Appendix C-7

Land Use Patterns, Deforestation in the Brazilian Amazon and Global Ecological Effects: A Dynamic Model of Regional Ecological Economics.

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1. **Introduction**

The Amazon region has been in the past a target of many misguided governmental policies, ranging from measures designed solely to bring forth the occupation of the territory, such as the Trans-Amazon highway, to those based on traditional economic development strategies, such as the incentives for cattle ranching (Repetto, R. e Gillis 1988; Biswanger 1991; Fearnside 1989; Mahar 1989). These strategies proved to be not only ineffective in generating lasting secondary economic benefits for the region, but to be disastrous from an environmental point of view, for they brought forth indiscriminate deforestation of the unique tropical forest ecosystem.

The causes of deforestation, however, are no longer easily identifiable by means of misguided government policies, but are the result of the complex inter-relations between the environment and the socio-economic reality of the region, of the country, and their ramifications to the global economy. These causes have been the object of much controversy, in view of the difficulty in obtaining and measuring precise data about the extent of the deforestation caused by each isolated agent and its role in the dynamics of deforestation. Nonetheless, in order to design policies that can be effective in the control of deforestation, greater knowledge concerning its causes and how they interact with each other is called for.

The model here presented was developed with the objective of investigating the causes of deforestation by portraying the complex inter-relations that occur, many times simultaneously, between the decisions of the instituted economic agents based on market indicators of relative scarcity and those resulting from spontaneous population pressures, resulting from the prevailing social inequality in the country.

The land use patterns of these agents were portrayed, their influence over the demand for more land, and the resulting consequences on the ecosystem functions of a global nature simulated with the intent of making projections of their dynamic tendencies over time. These projections were intended to contribute not only to the understanding of the underlying causes of deforestation but also to develop quantitative means of discerning when these ecosystem services, namely Biodiversity Conservation, Carbon Sequestration, and Climate Regulation, might be put at risk by forest depletion. This was done even though these could only be tentatively quantified at this point in the scientific knowledge of their aggregate functioning.

2. **Model Conceptualizaton[1].**

The main purpose of the model was to portray the land use patterns of the forces at play leading to deforestation in the Amazon and to be able make deforestation projections, as well as to simulate the ecological economic consequences of this phenomenon over time. Its basic conceptualization was territorial: the model calculates how much of Pristine Forest and Early Recovering and Late Recovering forest land remains at any point in time as the depletion takes place.

In order to achieve this, the total area of the Legal Amazon in Brazil, with the exclusion of urban areas and areas under legal protection (parks, extractive and Indian reserves), was considered as available for deforestation. The areas excluded were taken as inaccessible, that is, already under a form of use with no possibility of alteration. The areas already occupied by projects or considered to hold potential for their development were also excluded.

The forces considered as leading to forest clearing were project development (hydroelectric plants, large-scale mining), agriculture/cattle use, cutting or burning for subsistence farming, and cutting for logging (even selective logging is very destructive in the Amazon). River mining was excluded due to its greater environmental damage in the form of mercury pollution of the rivers and therefore not a large-scale forest-destructive activity.

The usage of the land for activities which entail forest clearing and allow for land regeneration (agriculture/cattle, subsistence farming, logging) were grouped into the land use sector. Pristine forest is cut and put into use (cut and in use), then abandoned at a rate which depends on the usable life of the land. Usable life is a graph of Perceived Land Availability. The more land is perceived to be available, the easier it is to move on to a new plot of land and the less time any given plot will be used in the Amazon. Perceived Availability is a dynamic concept, that changes as new forest land becomes scarcer and more difficult to reach. It is assumed that Actual Availability and Perceived Availability adjust to each other every five years. It is the perceived notion, however, that dictates scarcity-oriented economic behavior, such as the investment in land productivity, which determines the Usable Life of the land[2].

The model addresses primarily the causes of deforestation, therefore it adopts a theory for land utilization intensity that supposes it to be regulated by scarcity-oriented economic behavior and ease of access, expressed in terms of land availability. In fact, relative scarcity (or price) is not the only factor governing investment decisions in land productivity, but also land ownership and concentration, credit availability, and income distribution, for example. However, in frontier areas, where the cutting down of Pristine

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[1] MIT, 1997; Randers, J, 1980. Meadows, D. 1976.

