated by cutting out the cleared areas and weighing them to an accuracy of 10[-4]g (representing an average of 6.522 x 10[-2] km[2]). Measurements were made separately for three government smallholder colonization projects (Ouro Preto, Jaru, and Gy-Paraná) and two areas of cattle ranches up to 3000 ha, with some small squatters (Castro Alves and Gleba Corumbiara). The clearing results are shown in Table III.

The figures reveal rapid clearing in all five areas. Clearing is most advanced in the Gy-Paraná colonization project, having reached 15% of the area by 1978. Clearing expressed as percentages of the surveyed areas in each project are shown in Figure II.

The information available is inadequate to draw firm conclusions concerning the form of the clearing curves. However, since this is the longest time series available for this type of clearing, it is worth examining further the pattern of available data. Table IV compares linear and exponential curves fitted to the data for three projects for which clearing is reported beginning in 1973, as well as for the entire study area[*(2)*].

Although conclusions cannot be drawn from the small amount of data available, higher coefficients of determination indicate that the exponential representation explains a greater proportion of the variance than the linear one in all cases. Evidence suggesting exponential trends is by no means unequivocal, but such trends would, if sustained, lead to complete deforestation of all these areas within the present decade.

Any type of simple curve fitting procedure, whether linear, exponential or other, is bound to prove inadequate for providing sound projections of a process as complex as deforestation. The above is a very important warning, and I will repeat it at the conclusion of this article. As a first step towards creating more realistic models of this process, the progress of deforestation is currently being examined in one of Rondônia's government-sponsored smallholder areas, and in a similar area on the Transamazon Highway in Pará. Whithin individual lots, and within completely occupied blocks of lots, deforestation is not exponential. Average cumulative cleared areas increase roughly linearly, with some indication that the increase may slow after about eight years of occupancy. The LANDSAT data from Rondônia discussed above also show somewhat slower clearing for 1976 to 1978 than from 1975 to 1976. The continued flood of new migrants to the region, as well as the substantial part of the region's clearing represented by ranching or other large enterprises, insure that region-wide trends will continue to show sharp increases in cleared areas under current conditions. Eventually the rate of clearing should slow, but there is no reason to believe that this will occur in a smooth and symmetrical fashion, for example following a logistic growth path.

Expectations for the Future

Future rates of deforestation are not predictable with accuracy. Many global trends point to increased future deforestation in the Amazon. The impending end of tropical rainforests in Southeast Asia (Routley and Routley, 1977) will undoubtedly lead to substantial increases in pressure from international logging operations, presently much more active in Southeast Asia than in Amazonia. Much depends on government policy. The deforestation process itself is exceedingly difficult to control for cultural, institutional, and practical reasons (Fearnside, 1979). Government policy could affect deforestation through the choice and placement of agroecosystems encouraged in developments controlled or influenced by planners (Fearnside, in preparation). Policies affecting the size of the human population, and the distribution of income and land tenure in the area also potentially have a strong effect (Fearnside, nd). Government decisions affecting the wider economy could have an impact on deforestation. High inflation rates in Brazil, 112% in 1980, provide a strong motive for speculators to invest in land in Amazonia, bidding the price to levels above those that land would justify strictly as an input to agricultural production. Clearing then follows to secure the speculator's claim to the land (Fearnside, 1979). Trends in other parts of Brazil affecting migration to the Amazon include the government-encouraged production of alcohol from sugar cane and, even more importantly, financing the continued replacement of labor-intensive coffee plantations with mechanized soya bean and wheat cultivation.

Deforestation rates are closely tied to road building, an activity largely carried out by the government. The relationship between clearing and road building is probably not one of simple cause and effect either way, but rather a sort of coevolution between the two as a process of positive feedback. As roads are built or improved and feeder networks added, more migrants enter an area, and those already there dramatically increase their clearing rates; at the same time the presence of people in an area creates pressure justifying the expense of constructing still more and better roads. Asphalting the Cuiabá-Porto Velho Highway (BR-364), with an associated expansion of the feeder road network, is expected to occur in 1981 or 1982 with financing from the World Bank. The asphalting will undoubtedly lead to further rapid increases in clearing in Rondônia, as well as in areas to which migrants are going from Rondônia, such as Acre, Amazonas, and especially Roraima.

Fiscal incentives are another area in which government influence on clearing is strong (Mahar, 1979; Fearnside, 1979). The superintency for Development of the Amazon (SUDAM) has recently suspended new incentives for ranching in the portion of the region officially classed as high forest. This action is encouraging as an indication of official intentions, but its impact on clearing rates may not be as great as might be expected. On the scale of the Legal Amazon, the large area classified as "transition forest", where most SUDAM sponsored ranches are located, is exempt from the restriction on new incentives. In the high forest area, ranching projects already approved by SUDAM continue to receive their incentives; since most of these ranches have only cleared a tiny fraction of their total area, much clearing will still take place in high forest with the help of SUDAM incentives. It should also be remembered that before the restriction on new incentives almost half of the clearing in ranching areas was done without benefit of any incentives: in 445,843 ha of clearing in the area of the Belém-Brasília Highway surveyed by Tardin *et al.* (1978: 19), 45.4% had been cleared without incentives.

