ISSN 0034-7108

REVISTA BRASILEIRA DE BIOLOGIA

MCMXVI

ACADEMIA BRASILEIRA DE CIÊNCIAS

1997. Revista Brasileira de Biologia 57(4): 531-549.

LIMITING FACTORS FOR DEVELOPMENT OF AGRICULTURE AND RANCHING IN BRAZILIAN AMAZONIA*

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(With 3 figures)

ABSTRACT

Limiting factors restrict both the intensification of agriculture and ranching uses and the scale to which these land uses can be expanded. The expression of limiting factors on development is mediated through human planning: the perception of limits to agricultural yields and of the severity and probability of environmental impacts can lead to decisions to limit agricultural expansion. Limits to intensification of agriculture include agronomic limits on per-hectare yields, technological limits and research, and cultural limits. Limits to expansion of agricultural areas include physical resource limits such as phosphate deposits, limits of social values, institutional limits (including the credibility of institutions), limits on human habitation (such as health), and limits to environmental risks. Limits from considerations in political and military spheres often override "rational" decisions based on land capability and environmental consequences. This kind of "interference," however, can cause a variety of impacts that, if properly evaluated, would likely make the net result of such development projects a negative one for Brazil's national interests.

Key words: carrying capacity, limiting factors, Amazonia, deforestation, cattle ranching, economic development.

RESUMO

Fatores limitantes ao desenvolvimento da Agricultura e Pecuária na Amazonia brasileira

Os fatores limitantes restringem a intensificação do uso da agropecuária e a escala no qual esse uso da terra pode ser expandido. A expressão dos fatores limitantes sobre o desenvolvimento é mediada através do planejamento humano: a percepção dos limites para a produção agrícola e da severidade e probabilidade dos impactos ambientais pode levar às decisões que venham limitar a expansão agrícola. Os limites para a intensificaçao da agricul-

Received July 9, 1997
Accepted July 30, 1997
Distributed November 14, 1997

*Invited paper.

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tura incluem limites agronômicos sobre a produção por hectare, limites tecnológicos e de pesquisa, e limites culturais. Os limites para a expansão de áreas agrícolas incluem limites de recursos físicos tal como as reservas de fosfato, limites de valores sociais, limites institucionais (incluindo a credibilidade das instituições), limites de habitação humana (tal como saúde), e limites aos riscos ambientais. Os limites das considerações nas esferas políticas e militares frequentemente superam as decisões e as consequências ambientais. Esse tipo de "interferência", entretanto, pode causar uma gama de impactos que, se devidamente avaliados, provavelmente tornaria o resultado final de tais projetos de desenvolvimento negativo para os interesses nacionais do Brasil.

Palavras-chave: capacidade de suporte humano, fatores limitantes, Amazônia, desmatamento, agropecuária, desenvolvimento econômico.

INTRODUCTION: LIMITING FACTORS

Kinds of limiting factors

Justus Liebig (1840) observed that plants require certain chemical substances from soil and that they cannot grow unless a minimal quantity of each is present. The nutrient in short supply therefore limits growth of the plant – a principle that guides theory in ecology and the practice of applying fertilizers in agriculture to this day. This "law of the minimum" was expanded by Blackman (1905) to include the limiting effects of the maximum, and by Shelford (1911) to include the modifying effect of the tolerance of organisms when responding to minimum or maximum limits. Shelford's "law of toleration" completed the concept of limiting factors as generally applied today.

Most use of limiting factors focuses on the effects of a single factor, and, indeed, the reduction in complexity that this approach allows is one of its greatest strengths in making sense of an otherwise confusing array of possible influences. However, single factors rarely limit organisms or populations in the real world. Hubbell argued strongly against the "spate of single-factor answers in the last 20 years" (1973: 95). He suggests instead that "several factors may act simultaneously, conceivably equally" in limiting populations at any instant in time. Not only can production be co-limited by several factors, but synergisms among factors can result in greater production increases when certain combinations of factors are supplied together. The best example is water and nitrogen limitation of rangeland production in the Sahel region of Africa (see review by Hall, 1990).

Among the types of limiting factors affecting plant growth in general, including agriculture in Amazonia, are soil nutrients, water, light, carbon dioxide, and attacks of pests and diseases. In agricultural systems, limiting factors can be pushed back (up to a point) by outside inputs of energy, fertilizers and other items that depend on availability of capital.

The use of agricultural inputs from outside makes explicit definition of limits on these inputs (and consequently on human carrying capacity) necessary if consideration of limiting factors is to be meaningful. Outside inputs of energy, fertilizers and initial capital can circumvent local lacks. At the extreme, one could even have agriculture on the moon if importing everything were permitted. Practical limits in importing inputs are likely to be determined by markets for the agricultural products exported from the system and on the finite nature of available stocks of inputs in source areas. These limits are critical because of Amazonia's vast area: 5×10^6 km^2 in Brazil's "Legal Amazon" administrative region (Fig. 1).

Limiting factors on Amazonian development can be grouped into a series of classes, of which agronomic limitations represent only one. Also important are institutional limitations, limits imposed by social values, and by social mechanisms or customs, human living conditions, and by the macroeconomic context of development. Salati *et al.* (nd) have examined the question of limiting factors for sustainable development in Amazonia, grouping limitations into those affecting biological productivity and those in the institutional sphere. These authors point out the need for policy makers to understand that nature poses limits to agricultural production, and emphasize the poten-