[2] Equations and Graphs are detailed in the Appendix.

Forest is underway, it is assumed that the role of these factors is portrayed by the perception of land availability.

The cut land enters into Early Recovering and, over a period of time which is a function of Soil Recovery Time, enters into Late Recovering. Soil Recovery Time is a graph of Lag Rainfall. It is assumed that rainfall begins to diminish as a result of less evapotranspiraton due to forest cutting: given the conditions in the Amazon of extreme humidity and leaching, the initial effect of increasing Lag Rainfall is beneficial, diminishing Soil Recovery Time. However, eventually a threshold is reached after which, Lag Rainfall does begin to increase Soil Recovery Time.

Late Recovering land can be reused, or put back into cut and in use again, depending on the fraction of Available Pristine Forest and the Total Cutting Factor. The rate at which Late Recovering land is reused and at which Pristine Forest itself is cut and put into use is a function of the Total Cutting Factor. This factor is defined as being the product of the demand for more land and the effect of availability on cutting, which is a graph of availability itself (as availability of land increases, so does its effect on cutting, and vice-versa). The concept of availability, here, is the actual one, since it determines immediate decisions over cutting actions.

The demand for more land is a function of the time it takes for the cut area to be abandoned (as determined by the Effect of Perceived Availability on Usable Life), the number of unemployed workers at any point in time (relative to the land employment density as a function of the size of the Amazon), and the time it takes to adopt slash-and-burn agriculture. It is assumed that unemployed workers, with no other source of income, will go to areas of frontier and burn or cut down forest for subsistence farming and/or cattle grazing. Every two years the productivity of plots exploited under these conditions declines in the Amazon and they are abandoned for another plot (Fearnside 1989; 1990). This behavior relates to landless immigrants and not to indigenous peasants that may have ownership of the land and that, therefore, are considered to be employed on the land.

The Project Sector comprises the area already occupied by projects or considered to have potential for hydroelectric or mining development (mineral deposits and potential river areas). The nature of their potential for cutting was differentiated not only by the restriction to their potential area but also because the forest cover, once cleared, is considered unable to regenerate. This is, therefore, a worst case scenario, since many projects do devote some part of their land to reforestation. However, since it is extremely difficult to ascertain what in fact this represents at present, or would in the future, for the entire Amazon area, the worst case is assumed.

Each phase of the project cycle has a population impact in terms of employment: primary (direct jobs), secondary (jobs created by the population influx to the new cities, usually in the services) and unemployment (due to the extinction of many jobs after the project has been built and eventually abandoned). It is assumed that these unemployed

workers remain in the region, and if they cannot find adequate work, turn to forest clearing for subsistence.

The Population Sector assumes that the Amazon is a difficult and hostile environment, where, with the exclusion of the urban areas, there is little or no attractiveness to spontaneous migration. People go there either for employment in the Project Sector or on the Land. The primary driving force to net migration is relative job availability. The ratio of the Economically Active Population (PEA) to jobs determines whether or not there is unemployment in the region, and whether there is a driving force to in-migration, captured by the Effect of Jobs on Migration (which includes the lure of River Mining activities).

The Ecology Sector portrays three economic ecological functions of the Forest that were considered to indicate the impact of deforestation on ecosystem services: Carbon Sequestration (amount of standing Biomass expressed in percentage), Biodiversity Conservation (percentage of Species Remaining) and Climate Regulation (through the ratio of evapotranspiration to rain). Each stage of Land Recovery is associated with a certain degree (expressed in percentage) of conservation of the above ecosystem services. Total Carbon Sequestration at any point in time, for instance, is the sum of these areas multiplied by their particular indices.

Rainfall is expressed as a result of the relationship between evapotranspiration and net vapor from the sea. Scientists[3] believe that this relationship in the Amazon is such that each one of these variables is responsible for approximately 50% of the rain. Rainfall also has time in which to adjust to changed conditions in evapotranspiration, which is defined as being two years. That is, at any one time, the change in lag rainfall will be determined by the difference between actual and lag rainfall over the rainfall adjustment time.