Clearing rates would be affected by the wide range of development policies treated under Brazil's "Forest Policy" draft law. The original version of this law was drawn up by an interministerial commission in 1979.

Allegedly, the content of the draft law was subsequently altered to remove restrictions on clearing of high forest for ranching (Kerr, 1980). The representative on the interministerial commission from the National Scientific and Technological Council (CNPq) reports that the draft law has since been delayed, also in response to cattle ranching interests (*A Critica* (Manaus), 01 de julho de 1981).

Conclusions

1. Deforestation is occurring rapidly. Some indications exist that cleared areas may be increasing exponentially, based on trends in small farmer settlement areas in Rondônia from 1973 through 1978, but data are insufficient for firm conclusions. Features of the system consistent with an exponential pattern include a probable positive feedback relationship between roadbuilding and clearing. No simple algebraic equation can be expected to adequately represent the process of deforestation.

2. Clearing rates vary greatly in different parts of the region. Rondônia is the state --or territory-sized unit with the highest rate.

3. Clearing is not exponential within individual properties or blocks of completely occupied properties. The increased rate in settlement areas is largely due to the flood of new arrivals, which is likely to swell.

4. Assuming exponential trends, most parts of Amazonia would be cleared by the end of the century, and some, like Rondônia, within the present decade. It is emphasized that present trends need not continue: they can change either up or down. Calculations of cleared areas at future dates are useful as illustrations, not as predictions.

5. Many government decisions will affect future deforestation rates in the region.

6. Far more important than the date at which present trends would lead to complete clearing of the region, be it sooner or later, is the designation and protection of areas not to be cleared, and the wise use of areas designated for clearing such that 1) agronomically and socially sustainable agroecosystems are employed, 2) concentration of income and land tenure is limited, 3) total consumption is limited, and 4) population is maintained below carrying capacity, defined to include an adequate and sufficiently certain standard of living.[(3)]

Philip M. Fearnside, an ecologist, received his Ph.D. in Biological Sciences from the University of Michigan, Ann Arbor, Michigan, U.S.A. in 1978. He is specially interested in the estimation of carrying capacity for human agricultural populations. His work has been directed at this problem in the Brazilian Amazon since 1973. He is presently a Research Professor at the Instituto Nacional de Pesquisas da Amazonia (INPA), Caixa Postal 478, 69.000 Manaus, Amazonas, Brasil.

NOTES

1 Clearing and total area values for Rodonia slightly at variance with the Tardin *et al.* (1980) figures of Table II are given by Brazil, CNPq-INPE, Departamento de Sensoriamento Remoto, Divisão de Aquisição de Dados, Seção de Aeronave e apoio Cartográfico (1980, cited by Calvente, 1980: 27); total area 243,004 km[2], cleared by 1975 1,216.50 km[2], cleared by 1978 4,162.00 km[2]. Both sets of figures lead to clearing by the year 1988, assuming an exponential trend.

2 Note that, since deforestation is an irreversible process, deforested areas are only free to vary in an upward direction with time, thus violating the assumption of an independent and normally distributed dependent variable required for regression analysis (Sokal and Rohlf, 1969: 409).

3 I thank the Secretaria de Planejamento of the Território Federal de Rondônia for the tracings of LANDSAT images used for clearing estimates in the territory, and the Instituto Nacional de Colonização e Reforma Agrária (INCRA) for maps of the settlement areas. The clearing area estimates in Rondônia were done for Projeto Estimativa de Capacidade de Suporte de Agro-Ecossistemas Amazônicas/INPA by Topografia Schuster, Ltda., Manaus. Financial support came from the Projeto do Trópico Umido (PTU) of the Conselho Nacional de Pesquisas Científicas e Tecnológicas (CNPq). All responsibility rests with the author.

REFERENCES

Brazil, Conselho Nacional de Pesquisas Científicas e Tecnológicas-Instituto Nacional de Pesquisas Espaciais (CNPq-INPE), Departamento de Sensoriamento Remoto, Divisão de Aquisição de Dados, Seção de Aeronave e Apoio Cartográfico. (1980): INPE, São José dos Campos, São Paulo.

Brazil, Território Federal de Rondônia Secretaria de Agricultura (1980): *Sistema Agrícola de Rondônia para o Pequeno Produtor*. (Porto Velho, Secretaria de Agricultura) 5 vols.

Calvente, A. T. (1980): *Formações não Capitalistas no Movimento de Ocupação da Amazônia: Colonização Agrícola em Rondônia--1970/1980.* Masters Thesis in Economics, (Universidade de Brasília, Brasília. 184 pp.

A Crítica (Manaus) 01 de julho de 1981. "Ninguém provou venda da Região Amazônica". Cad. 1, p. 3.