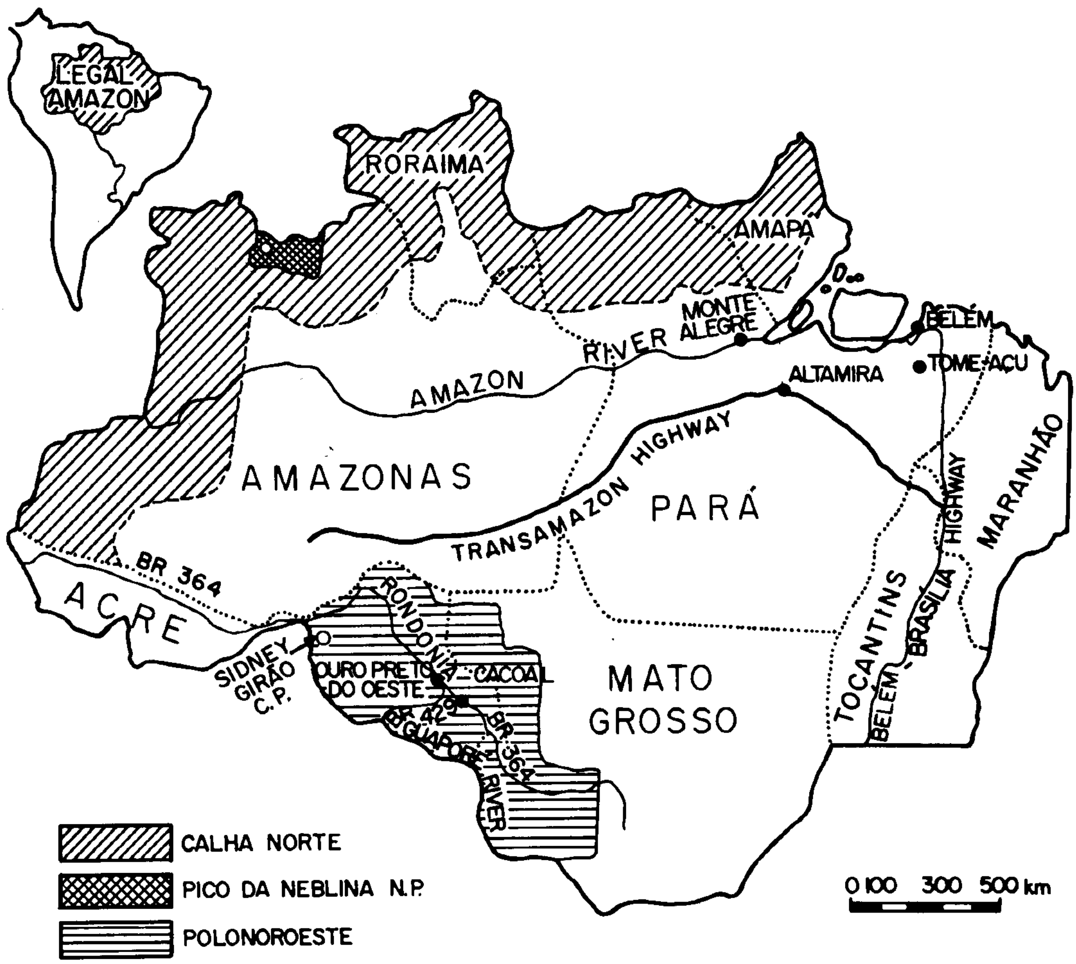

Fig. 1 — Brazil's Legal Amazon region.

tial for improving efficiency by making better use of indigenous knowledge and by institutional streamlining through participation of organizations acting at different levels, ranging from the micro (grassroots) to the macro (public policy) level.

Limits on development act in two ways: limits on per-area production imposed by restrictions on the intensification of use on any given hectare of land, and restrictions on the area to which the activity can expand, as dictated, for example, by the area "available." Some of the factors are interchangeable between the two types of restrictions, such as fertilizer, labor, and capital between intensifying production per hectare and expanding the number of hectares. Some factors are not interchangeable, as they do not involve allocation between competing options; examples include impediments imposed by social values and macroeconomic factors.

Expression of limiting factors

Mediation of Planning

Assessing limiting factors for development is fundamentally different, in some ways, from assessing limiting factors for a population of organisms in a natural ecosystem or in a farmer's field. Development limits are mediated by human intelligence, through the mechanisms of planning (including zoning) and a variety of regulatory hurdles (including environmental impact assessments). If poor soil will lead to failed crops, or if clearing will lead to soil erosion and land degradation, then perception of these limits can lead to decisions not to cut forest for agriculture. Rather than simply allowing settlers to encounter the physical limits for themselves, an additional layer of information, value judgments and decision-making is interposed between the physical limitations and the decisions on development. What, for example, are the acceptable risks of crop failures? What are the acceptable risks of major environmental catastrophes? These and a wide variety of other considerations will determine the limiting factors applicable to development of agriculture and ranching in Amazonia.

Effect of Variability

Variability of any factor, rather than only mean levels, is an essential aspect of limitation. Soil phosphorus, rainfall, money or other necessities vary greatly in space and time. The ability to survive shortfalls of a given factor depends, in part, on such mechanisms as a monetary cushion (i.e., cash, or an equivalent reserve such as cattle, that can be called upon when needed). In traditional agricultural societies, cash and storage of value and products are rare, but forms of insurance are provided by sharing among members of kin or community groups, and by what Allan (1965) has termed the "natural surplus of subsistence agriculture." This mechanism involves planting more area of each crop than would be needed for the mean yield to supply subsistence needs, thereby providing a cushion against shortfalls.

LIMITS TO INTENSIFICATION

Agronomic limits on per-hectare yield

Liebig's "law of the minimum" is applied in agriculture in the form known as the "linear response and plateau model." Crop yield response below a sufficient or "check" level of each nutrient is assumed to be linear, while no response occurs above this threshold. This model has been shown to be adequate for practical purposes for agronomic work on tropical soils, with only marginally better results being obtained using quadratic functions (Waugh *et al.*, 1975). The linear response and plateau model has been applied to crops used by colonists on Brazil's Transamazon Highway (Fearnside, 1986a). Because of acid soil in most of the area (and in most of Amazonia), pH is most often the limiting soil character, for example, for maize (*Zea mays*), beans (*Phaseolus vulgaris*), cowpeas (*Vigna sinensis*), bitter and sweet manioc (*Manihot esculenta*), black pepper (*Piper nigrum*) and cacao (*Theobroma cacao*). The dominance of pH tends to exaggerate its implied role in maintaining crop yields over time. The pH may be kept at a reasonable level by frequent burning of agricultural fields, but other limits, such as lack of organic matter and the various cations associated with it, are likely to appear within a few years (Fearnside, 1986a). Rice (*Oryza sativa*) is limited by pH in combination with organic matter, aluminum ions and total phosphorus (Fearnside, 1986a). In the case of cattle pasture, available phosphorus limits production (Serrão & Falesi, 1977; Fearnside, 1979a). The yields of all annual crops depend not only on soil fertility but also on planting density, interplanted crops, and attacks of pests and diseases.

Technological limits and research

The temptation is always strong to believe that research will remove virtually all limits to development, and nowhere are such flights of imagination freer to run wild than in Amazonia. Because of the region's vast area, assumptions of huge areas of intensive agriculture in Amazonia are the most important factor underlying fantastic global conclusions on the earth's carrying capacity for humans. This may be assumed to be a part of then-US president Ronald Reagan's belief that "farm studies" had shown that the world could support 28 billion people if other countries could be persuaded to cultivate their tillable land at the intensity found in the United States (Holden, 1980: 989).