In turn, the delay in rainfall has an effect on evapotranspiration itself. The effect of lag rainfall on evapotranspiration, which is also highly unknown for the Amazon as a whole, is portrayed as a graph which increases exponentially: the greater the lag in rainfall, the less evapotranspiration. Total evapotranspiration, therefore, is the effect of rain on evapotranspiration, multiplied by the sum of the various evapotranspiration indices of the different forest cover stages (assuming pristine forest has 100% evapotranspiration potential).

Total Biodiversity Loss (fraction of species remaining) is calculated in much the same way. It is assumed that two ecological factors have greater influence on species extinction: the effect on temperature and humidity caused by the decrease in rain (effect of rain on species) and the amount of pristine forest still remaining (Effect of Pristine on Extinction). Both are portrayed as graph relationships of biodiversity loss. The latter effect is the result of the following reasoning: If there is considerable untouched forest still remaining, the chances of there also being considerable number of species still remaining are much greater, but diminish exponentially with forest reduction. The Effect

[3] Salati (1983 and 1984)

of Lag Rainfall on Species Extinction is considered to be that of the gradual process of desertification that takes place through the loss of evapotranspiration due to biomass reduction.

Both these effects are very long-term phenomena. Neither the process of desertification nor the consequence of reducing the pool of species present over the vast territorial extension of the forest, occur very rapidly, when the forest remaining is still considerable, but increase exponentially after a critical threshold of forest reduction is reached. The exact amount of forest reduction necessary to reach this critical threshold is not as yet scientifically known, since it would involve considerable research regarding the resilience of this tropical forest ecosystem as a whole, but is postulated intuitively.

In regard to the impact of projects, the total area of the Amazon devoted to the Potential Project Area is not significant enough to warrant a study of their deforestation impact on ecosytem services. These depend solely on territorial extension of forest cover, such as Climate Regulation and Carbon Sequestration, which are a function of biomass. In the case of Biodiversity Conservation, however, the extension of the forest alone does not portray the impact, since it is known that there are many endemic species in the Amazon which might only occur in certain sites. This is true with hydroelectric dams that often are located in remote and still untouched areas. Therefore, the worst case scenario is chosen, and it is assumed that projects have a particularly high impact on Biodiversity Conservation, by choosing especially rich areas.

3. Simulation Results

The model was run with the parameter specifications described above, and the following initial areas, expressed in percentage of the total Legal Amazon area:

_ Area at present (1999) estimated to be already under Cut and in Use: 10.6%
_ Area in Early Recovering: 5%
_ Area in Late Recovering: 1%

The areas considered as static and excluded from the model:
_ Area allocated to Projects and comprising potential project development[4]: 4%
_ Area under Environmental Preservation[5]: 2.74%
_ Area under Urban use[6]: 1%
_ Indian Reservations: 19%

The percentages of potential Species Reduction used as a measure of Biodiversity Conservation under the stages of land use:

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[4] Data from Eletrobrás,(State Electric Energy Co); DNPM (State Mineral Research Dept) and based on informal conversations with Prof. E. Reis at IPEA.
[5] According to study of the WWF (1997), In: Teixeira (1998)
[6] Author's overestimate, based on data from IBGE (Brazilian Statistical Institute) and on informal conversations with E. Reis (IPEA).

_ Species Reduction under Cut and in Use: 80%
_ Species Reduction under Early Recovering: 60%
_ Species Reduction under Late Recovering: 40%
_ Species Reduction under Projects: 100%

The percentages of Carbon Sequestration potential under each stage of vegetative cover[7]:

_ Carbon per Cut and in Use: 5%
_ Carbon per Early Recovering: 50%
_ Carbon per Late Recovering: 80%

The percentages of evapotranspiration potential under each stage of vegetative cover[8]:

_ Evapotranspiration per Cut and in Use: 60%
_ Evapotranspiration per Early Recovering: 80%
_ Evapotranspiration per Late Recovering: 95%

The simulations represent the dynamic tendencies of the main parameters of the model. Pristine Forest depletes completely by the year 2100. The comparison between the two simulation periods demonstrates how the time horizon influences the perception of the problem. If the simulation is run only until 2050, the stock of remaining pristine is still considerable (over 50%). However, if the simulation is run until the year 2100, the vertiginous fall in forest stock is clearly observable from the present.