Fearnside, P.M. (1979): The development of the Amazon Rain Forest: priority problems for the formulation of guidelines. *Interciencia*, 4 (6): 338-342.

Fearnside P.M. (nd): *Carrying Capacity for Human Populations: Colonization of the Brazilian Rain forest.* To be published.

Jornal do Brasil (Rio de Janeiro) 26 de junho de 1977. "Amazônia: o verde esconde um areal esteril". p. 7.

Kerr, W.E. (1980): Mudanças possíveis na política econômica que colaborariam para deixar a floresta em paz. Mensagem pronunciada ao Projeto Jaraqui em 10/05/80, Manaus-Amazonas. (to be published. ms. 8 pp)

Mahar, D. J. (1979): Frontier Development Policy in Brazil: a Study of Amazonia. (New York, Praeger) 182 pp.

Muthoo, M.K. (1977): *Perspectivas e Tendências do Setor Florestal Brasileiro 1975 a 2000.* (Brasília, Instituto Brasileiro de Desenvolvimento Florestal) Seríe Técnica, 8: 2 vols.

Myers, N. (1980): *Conversion of Tropical Moist Forests.* (Washington, D.C., National Academy of Sciences) 205 pp.

Penteado, A.R. (1967): *Problemas de Colonização e de Uso da Terra na Região Bragantina do Estado do Pará.* (Belem, Universidade Federal do Pará) 488 pp.

Routley, R. and Routley V. (1977): Destructive forestry in Australia and Melanesia. pp. 374-97 In: Winslow, J.W. (ed.) *The Melanesian Environment.* (Canberra, Australian National University Press) 562 pp.

Pielou, E.C. (1974): *Population and Community Ecology: Principles and Methods.* (New York, Gordon and Breach Science Publishers) 424 pp.

Reis, M.S. (1978): Uma definição técnico-política para o aproveitamento racional dos recursos florestais da Amazônia brasileira. Conferência proferida durante o 3o Congresso Florestal Brasileiro, Manaus, Amazonas, 04-07 de dezembro de 1978. (Brasília, Projeto de Desenvolvimento e Pesquisa Florestal (PRODEPEF)/Instituto Brasileiro de Desenvolvimento Florestal (IBDF)) 21 pp.

Serrão, E.A.S., Falesi, I.C., de Viega, J.B., and Texierira Neto, J.F. (1979): Productivity of cultivated pastures on low fertility soils in the Amazon of Brazil. pp.. 195-225 *In:* Sánchez, P.A. and Tergas, L.E. (eds) *Pasture Production in Acid Soils of the Tropics: Proceeding of a Seminar held at CIAT, Cali, Colombia 17-21 April, 1978*, Series 03 EG-05. (Cali, Colombia, Centre International de Agricultura Tropical) 488 pp.

Sioli, H. (1973): Recent human activities in the Brazilian Amazon Region and their ecological effects. pp. 321-34: *In:* Meggers, B.J., Ayensu, E.S. and Duckworth, W.D. (eds.) *Tropical Forest Ecosystems in Africa and South America: A Comparative Review* (Washington, D.C., Smithsonian Institution Press) 350 pp.

Soili, H. (1980): Foreseeable consequences of actual development schemes and alternative ideas. pp. 257-68 *In:* Barbira-Scazzocchio, F. (ed.) *Land, People and Planning in Contemporary Amazonia.* Centre of Latin American Studies Occasional Publication No. 3. (Cambridge. U.D., Cambridge University) 313 pp.

Sokal, R.R. and Rohlf, F.J. (1969); *Biometry: the Principles and Practice of Statistics in Biological Research* (San Francisco, W.H. Freeman and Co.) 776 pp.

Tardin, A.T., dos Santos, A.P., Lee, D.C.L. Maia, F.C.S., Mendoça, J.J., Assuncao, C.V., Rodrigues, J.E., de Moura Abdon, M., Novares, R.A., Chen, S.C., Duarte, V, and Shimabukuro, Y.E. (1979): *Levantamento de Areas de Desmantamento na Amazônia Legal Através de Imagens de Satélite Landsat.* INPE - COM3 / NTE C.D.U. 621.38SR. (São José dos Campos, São Paulo, Instituto Nacional de Pesquisas Espacias) 9 pp.

Tardin, A.T., dos Santos, A.P., Morais Novo, E.M.I., and Toledo, F.L. (1978) Projetos agropecuários de Amazônia: desmatamento e fiscalização-relatório. *A Amazônia Brasileira em Foco*, No. 12: 7-45.

Tardin, A.T., Lee, D.C.L., Santos, R.J.R. de Assis, O.R., dos Santos Barbosa, M.P. de Lourdes Moreira, M., Pereira, M. T. Silva, D. and dos Santos Filho,C.P. (1980): *Subprojeto Desmatamento, Convêino IBDF/CNPq-INPE 1979.* Instituto Nacional de Pesquisas Espaciais (INPE) Relatório No. INPE-1649-RPE/103. (São José dos Campos, São Paulo, INPE) 44pp.