It is easy for planners to convince themselves that crop yields can increase indefinitely, and that they can increase at ever increasing rates. For example, when the Brazilian Enterprise for Agriculture and Cattle Ranching Research (EMBRAPA) was founded in 1974, a series of projections of per-hectare yields were made for different crops assuming linear, logarithmic and exponential growth in yield (Páez & Dutra, 1974). Recently, Gallopín and Winograd (1995: 27) arrived at a rosy conclusion regarding the prospects for a "sustainable scenario" by assuming that per-hectare yields of crops will increase exponentially at 1.5-2.0%/year (see Fearnside, 1996a). The idea that exponential growth is an option is misleading, and the notion that one can select it as if picking something off a shelf is even more dangerous. In reality, Brazilian per-hectare yields have traditionally been almost constant, increases in the total harvest coming instead from expansion of areas under cultivation (Paiva *et al.*, 1976: 62-68).

The best-known attempt to push back the limits of soil restraints on sustaining agricultural production through time is the project to develop continuous cultivation undertaken by North Carolina State University (NCSU), in conjunction with Peruvian institutions, at Yurimaguas, Peru (Sánchez *et al.*, 1982; Nicholaides *et al.*, 1985; see Fearnside, 1987, 1988; Walker *et al.*, 1987). Soil depletion is a fundamental problem that becomes increasingly expensive and problematic to correct as time proceeds under continuous cultivation. All nutrients removed in harvested crops or lost through erosion, leaching, and other processes can be replaced in the form of fertilizers. The cost of replacing them must include not only the substantial expense of purchasing fertilizers and transporting them to the site, but also the expense of identifying which elements are missing, and in what amounts, for each field, and communicating this information to the farmer in time to allow correction of the deficiencies before yields are affected. The principal macronutrients (nitrogen, phosphorus and potassium), together with lime, account for most of the expense of purchase and transport. Sánchez *et al.* (1982: 825) state that the quantities of fertilizer needed to supply these elements are similar to those used by farmers in the southeastern part of the United States. While this fact might seem to imply that agriculture could be as profitable in the Amazon as in the Carolinas, it should be remembered that long distances make the cost of fertilizer much higher and prices received for crops are much lower than is the case elsewhere.

Correction of micronutrient depletion, while requiring only small weights of imported fertilizer, would add substantially to the cost and risk to farmers practicing the system. Nutrients must be balanced to avoid detrimental synergisms. The system requires analysis of soil and plant samples after each crop in order to calculate the proper nutrient mix for fertilization. It is awesome to imagine the expansion of laboratory and extension services that would be necessary to handle the millions of samples that would be generated should the Yurimaguas technology be widely implemented. While these services have been provided free of charge (i.e., as a subsidy) by NCSU in the case of the farmers collaborating with the Yurimaguas experiment station, either farmers, taxpayers or consumers in Amazonian countries would have to bear these expenses should the system be expanded. When Sánchez *et al.* (1982) published the first results of the experiment, the eight-year-old experimental plots required – in addition to N, P and K – replacement of five other nutrients: magnesium, copper, zinc, boron and molybdenum. Three years later, two more nutrients had been added to the list: sulfur and magnesium (D. Bandy, personal communication, 1985). The research group complained about the difficulty of obtaining adequate purity in the soil samples and sufficient precision in the laboratory analyses: with micronutrients, a difference of only a few parts per billion can have a large impact on crop yields. The difficulty of obtaining such precision would undoubtedly be much greater for farmers handicapped by geographical isolation, lack of education, and a tenuous link to laboratory facilities through a chain of often poorly trained and poorly motivated extension personnel. Any error or delay in calculating the correct mix of fertilizers can cause losses in yields. Sánchez *et al.* (1982: 824) admit: "In the complete treatment, fertilizers and lime were added according to recommendations based on soil analysis. During the second or third year, however, yields began to decline rapidly. Soil analysis identified two possible factors ... lime, and ... magnesium." If yields can suffer from misassessment of nutrient needs in an experimental plot closely monitored by a highly qualified team of research agronomists, one would expect such crop yield declines to be much more frequent in the fields of Amazonian farmers. Failures would be higher because of the uncertain supply of inputs and information about which inputs are needed.

Separate information is needed for each field in order to make the system work properly. Sánchez *et al.* (1982: 824) state that "the timing of the appearance of soil fertility limitations and the intensity of their expression varied among the [3 test] fields, even though they were near each other, were on the same soil mapping unit, and had the same vegetation before clearing. The intensity of the fire during clearing is considered a factor contributing to this variability." The difficulty of getting results in time for appropriate corrective measures when only a few experimental fields are involved should give some indication of the magnitude of problems that would be faced by farmers in trying to extract such results from government-run soils laboratories and their associated bureaucracies. A parallel situation may be found in the difficulties of farmers on Brazil's Transamazon Highway in obtaining the release of credit disbursements at the appropriate time in the agricultural year (Moran, 1981).

Cultural limits

The idea that Amazonia might one day resemble the valleys of the Ganges or the Yangtze, with dense human populations supporting themselves on irrigated rice, points both to the importance of cultural limitations and to the great leeway that exists between physical limits and restraints on human populations. Amazonia is not likely to undergo such a transformation in the foreseeable future if only because the population that inhabits the region would have to undergo radical cultural changes to make the backbreaking routine of transplanting rice attractive. It is unlikely that Amazonian agriculture will change through transfusions of immigrants from other places where more intensive methods are already part of the cultural tradition. The Japanese immigrants at Tomé-Açu provide a good example (Fearnside, 1980a; Subler & Uhl, 1990), as do Gaúchos brought to the Transamazon Highway from the extreme south of Brazil by INCRA with the mistaken expectation that they would serve as a model for colonists from other parts of the country (Moran, 1981).

Cultural change leading to intensification or disintensification of agriculture has been the subject of much discussion among social scientists (reviewed by Brookfield, 1972). Boserup (1965: 62-63) pointed out the tendency of people who migrate from densely to sparsely populated areas to abandon the intense methods formerly employed in favor of extensive methods. This has often occurred in Amazonia, for example, among colonists who arrived on the Transamazon Highway from other parts of Brazil in the 1970s.

Educational limitations restrict the types of agricultural options that can be implanted. A case in point is the decision of the Cotrijui cooperative in 1986 to give up on a proposed silkworm-raising initiative in Mato Grosso because, according to officials of the cooperative, settlers in the area were considered to have insufficient education to master the technology.

LIMITS TO EXPANSION

Physical resource limits

Aside from limits of space, physical resources, such as phosphate deposits, restrict the areas to which different land uses can expand. Land-use decisions embody value judgments as to what use should be made of different pieces of land. When decisions are made at a regional scale, as in the economic-ecological zoning now underway in Brazil, the scale of the areas falling into different uses results in emergent properties that are not thought of at a micro level. A formula for making these decisions is not easy to arrive at in a way that guarantees "wisdom" in balancing the different roles that each location might play in the ecosystem and in society. The tendency of zoning methodology up to now, for example, has been to evaluate the different restrictions on agricultural choices imposed by soil quality, topography, rainfall, and other physical factors. The most fertile sites are then allocated to the most intense uses, while those with little agricultural potential are zoned as forest reserves.