The simulation results also lend evidence to the fact that the process of regeneration of the tropical forest is by far too slow to avoid complete depletion of its cover, as the trajectory of the variable Available Cuttable (Pristine + Late Recovering) demonstrates, by also being depleted around the year 2100.

The Usable Life of the land, although rising sharply from approximately the year 2050 and retarding the rate of cutting, does not do so in time to avoid complete forest depletion. This demonstrates that the scarcity effect, expressed as a function of how much land is perceived as still being available, is ineffective to act in time to halt the destruction of forest cover. The time horizon in which economic decisions based on scarcity are taken is insufficient to foresee this tendency in time to revert the process of forest depletion.

The parameter Cut and in Use, which represents the rate of deforestation, increases steadily from the present. The Total Cutting Factor includes the Demand for More Land and the Effect of Availability on Cutting, and is composed both of spontaneous population in-migration, embodied as unemployed workers seeking subsistence through slash and burn agriculture at the forest frontier, but also of the rate of abandonment of the area in Cut and in Use and of the Effect that Availability of Land itself has on cutting actions. Which of these factors possesses greater weight in the

[7] Based on data from the ABRACOS project (In: Nobre,C.A.et al *Amazonian Deforestation and Climate*)
[8] idem

process of deforestation depends on the time horizon analyzed and on the circumstances of the Brazilian economy during particular years. The Density of Employment on Land is very low, and as it is kept stabilized, it becomes necessary that a considerable amount of unemployment take place (through the Effect of Jobs on Migration) for the deforestation by this agent to become significant. Medium to large farms or ranches, on the other hand, whose initial area is much greater and who clear more land at any one point in time can possess an immediate significant impact, even if the abandonment is not so frequent.

The results for the Ecology Sector (graphs 3 and 4) show that the variable Lag Rainfall maintains itself stabilized at a relatively high level, indicating a reduction in rainfall of 10 to 20% of the total. Although this does not seem very significant in numerical terms, scientists specialized in the study of this phenomena in Amazonia believe such a reduction will already cause significant impacts to the ecosystem. Salati (1983), for example, concludes: "It is important to note that a reduction in rainfall in the order of 10 to 20% will be already sufficient to induce profound modifications in the present ecosystem. There will be successive modifications of flora and fauna until a new ecological equilibrium is achieved. There are indications that this is a positive feedback and that the dynamic equilibriums achieved subsequently will be of short duration. It is impossible at the present level of knowledge to foresee what the characteristics of this new equilibrium will be" (p. 32). Aside from the ecosystemic effects, there are indications that the reduction in the level of rainfall will also affect nearby regions, since Amazonia is probably a source of vapor for the Brazilian Mid-West also[9].

The dynamic behavior of the parameter Fraction of Species Remaining appears to indicate that the rate of reduction in species will not occur at the same level as the other ecological functions of the forest, given it maintains itself as relatively high, despite deforestation. There are various explanations for this: the percentage of species remaining is influenced by factors other than deforestation itself, through the Effect of Rain on Extinction and the Effect of Remaining Pristine on Extinction**.** It has been demonstrated that Lag Rainfall does not decrease significantly in percentage terms, but its effect is nonetheless significant. Therefore, its effect on species is underestimated. On the other hand**,** the Effect of Remaining Pristine on Extinction is only felt, by definition, when the quantity of remaining forest is small, and therefore is also underestimated, given the extension of the forest is proportionally large most of the time. In addition, it must be taken into account that the activity considered to be most harmful to biodiversity was that of projects that are considered to potentially occupy just 4% of the Amazon area.