The need for caution in designating areas for agriculture is illustrated by the question of agricultural expansion in Acre. Preliminary zoning maps produced by EMBRAPA indicate large areas for agriculture, including the western two-thirds of Acre (Brazil, EMBRAPA, 1988). A preliminary zoning by the Brazilian Institute for Geography and Statistics (IBGE) differs from that of EMBRAPA on its recommendations for most of Amazonia, but agrees that western Acre should be used for agriculture (Régis, 1989). This area's soils are believed to be better than those of most of Amazonia, at least at a very general scale. Acre is also the best area for establishing extractive reserves, both because of relatively high densities of forest trees that produce valuable products and because of better social organization among the forest's human inhabitants (Allegretti, 1990; Fearnside, 1989).

Land-use decisions based on permitting the maximum intensity that physical conditions will allow can quickly pass limits in other spheres when individual zoning allocations are considered together. Zoning is more than the sum of its parts. Misleading results can be expected from zoning methods that fail to include provisions for limitations of various types on the area that can be allocated for any given land use. One may examine each cell in a grid in a geographical information system (GIS), comparing the soil, rainfall, etc., with the demands of a given crop, and conclude that each individual cell can be allocated to the use in question, and yet arrive at a global conclusion that is patently unrealistic. This, for example, is the explanation of the conclusion that Brazil could support seven billion people, reached by a study conducted by the Food and Agriculture Organization of the United Nations (FAO), in collaboration with the United Nations Fund for Population Activities (UNFPA) and the International Institute for Applied Systems Analysis (IIASA) (FAO, 1980, 1981, 1984; Higgins *et al.*, 1982).

It is worthwhile examining the FAO/UNFPA/IIASA study in some detail, as the illusion embodied in it that Amazonia can be turned into a major breadbasket – an idea that long predates the FAO/UNFPA/IIASA study – is a persistent and pernicious one in Brazilian planning for the region. The study's results contain numerous glaring inconsistencies with reality, indicating that such efforts need to be based on more ground truth. The Brazilian Amazon is all mapped in the FAO/UNFPA/IIASA study as capable of supporting between one-half and one person per hectare at the present low-input level of technology, and between five and ten people per hectare with high inputs (fertilizers, mechanization and an optimal mix of rain-fed crops). These calculations lead to the conclusion that Brazil could support an incredible 7.1 billion people, were high-level inputs applied (Higgins *et al.*, 1982: 104). The implied possibility of converting the region to high-input mechanized agriculture runs up against limits of resource availability to supply the inputs. Amazonia has virtually no deposits of phosphates; transporting them is expensive and, when the vast extent of Amazonia is considered, quickly enters into conflict with the absolute limits of this resource. The temptation is strong to view Amazonia as a potential cornucopia capable of solving population and land distribution problems; the limits of applying the intensive agriculture suggested make this a cruel illusion (see Fearnside, 1990a). These limits are best illustrated by the inviability of applying to any significant part of Amazonia the Yurimaguas technology for continuous cultivation discussed previously.

One of the factors leading to the high carrying capacity values the study ascribed to Amazonia is the assumption that land quality in uncultivated areas is equal to that in already cultivated ones. The study goes so far as to claim that "there is evidence that the productivity of the reserves may be higher, but, for the sake of simplicity, it is assumed that the potential productivity of the unused land is the same as that of the land under cultivation" (FAO, 1984: 43). Unfortunately, as is true in most parts of the planet, the best land is brought into cultivation first, with land quality progressively declining in new settlement areas until only very marginal lands remain. In Rondonia, for example, 42% of the land in colonization projects settled in the 1970s was classified by a government soil survey as "good for agriculture with low or medium inputs;" for projects started in the first half of the 1980s, 15% of the land was so classed, while for planned areas the amount is a minuscule 0.13% (Fearnside, 1986b).

The FAO/UNFPA/IIASA study's implied recommendation that developing countries should encourage migration into tropical lowlands from more highly populated areas at higher altitudes and/or latitudes (e.g., FAO, 1984: 21) is likely to prove an environmental catastrophe, as similar programs already have in such countries as Colombia, Ecuador, Bolivia and Indonesia. The suggestion that "fragmented" land holdings must be grouped into "consolidated" properties as part of the transition to high-input agriculture (FAO, 1981: 16) would play havoc with the social function of many tropical settlement programs. The conclusions on human carrying capacity are affected by the study's lack of consideration of equity in the distribution of food produced, in addition to the active anti-equity bias of the land tenure system the report implicitly recommends.

The necessity of phosphate fertilizers makes prospects poor for maintaining the most common land use in deforested areas – cattle pasture – over large areas in Amazonia. In the early 1970s when the fiscal incentives program for Amazonian pastures was rapidly expanding, the agency that is now EMBRAPA maintained that pasture improved the soil (Falesi, 1974, 1976). Unfortunately, available phosphorus declines sharply from the peak caused by ash from initial burning of the forest; after ten years, levels of this critical element are at least as low as those under virgin forest and far below the amounts required by pasture grasses (Fearnside, 1980b; Hecht, 1981, 1983). In 1977 EMBRAPA changed its position that pasture improves the soil, recommending instead that productivity be maintained by applying annually 50 kg/ha of phosphorus, equivalent to about 300 kg/ha of superphosphate (Serrão & Falesi, 1977; Serrão *et al.*, 1979). The much greater productivity of pasture when fertilized with phosphate is obvious (Koster *et al.*, 1977). The problems are the cost of supplying phosphate and the absolute limits to minable stocks of this mineral.

A report on Brazil's phosphate deposits published by the Ministry of Mines and Energy indicates that only one small deposit exists in Amazonia, located on the Atlantic coast near the border of Pará and Maranhão (de Lima, 1976) (Fig. 2). In addition to the deposit's small size, it has the disadvantage of being made up of aluminum compounds that render its agricultural use suboptimal, but not impossible if new technologies were developed for fertilizer manufacture (dos Santos, 1981: 178). An additional deposit has been reported on the Rio Maecuru, near Monte Alegre, Pará, but estimation of its size is incomplete (Beisiegel & de Souza, 1986). Almost all of Brazil's phosphates are in Minas Gerais, a site very distant from most of Amazonia. Brazil as a whole is not blessed with a particularly large stock of phosphate – the United States, for example, has deposits about 20 times larger (de Lima, 1976). On a global scale most phosphates are located in Africa (Sheldon, 1982). Continuation of post-World War II trends in phosphate use would exhaust the world's stocks by the middle of the next century (Smith *et al.*, 1972; United States, CEQ & Department of State, 1980). Although simple extrapolation of these trends is questionable because of limits to continued human population increase at past rates (Wells, 1976), the conversion of a substantial portion of Amazonia to fertilized pasture would greatly hasten the day when stocks of phosphate are exhausted in Brazil and in the world. Brazil would be wise to ponder carefully whether its remaining stocks of this limited resource should be allocated to Amazonian pastures.

Large expanses of pasture can be expected to be subject to disease and insect outbreaks in the same way as other large monocultures. Switching the grass varieties planted can counter such problems to some extent, but the cost and frequency of such changes can be expected to increase. *Brachiaria decumbens* (*braquiária*), a pasture grass formerly common on the Belém-Brasília Highway, was devastated in the early 1970s by outbreaks of the homopteran known as *cigarrinha* (*Deois incompleta* Ceropidae). Guinea grass or *colonião* (*Panicum maximum*) became a favorite in the area, and its performance was described by EMBRAPA as

Fig. 2 — Phosphate mines and deposits in Brazil (from de Lima, 1976). The deposit in the Maecuru River valley is from Beisiegel & de Souza, 1986.

"magnificent" (Falesi, 1974). Yield declines later became apparent as available phosphorus depletion and invasion of weeds proceeded. Weed invasion in *Panicum maximum* is facilitated by the bunchy growth habit of this species, which leaves bare spaces between the tussocks of grass and by poor germination of seeds produced by the grass in the field. By the 1980s, *cigarrinha* had adapted to *Panicum maximum* as well, but not yet at the devastating levels reached in *Brachiaria decumbens*. In the late 1970s EMBRAPA began recommending creeping signal grass or *braquiária da Amazônia* (*Brachiaria humidicola*). This species was at first tolerant of *cigarrinha* attack, but the insects have become increasingly well adapted to this species. EMBRAPA now recommends *brizantão* (*Brachiaria brizantha*) and andropogon (*Andropogon gayanus*) pasture grasses. The continual changing of species and fertilizer recommendations does not change the basic characteristics of pasture that make its sustainability doubtful.

The sustainability of pasture, as well as its social and environmental impacts, are closely tied to the potential size of these areas. A small area of pasture can be maintained on imported nutrient inputs while a large one cannot. A small area would cause climatic impacts that are within the capabilities of natural systems to correct or absorb, whereas a large area would at some point trigger processes that lead these equilibria to degenerate (Fearnside, 1985, Salati & Vose, 1984). The most worrisome characteristic of pasture is that there is no immediate limit to thwart its continued expansion. Unlike annual and especially perennial crops, market limits for the system's products are unlikely to halt its expansion: the demand for beef is tremendous and would be even greater if more meat were to become available. The availability of labor also does not restrain pasture as it does other crops because of low labor demands of extensive systems used in Amazonia (Fearnside, 1980c, 1986a). Pasture's dominance among land-use choices allows a small human population to have maximum impact on deforestation (Davidson, 1987: 8; Fearnside, 1983a).

Input limitations set strict bounds on the expansion of all fertilizer-demanding agricultural systems, including agroforestry systems (Fearnside, 1995a). Markets for the products would restrict the expansion of many land uses (especially perennial crops, such as cacao) that might otherwise be desirable choices from the standpoints of sustainability and environmental impact.

Market limits, reflected in falling cacao prices since 1977, make the advantages of cacao (e.g., Alvim, 1981) unlikely to continue for long even in the small portion of Amazonia that is presently devoted to this land use, let alone in other areas that might be zoned for expansion of cacao plantations. In Rondonia, the primary cacao-growing area in Brazilian Amazonia, the World Bank's POLONOROESTE project (a regional development project that included paving the BR-364 Highway), had cacao as the mainstay of its agricultural program. The Bank's proposal for POLONOROESTE, written *before* the project was launched, projected the decline in cacao prices that, in fact, has since occurred as predicted (IBRD, 1981).

Limits of social values

Henry Walter Bates (1863), the great nineteenth-century naturalist who mistakenly believed that Amazonian soils were fertile, marveled that in Amazonia a [white] farm owner could make an acceptable living with less than dozen slaves. Social values have obviously changed since the time of Bates to exclude production systems based on slavery, or at least the type of slavery that was abolished in Brazil in 1888. The limits of social acceptability are not static. The "slavery" of charcoal workers in the Grande Carajás area, for example, represents a system that sooner or later must come to an end on the grounds of social justice. Denunciations of slavery in Brazil before the International Labor Court in Geneva in 1994 provoked a continuing scandal involving Brazil's charcoal industry (Sutton, 1994; Pachauski, 1994; Pamplona & Rodrigues, 1995). The question of whether other socially questionable practices should be accepted as givens has profound implications for what limits production. Changes in Amazonia's land tenure situation and practice of land speculation would greatly affect the direction of development. The amount of land "available" for intensive development also depends on whether it is regarded as acceptable to obliterate indigenous cultures.

Institutional limits

Institutional limits to development take many different forms. One example is the institutional limitation imposed by extension and other support services for agriculture. These include infrastructural limits, such as the impracticality of soil laboratories being able to attend the demand that would be needed to extend the Yurimaguas technology to wide areas. They also include cultural limits, such as the refusal of extension agents to visit farms beyond reach of their vehicles. The cultural barriers to communication between extension agents and small farmers in Amazonia are sufficient to negate almost all effect these agents might have (see Moran, 1981; Fearnside, 1986a).

Financing, ranging from bank loans for small farmers up to major international loans for development projects, represents a limiting factor for many kinds of land use. The limited nature of funds available for allocation through financial institutions obviously poses a limit to the level of financing. This is not the only kind of limitation, however.

In the case of financing for agriculture, bureaucratic restrictions on loans commonly rule out financing for the poorest layers of society. Land titles are normally required by banks financing agriculture, and the poorer farmers are least likely to have these. Various kinds of guarantees demanded for "high risk" initiatives can also stand in the way. An example is the demand (relaxed in 1995) by the German government for guarantees in case of misuse of funds by the various cooperatives and other nongovernmental organizations to be funded through the demonstration projects (PD/A) sector of the Pilot Program to Conserve the Brazilian Rain Forest.

One institutional limit that affects major international development loans is that of institutional credibility. This acts as a limiting factor when loans are not approved (or not contemplated) due to lack of trust in the commitment of implementing institutions to respect environmental limits. Such lack of trust can have a firm basis in fact, and bears some examination.