In short, the conservation of biodiversity is a phenomenon by far too complex to be adequately portrayed. The numerous ecological inter-relations that exist between organisms and communities, and that bring forth chain reactions to a single disturbance alone, could not be considered. However, as we are very far from establishing scientifically the nature of these reactions in face of the enormous complexity of the ecosystems that make up Amazonia and its sheer territorial extension, hypothesis would have to be formulated for these reactions. These could then be tested in the model, once the magnitude of their territorial impact is known.

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[9] idem

The other variables of interest in the Ecology Sector accompany the logic of the deforestation process and its dependency on the calculation of remaining biomass. Evapotranspiration and Carbon Sequestration both possess a trajectory similar to Pristine Forest. The assimilation of carbon which occurs in the regeneration phases (primary and secondary) could not be taken into account, however, due to the lack of scientific knowledge regarding not only the importance of this assimilation during regeneration of abandoned areas, but also regarding the extent and nature of these areas in Amazonia. Likewise, the Evapotranspiration potential of these areas was estimated solely on the basis of remaining biomass, without consideration of the nature of each ecosystem affected and its particular water retention characteristics.

The tendencies identified by the results also indicated that the process of forest regeneration is by far too slow to avoid complete forest depletion, as demonstrated by the trajectory of the variable Available Cuttable (Pristine+Secondary Recovery), is very similar to Pristine Forest **itself.** This indicates that the rates of cutting and abandonment are too rapid to allow regeneration to take a significant role, especially since this process occurs only over a long time horizon.

In terms of the results for Employment and Unemployment, it can be observed that Employment on Land is associated to the areas in Cut and in Use (graph 7), since according to the basic hypothesis of the model, the migrating population is not employed on land. However, increases in the density of this employment have an immediate effect on retarding the rate of cutting.

5. Conclusions.

The model here described, due to the nature of the problem addressed, emphasizes methodological development rather than the estimation of parameter values. In the case of the Amazon this was essential, since ecosystem services at the aggregate level are still mainly unknown as well as their human interactions. Therefore, many empirical questions remained, and some relationships had to be established on the basis of what information was available allied to common sense.

Nonetheless, the dynamic behavior of the main parameters in the model confirmed what has become widely accepted by experts in the area, without yet having quantified a more precise structural causation: *the resource base is under threat*. It is under threat not only due to the demand for land on the part of the spontaneous mobility of an ever-increasing destitute population of rural landless poor, but also due to the lack of incentive to conserve on the part of the instituted agents of the economy, in face of the enormous availability of land in Amazonia. The land market, or the price of land (of which Perceived Availability can be considered as a *proxy*), only reflects forces of supply and demand pertaining to a particular piece of land over a limited time horizon. Therefore, economic perceptions, which are based on relative scarcity, are formed over a time horizon that is too short to take into account the intrinsic long-term nature of the issues at hand. This is also due to the great extension of the Amazon Forest, whose

ecosystem services of a global nature are captured only when it acts as a regional entity. This economic perception of the whole is what forest conservation requires and remains uncaptured by the market.

The increase in the rate of deforestation and the increase in population pressures have been positively correlated over the last thirty years in the Amazon (Seroa da Motta 1993), without the establishment of a causal relationship. The behavior exhibited by the dynamic tendencies of the main parameters of this model have, however, established this causality and qualified this population. The results indicated model sensitivity[10] to spontaneous population attraction (expressed as the Normal Migration Rate) allied to the Effect of Employment on Migration, independent from the normal reproduction rate of the population. This effect occurs with the development of activities that attract the underprivileged population, but are temporary in nature and therefore a source of future unemployment. Notoriously these are River Mining activities that, when extinct, leave behind a trail of river pollution and erosion and Projects, which attract large contingents of workers during construction, through the creation of direct and principally indirect jobs in the services sector and thus causing the formation of small towns.

Timber extraction, despite its predatory nature, cannot be considered as a temporary activity in the Amazon, given the vastness of forest extension. However, by making use of the unemployed who are present in the rural areas and by creating incentives for migration to the forest frontier, this activity considerably aggravates the other factors. The presence of employment incentives (positive Effect of Jobs on Migration) without greater land use intensity (increased Usable Life of the Land) and/or greater labor use intensity (increased Density of Employment on Land) is explosive for the rate of deforestation.