Brazil, like many other countries, has a regulatory system governing evaluation and approval of proposed development projects. This system is composed of a series of decrees, laws and constitutional provisions, and is designed to assure that wise development choices are made. Components of the system include the requirement since 1986 that proposed major developments be examined through an Environmental Impact Report (RIMA) and a Study of Environmental Impacts (EIA). Unfortunately, many of the mechanisms that make up this system have failed repeatedly in specific instances to fulfill their role in guaranteeing environmental protection. Strengthening the regulatory system would be necessary to relax the limiting effect that lack of credibility places on multilateral bank financing.

An example is provided by the improvement of the BR-429 highway in Rondonia. This road, connecting Presidente Medici with Costa Marques, opens the Guaporé River Valley to settlement. Virtually none of the land opened by the road is suitable for agriculture with low or medium inputs, and settlement could only be expected to bring severe agricultural, social and environmental problems (Fearnside, 1986b). Because all Rondônia, including the Guaporé Valley, is part of the area of influence of the World Bank-financed POLONOROESTE project, the Brazilian government had committed itself to protecting the environment in all of this area when it accepted financing for POLONOROESTE (which rebuilt the BR-364 highway linking Cuiabá with Porto Velho and provided associated development funding). When the plan to improve the BR-429 road for all-weather traffic became a public controversy, the Governor of Rondonia made a solemn public statement before World Bank representatives that the BR-429 would not be improved (witnessed by this author, 16 Sept. 1987). A few months later the improvement had taken place nevertheless.

Aside from discrepancies between discourse and action, environmental protection may be an impossibility even when action is taken. No matter how sincerely government authorities may swear that deforestation will be avoided in any given development project, much of the clearing process remains outside government control. For example, a road through a reserve to open up an area on the other side may appear as a good idea when listening to the solemn guarantees of government agencies that no settlement will be allowed along the road, but developments in practice are apt to be different once the road is built. The best example is the road through the

Cuyabena Reserve in Ecuador for opening oil fields initially developed by Texaco.

How to control deforestation is one of the most important and most difficult problems for any development policy. In the Brazilian Amazon a tradition prevails that is over 400 years old of complete disregard for any law designed to preserve the flora and fauna of the area (Sternberg, 1973). In all of Brazil the law is perceived as something which is only to be applied to "enemies," and which can always be avoided by means of the omnipresent *jeito* (Rosenn, 1971). A tradition exists dating from colonial times of maintaining thousands of laws technically in force, and only applying a few of them. These problems make it difficult to formulate effective laws to control deforestation, and it is not reasonable to expect that this context of the problem will change in the near future.

Limits on human habitation

Human health problems, particularly malaria, have kept wide areas of Amazonia from being densely settled over the past five centuries. In small farmer settlement areas today, malaria has a significant impact on agricultural production (and on the dependability of that production) by incapacitating key family members at the time of year when their labor is needed for specific agricultural tasks. The effect of human health on labor supply and ability to perform agricultural tasks has been quantified for Transamazon Highway colonists (Fearnside, 1978, 1986a) using data on the seasonality of hospital admissions in Altamira (Smith, 1976).

Land conflicts represent a limit on agricultural activities in many parts of the region. In areas such as the *Bico do Papagaio* region in northern Tocantins, which is notorious for bloodshed over conflicting land claims, some types of development would be difficult. Even in the absence of land conflicts, rapid turnover in settler populations adds an aspect of instability to land uses that require maintaining a consistent management system over a long period.

Limits to risk

Environmental Risks

Environmental impacts limit the allocation of land to many uses. Susceptibility to soil erosion, for example, is a straightforward constraint. Allocations may affect nearby areas as well, as when small farmers are placed in close proximity to natural forest reserves. Invasion of reserve areas often follows, making use of the road infrastructure implanted for the small farmers. Examples include the Sete de Setembro Indigenous Area near Cacoal and the Uru-Eu-Wau-Wau Indigenous Area near Ouro Preto do Oeste (both in Rondonia). Interposition of silviculture has been suggested as an effective barrier where this land use is viable (Fearnside, 1983a; Davidson, 1987: 8). Small farmers are not alone in their impact on nearby forest areas: burning of cattle pastures on large ranches can lead to fires entering adjacent forest, especially if it has been selectively logged (Uhl & Buschbacher, 1985).

Limiting factors imposed by the need to meet environmental quality standards should be interpreted in terms of conceptualization of the landscape as a mosaic of different areas where different criteria apply, including requirements for environmental quality (Odum, 1969; Eden, 1978; Fearnside, 1979b). This vision fits well with the current paradigm of buffer zones around conservation units, with different levels of biodiversity and other aspects of the original ecosystem maintained in concentric circles around the core areas (Sayer, 1991).

The most obvious limiting factor for expansion of agriculture and ranching in Amazonia is the area of forest that must be maintained intact. The different forms of land use imply environmental impacts (with distinct levels of impact depending on whether the land use proves to be sustainable). The impact of converting forest to another land use depends not only on the patch of land for which conversion is being considered, but also on what has been done with the remainder of the region. As the cumulative area cleared increases, the danger increases that each additional hectare of clearing will lead to unacceptable impacts. For example, the risk of species extinctions increases greatly as the remaining areas of natural forest dwindle. The role of Amazonian forest in the region's water cycle also implies increasing risk with the scale of deforestation: when rainfall reductions caused by losses of forest evapotranspiration are added to the natural variability that characterizes rainfall in the region, the resulting droughts would cross biological thresholds leading to major impacts (Fearnside, 1995b). These thresholds include the drought tolerance of individual tree species and the increased probability of fire being able to propagate itself in standing forest. Fire entry into standing forest in Brazilian Amazonia already occurs in areas disturbed by logging (Uhl & Buschbacher, 1985; Uhl & Kauffman, 1990). During the El Niño drought of 1982/1983, approximately 45,000 km^2 of tropical forest on the island of Borneo burned when fires escaped from shifting cultivators' fields. Of the 35,000 km^2 of this area in the Indonesian province of East Kalimantan, at least 8,000 km^2 was primary forest, while 12,000 km^2 was selectively logged forest (Malingreau *et al.*, 1985). In Amazonia, "mega-El Niño" events have caused widespread conflagrations in the forest four times over the past 2000 years (Meggers, 1994). The effect of large-scale deforestation is to turn relatively rare events like these into something that could recur at much more frequent intervals. How these dangers are incorporated into land-use decisions greatly influences the carrying capacity of the region for humans. If one assumes that the entire region could be converted to agricultural use without unacceptable consequences, then the carrying capacity one would calculate would be much higher than if one assumes that enough forest must remain intact to keep the risk of environmental catastrophes within defined limits.

Figure 3A shows the relationship between the magnitude of an impact and the maximum probability of the impact occurring that society is willing to accept. Small impacts, such as failure of a given crop, may be acceptable even if they occur every year (probability of 1.0), but society should insist on there being only a very tiny probability of a major catastrophe, such as a year dry enough to allow fire to destroy large areas of standing tropical forest. This is analogous to precautions against explosions or other major accidents involving nuclear power plants: only infinitesimally small risks are acceptable to society. The acceptability of risk to society (Fig. 3A) is not a scientific question, but rather a moral and political one that needs to be debated and decided in a democratic manner.

A rough sketch of the possible relationship of environmental risk to expansion of cleared area is given in Figure 3B. Unlike the relation of acceptable risk to magnitude of impact (Fig. 3A), the relation of risk to deforestation (Fig. 3B) is a scientific question; construction of a curve of this type based on field studies should be a high priority. As deforested area increases, the probability increases of a major perturbation such as a severe drought that exceeds the tolerance of many tree species adapted to a relatively stable climate.

The maximum permissible amount of deforestation can be calculated from graphs A and B of Fig. 3. Starting with the size of the impact that would be provoked by perturbation from deforestation, one can determine the corresponding maximum acceptable level of risk to society from Fig. 3A. One can then determine from Fig. 3B the percentage of forest that could be cut and still stay within bounds of this acceptable level of risk.

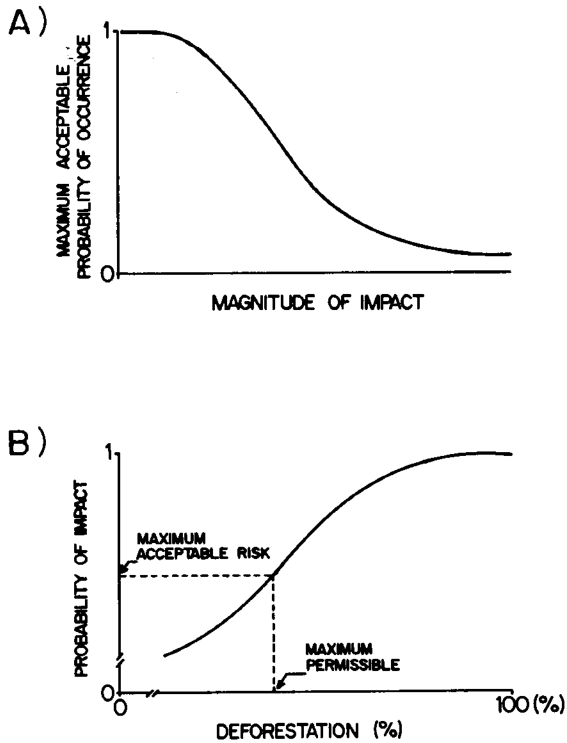

Fig. 3 — A) Relationship of the level of acceptable risk to the magnitude of the impact. Given that some of the consequences of deforestation are grave, the maximum acceptable probability of these impacts occurring should be low (Source: Fearnside, 1993b). B) The maximum percentage of deforestation permissible as determined from the maximum acceptable risk (this probability is determined from part A) (Source: Fearnside, 1993b).

Agricultural Risks

Development choices create risks not only for those participating in development activities and those living in the immediate vicinity of the projects, but also for third parties who may be thousands of kilometers away. For example, when cacao was promoted in Rondonia as the agricultural mainstay of the World Bank-financed POLONOROESTE project, the risk was substantially increased of witches' broom disease (caused by the fungus *Crinipellis perniciosa*) spreading to Brazil's principal cacao-growing region in former Atlantic forest areas of the state of Bahia. With direct bus service connecting Rondonia with Bahia, it was only a matter of time before the fungus jumped this geographical gap. The disease, in fact, entered Bahia in 1988, only seven years after the POLONOROESTE project began, and devastated cacao there over the course of the succeeding seven years. Undoubtedly, the loss to Brazil's economy represented by destruction of cacao in Bahia surpassed all economic gains from agriculture in the POLONOROESTE area.

Health Risks

Another example is the risk posed by onchocerciasis, or African river blindness, a disease that in South America is limited to the frontier between Roraima and Venezuela. The disease, thought to have been introduced to the area by missionaries who had worked in Africa, is spread by black flies (*Simulium* spp.) that occur over wide areas of Brazil. Isolated cases have already appeared in other parts of the country, such as Goiás, in gold miners returning from Roraima (Gerais & Ribeiro, 1986). If military plans go forward to maintain garrisons in the area and to open these frontier areas to colonization for geopolitical reasons, the risk would be substantially increased of major outbreaks of river blindness throughout Brazil.

LIMITS OF POLITICAL AND MILITARY INTERFERENCE

Rational planning may be based on perception of limits, leading to decisions, for example, not to encourage agricultural settlement in areas where low soil fertility and other aspects of agricultural site quality make predicted yields low. However, other sectors of Brazil's decision-making system may interfere, for example, for military or geopolitical reasons, to override this kind of rationality. The limits to development in portions of the region that are subject to this kind of alternative rationality are different from those that might be deduced in other areas. Government fiats cannot, however, override natural laws, such as the relationships between soil fertility and agricultural yield. They can alter the outcome of events, however, by supplying fertilizers and other inputs as subsidies and by inducing farmers to commit themselves to farming certain areas through promises of land titles and various forms of assistance.

Military development has a potentially important role in promoting projects that will lead to deforestation in frontier areas. It has also obstructed (but not completely impeded) demarcation of indigenous areas in a 150 km-wide strip along the borders, thereby facilitating the entry of gold miners (*garimpeiros*), loggers, squatters, and others in these areas (de Oliveira Filho, 1990).

Military plans for development are made independent of the zoning exercise, and also of the normal procedures for obtaining environmental clearance. This independence is not granted in the decrees that mandate zoning and environmental impact reports (RIMAs), but military developments are, in fact, executed with complete freedom. According to IBAMA staff, for example, in 1990 the army built a road cutting through the Pico da Neblina National Park without even consulting IBAMA (the agency responsible for national parks), let alone passing through the environmental review procedures required for highway construction.

Settlement of the area along Brazil's international borders has been an objective of the country's military for many decades. The best example of the danger of allowing military considerations to determine the location of settlement projects is the Sidney Girão Colonization Project, which was placed on Rondonia's border with Bolivia for strategic reasons in the early 1970s (Mueller, 1980). The poor soil in the area resulted in the lots being abandoned so rapidly that the government was unable to fill the project until all of the other settlement areas in Rondonia were overflowing with land-seeking migrants. The failure of the project has been officially recognized as being due to the poor soil (Valverde *et al.*, 1979).

Construction of the Northern Perimeter Road (BR-210), to open access to lands near Brazil's borders with Colombia, Venezuela and the Guianas, began 1973, but was halted in 1974. Disillusionment with the poor soils revealed by publication of RADAMBRASIL maps for the area contributed to this decision (Foresta, 1991: 28).