The resulting policy conclusion is that, given the difficulty in monitoring large areas of forest and in controlling spontaneous population movements towards the forest frontier, it would be to advisable for the government to influence market indicators that create incentives to conserve by those agents of deforestation which respond to these indicators— generally those that also possess land entitlement. However, this can only be adequately attained by a better understanding of how the economic context (macroeconomic, regional and local) influences decision making in the private sector as regards intensity of land and labor utilization in Amazonia. In particular, how the price of land, the type and accessibility of rural credit, macroeconomic policies (including the exchange rate), and instability in general affect the rate of deforestation by these agents.

Government policies aimed at generating employment in rural areas and measures destined to increase the labor/land ratio in general will be equally effective towards diminishing the rate of deforestation. By increasing the Land Employment Density, they will have an effect over unemployment and the demand for more land. Rural employment can also be seen as land entitlement. Therefore, measures taken towards settling landless

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[10] Please refer to the doctoral dissertation, approved in July 1999 under the same title, where model validation by sensitivity analysis of the main parameters as well by calibration with historical data are presented .

families, as long as this is done outside the areas of forest frontier, will be doubly beneficial. They will provide greater assurance of security to the already entitled landowners, avoiding deforestation as a means of preventing invasions; moreover, they will diminish the number of unemployed and their mobility, dampening the impact of this population over the forest frontier.

It is important to note that the social issue of unemployment in the Amazonian region is not one restricted to its boundaries but expands itself to the adjacent regions, to the national level, and even to the international sphere. The opportunities present in the Northeast region of Brazil and in the urban areas of Amazonia, for example, are factors that directly influence the relative attractiveness of migrating to the forest frontier. Therefore, any progress in the direction of bettering the quality of life present in these areas will have an effect in halting the pressures over the remaining forest. At the international level, the activities in the Amazon which are geared to export (timber and soy beans) and that are influenced by the exchange rate, could be directed towards the adoption of more labor and land intensive modes of production, which however goes against prevailing technology. Therefore, deforestation is not the product of the expansion of the agricultural frontier in Brazil alone, but also directly results from the adoption of technological options that are estranged from the reality of the region in which they operate and which are geared to satisfying a world market.

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References:

Aylward, Bruce. "Appropriating the Value of Wildlife and Wild Lands" In *Economics for the Wilds.* Swanson, Timothy e Barbier, Edward eds. Island Press. 1992.

Becker, Bertha K. “Spontaneous/Induced Rural Settlements in Brazilian Amazonia” Nairobi, UNCHS 1986.

Becker, Bertha K “Novos Rumos da política regional: por um desenvolvimento sustentável da fronteira Amazônica” In Becker, Bertha K & Miranda, Mariana, eds *A Geografia Política do Desenvolvimento Sustentável*. Editora UFRJ. 1997.

Becker, Bertha K *Amazônia* Edit. Ática. 1994

Biswanger, H.P. "Brazilian Policies that Encourage Deforestation in the Amazon". World Development, Vol.19, nº17. 1991.

Costanza, R. Sklar, F. & White, M. “Modeling Coastal Landscape Dynamics” BioScience Vol.40 No.2 Fev.1990.

Costanza, R.;Cowling, R.;Higgins, S.,Turpie, J., Maitre,le D.C., Marais,C.,Midley, G. *An Ecological Economic Simulation Model of Mountain Fynbos Ecosystems: Dynamics, Valuation and Management*. Curso de Economia Ecológica ministrado na Universidade de Capetown, Africa do Sul. 1995

Costanza, R,Folke, C., Maler, Karl-Goran, Wainger, L. “Modeling Complex Ecological Economic Systems – *Towards na evolutionary, dynamic understanding of people and nature*” BioScience Vol.43 No.8. September 1993.

Costanza, R., Bockstael, N., Strand, I., Boynton, W., Bell,K. & Wainger, L. “Ecological Economic Modeling and Valuation of Ecosystems”.Ecological Economics Journal. 1995.