The Calha Norte Project to construct military bases and/or airstrips at 16 locations along Brazil's northern borders, was announced in 1986, and implementation proceeded without any environmental impact study – even though the entire project came into being after RIMAs had become mandatory. The area affected by bases such as these is potentially much larger than the surroundings of the military installations. Although not indicated in the project budget, the plan called for construction of highways and the promotion of settlements. The statement of motives (*exposição de motivos*) proposing the project to then-President José Sarney stated clearly that "it is fundamental that government action also contemplate increasing the road infrastructure ... and the increase of colonization in that border region" (Setubal *et al.*, 1986: 3). Once the roads are built, squatters and speculators can be expected to enter to cut the forest independent of any government policies, as has already happened repeatedly in other parts of the region (Fearnside & Ferreira, 1984). No part of the Calha Norte Project area is shown on RADAMBRASIL maps as being suitable for agriculture (Brazil, Projeto RADAMBRASIL, 1974-1977, Vols. 6, 8, 9, 11, 14).

In 1991, plans were announced for the Trans-frontier Highway, an 8000-km road which, for strategic reasons, would parallel all of Brazil's international borders in Amazonia (*Jornal do Brasil*, 12 August 1991). The project withered when funds were not approved by the National Congress.

In 1993, Brazil's top military leaders drafted a list of nine demands, with which then-President Itamar Franco concurred (*Folha de São Paulo*, 11 August 1993). The demands included the resumption of colonization in Amazonia and the "review" (i.e., reduction) of indigenous areas in the region.

In 1995, most of the functions of the Calha Norte Project were incorporated into plans for SIVAM – a major military project to maintain radar surveillance of Amazonian air space. Highways and settlements do not appear in the plans that have been made public to date. Although individual military proposals rise and fade with some regularity, pressure from military leaders for settlement along Brazil's Amazonian frontiers remains an unchanged feature of the political landscape in which development planning takes place.

GUIDELINES FOR RESEARCH AND ACTION

When confronted with the existence of a limiting factor, the normal reaction on the part of both decision-makers and researchers is to concentrate effort on finding a way to overcome the limitation. The question of whether or not the limit should be pushed back in the first place is normally not even considered. However, this basic question must be answered before any effort to overcome a limitation can make sense.

Once a decision has been reached that limits must be pushed back to some extent, then it is necessary to obtain information on the full range of factors that limit attainment of the defined development objectives. Information is needed on the unit costs and scaling effects of confronting each limitation. The simple reflex that all limiting factors must be beaten back is both wasteful and unwise. Once relevant information is organized and interpreted, the effectiveness, cost, and the social and environmental side effects of attacking the different limits can be compared.

Which limits should be respected and which should be fought against depends on what the limits are. For example, most would agree that limits such as obeying Brazil's labor laws must be respected, while lack of education and problems of inefficiency and corruption in institutions must be fought against. Agreement is less easy on other kinds of limits, such as those that involve allocation of public resources or the redistribution of land holdings. A common reaction is to view as givens the current highly unequal distribution of land tenure and any decisions based on military and geopolitical arguments, and to concentrate attention only on technical advances against soil restraints. I would suggest that soil and related physical conditions are much more "given" than are restraints that result from the country's social and decision-making hierarchy, and that the latter category is where attention should be focused.

What are the ingredients of a rational decision on the question of attempting or not attempting to overcome a limitation on development? The starting point must be a clear definition of the objectives of development. For example, if the objective of development is to provide a sustainable livelihood for the populations of the region, then little benefit will be achieved by augmenting the productivity or the life expectancy of cattle pastures on large ranches by supplying fertilizers and improving management. Many efforts to push back limits to agricultural crop production have as their rationale supporting an ever-larger population of farmers, for example, of immigrants who come to Amazonia from other parts of Brazil. This is not necessarily in the best interests of Amazonia's current population and their descendants. It would be better to recognize that the ability of Amazonia to support population is limited and to guide development in such ways that the population size and environmental impacts are kept within those limits (Fearnside, 1996b).

There is no such thing as sustainable development for an infinite number of people, nor for a fixed population that is infinitely rapacious. There is also no way that development aimed at increasing the size of the pie can address problems that are rooted in highly unequal distribution of the pie. Many physical limits represent restrictions that need to be respected and lived with rather than as an agenda of items to be attacked. Recognition of this fact forces one to face fundamental problems of development that many people would prefer not to think about – resulting in a tendency to deny the existence of limits. Admitting to the finite potential for growth of the pie does not condemn the poor to poverty, but rather condemns the rich to dividing the pie (Fearnside, 1993a).

A formidable array of limiting factors stands in the way of sustaining production in large areas of Amazonia if forests are converted to agriculture and ranching. This does not mean that the outlook need be gloomy for sustaining the region's current population, provided the means of support is derived from the forest itself rather than through replacing it with nonforest land uses. This author believes that the best long-term strategy for providing a sustainable basis of development for the current population of rural Amazonia and their descendants is to tap the potential monetary value of the environmental services provided to the rest of the world by the natural forests in Amazonia (Fearnside, 1997).

CONCLUSIONS

1. Limiting factors restrict both the intensification of agriculture and ranching uses and the scale to which these land uses can be expanded.

2. The expression of limiting factors on development is mediated through human planning. Perception of limits to agricultural yields and of the severity and probability of environmental impacts can lead to decisions to limit agricultural expansion.

3. Limits to intensification of agriculture include agronomic limits on per-hectare yields, technological limits and research, and cultural limits.

4. Limits to expansion of agricultural areas include physical resource limits such as phosphate deposits, limits of social values, institutional limits (including the credibility of institutions), limits on human habitation (such as health), and limits to environmental risks.

5. Limits from considerations in political and military spheres often override "rational" decisions based on land capability and environmental consequences. This kind of "interference," however, can cause a variety of impacts that, if properly evaluated, would likely make the net result of such development projects a negative one for Brazil's national interests.

6. While some limiting factors can be pushed back through technological advances and institutional changes, many of the restraints on agriculture and ranching development must simply be accepted and lived within. Rather than expansion of agriculture and ranching, other strategies should be pursued to support Amazonia's population, especially by tapping the value of the environmental services of intact forest.

Acknowledgments — This paper was presented at the "Workshop: Sustainable Biosphere Project: Amazon Basin Case Study," 18-20 June 1996, Manaus, Amazonas, Brazil. I thank the conference organizers for permission to publish this version. Portions of the text have been adapted from Fearnside, 1987, 1990a and 1990b. E. Salati and S. V. Wilson made valuable comments on the manuscript.

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