Fearnside, P.M. "Forestry Management in Amazonia: The need for new criteria in evaluating development options”. State of Pará Development Magazine nº 25. Jan/Dez 1989

Fearnside, P. "Predominant Land Uses in Brazilian Amazonia" in *Alternatives to Deforestation - Steps Towards Sustainable Use of the Amazon Rain Forest* Anderson, A. editor. Columbia University Press 1990.

Fearnside, P. “Plantation Forestry in Brazil: Projections to 2050”. Biomass and Bioenergy . 1998.

Faeth,P., Cort, C. & Livernash, R. “Evaluating the Carbon Benefits of Forestry Projects in Developing Countries”. World Resources Institute. EPA. Fev. 1994.

Forrester, Jay W. *Principles of Systems* Cambridge, Mass. MIT Press. 1968

Forrester, Jay W. *Collected Papers of Jay W. Forrester*. Cambridge, Mass. MIT Press. 1975.

Mahar, D. "Government Policies and Deforestation in Brazil's Amazon Region" World Bank in cooperation with The World Wildlife Fund and The Conservation Foundation. 1989.

Margulis, S. "The performance of the Brazilian Government and of The World Bank with regard to the environmental issues in the Ferro Carajás Project" Discussion paper nº193. IPEA. (Institute for Applied Economic Research) August 1990.

Meadows, Donella H. "The Unavoidable A Priori". Proceedings from the 1976 Conference on System Dynamics Modeling. Stockholm, Sweeden.

MIT, 1997. Building a System Dynamics Model. Part 1: Conceptualization. MIT System Dynamics in Education Project: Road Maps to System Dynamics.Under the supervision of Dr. Jay W. Forrester.

Nobre, C.A. & Gash,J. "Desmatamento muda clima da Amazônia" Revista Ciência Hoje. 22(128):32-41, 1997.

Nobre,C.A.et al *Amazonian Deforestation and Climate.* John Wiley and Sons. 1996.

Randers, Jϕrgen.. "Guidelines for Model Conceptualization" In *Elements of the System Dynamics Method*. Portland, Oregon. Productivity Press. 1980.

Reis, E.J. *UNEP Greenhouse Gas Abatement Costing Studies: Brazilian Country Study Report. The Contribution of Brazilian Amazon Deforestation to Carbon Dioxide Emissions*. June 1993.

Reis, E.J. & Margulis, S. "Economic Perspectives of Amazonian Deforestation". Discussion Text no. 125 IPEA. 1991.

Reis, E.J. & Guzman, R.M. "An Econometric Model of Deforestation in the Amazon" Economic Research and Planning.no.215 IPEA. 1991.

Reis, E.J. & Margulis, S. "The impacts of the Carajás Siderurgic Pole on Amazonian Deforestation". Perspectives of the Brazilian Economy Series. IPEA. 1994.

Repetto, R. & Gillis, M. eds. *Public Policies and the Misuse of Forest Resources.* Cambridge University Press. 1988.

Salati, E. & Marques, J. “Climatology of the Amazon Region”.In: Sioli, H. ed. *The Amazon: Liminology and landscape ecology of a mighty tropical river and its basin*. DRW.Junk Publishers. 1984.

Salati, E. “The Forest and the Hydrological Cycle”. In Dickinson, R.E. ed. *The Geophysiology of Amazonia _ Vegetation and Climate Interactions*. John Wiley & Sons. 1987.

Salati, E. “O Clima Atual depende da Floresta”. In Salati et.al. 1983.

Salati, E., Shubart,H. & Oliveira, A E. *Amazônia: Desenvolvimento, Integração e Ecologia*. CNPq. Ed. Brasiliense. 1983

Salati, E. Ferreira, A.M.M. “The Large-Scale Biosphere Atmosphere Experiment in Amazonia”.Subcomponente: Dimensão Humana. Nov.1997

Seroa da Motta, R. "Past and Current Policy Issues Concerning Tropical Deforestation in Brazil". Kiel Working Paper nº.566. The Kiel Institute for World Economics. March 1993.

Walker, R. & Homma, A.K.O. “Land use and land cover dynamics in the Brazilian Amazon: an overview”. Ecological Economics Journal. July 1996.