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HUMAN CARRYING CAPACITY ESTIMATION IN BRAZILIAN AMAZONIA AS A BASIS FOR SUSTAINABLE DEVELOPMENT

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SUMMARY

Sustainable development requires that population and consumption remain within the limits of carrying capacity, while preventing a decline in the carrying capacity of an area requires that productive systems implanted through development be sustainable. Zoning can be a valuable tool in influencing land-use decisions, but we cannot expect government decrees to be capable of causing the landscape to evolve toward the sustainable patterns which have been recommended through zoning. A prerequisite for influencing land-use change is understanding the social processes involved in land-use decisions, beginning with deforestation dynamics. Work to estimate carrying capacity needs to embrace the wide variety of production systems used and contemplated for Amazonia and to be able to interpret this information at scales ranging from local communities to the region as a whole. This will require not only studies of different land-use systems in rural areas, but also integration with studies of energy use and support limits of urban populations. Risks of environmental impacts must be quantified under different development scenarios, and limits of acceptable risk identified and integrated into analyses of carrying capacity.

Tapping the value of environmental services of standing forest represents a promising means of sustaining Amazonia's population over the long term, but numerous obstacles exist. These include halting deforestation before opportunities are lost and supporting the population in non-damaging ways while the institutional groundwork is laid for using the environmental services involved. Research is needed to quantify the magnitude of services and the appropriate monetary value per unit of service. Diplomatic agreement must be reached on these values, which can be expected to be quite different from estimates of the 'true' values based on research. A series of social arrangements must be proposed and implemented if the value derived from environmental services is to fulfil its dual role of maintaining both the forest and the human population in Amazonia.

Keywords: human carrying capacity; Brazil; Amazonia; human population; tropical agriculture; rainforest

INTRODUCTION

Sustainable development and carrying capacity

The present paper explores the relationship between carrying capacity and sustainable development and the challenges to estimating carrying capacity and to applying carrying capacity findings to influence the course of development in the region. An important factor for the future will be the extent to which the potential value of environmental services can be tapped as a basis for supporting the population.

Forests in Brazil's 5 X 10^6 km^2 'Legal Amazon' region (Fig. 1) represent a tremendous potential resource for sustainable development, but only if the forests remain standing. "Sustainable development" means different things to different people, but here will be used in the sense of creation of a basis for lasting support of a population. Sustainable development requires specification of the minimum acceptable levels of consumption and environmental quality, and the maximum acceptable risk that these standards will not be met. In order to be 'development', the population involved must be supported in the region in question, which in this case is Amazonia; export of commodities with minimal returns to the people of the region is not development, even if highly profitable for some and even if, as is rarely the case, production can continue indefinitely. Although the term 'development' has been misused as a synonym for 'growth' by many sustainable development proponents (see review by Whalers 1994), development does not necessarily require continual increase in the economic system's throughput of matter and energy. Such growth is ultimately limited, obliging further development to take the form of changes in the way resources are used and benefits distributed (Goodland & Ledec 1987).

[Figure 1 here]

Sustainable development requires that population and consumption remain within the limits of carrying capacity, while preventing a decline in the carrying capacity of an area requires that the productive systems implanted through development be sustainable. Of course, sustainable development has additional requirements beyond stable population and resource demand (e.g., Barbier 1987), and maintaining carrying capacity requires more than having sustainable production systems. Nevertheless, carrying capacity and sustainable development are tightly linked.

The term 'carrying capacity' has been used in a variety of ways, sometimes referring to an <u>instantaneous</u> relationship between available resources and the consumption requirements of a population, as in the logistic equation of population biology (e.g., Wilson & Bossert 1971). In the present paper, however, the term is used exclusively with reference to <u>sustainable</u> levels of population and consumption. Carrying capacity in the present case refers to the number of people that can be supported for an indefinite period, given assumptions concerning production technology and the population's levels and patterns of consumption.

Carrying capacity is not fixed, but neither is it infinitely expandable (Cohen 1995). Carrying capacity can be increased through changes in the ways resources are used and distributed. Carrying capacity can also decline through environmental degradation, through increasing inequality in the distribution of resources, and through adoption of inefficient use patterns like cattle pasture, all of which are occurring in Amazonia today. Cattle pasture has little chance of proving to be sustainable, particularly if its phosphate demands are extrapolated to large areas (Fearnside 1979a, 1980), and it also plays a key role in the concentration of land tenure (Fearnside 1985a; Hecht 1985). Cattle pasture dominates land-use transformations today; if present patterns continue unchanged, the landscape would eventually approach an equilibrium of 44% productive pasture, 5% degraded pasture and 45% secondary forest derived from pasture, and only 4% farmland and 2% secondary forest derived from agriculture (Fearnside 1996a).

Sustainable carrying capacity can be operationally defined in terms of a gradient of probabilities of failure (Fig. 2). Failure rates are those sustainable over some long time period at the corresponding human population densities. The criteria for failure can be defined in a variety of ways and can include multiple limiting factors or combinations of factors. They can include measures of environmental degradation as well as individual consumption. The maximum acceptable probability of individual failure, as well as the criteria for failure, can be chosen in accord with socially-defined values. Probability of failure increases with human density in a hypothetical relationship that should apply within some range of possible human densities. Note that the curve in Fig. 2 rises to a failure probability of one on meeting the vertical axis. The probability of failure would be expected to rise at low population densities because the probability of failing to maintain adequate consumption standards would increase due to difficulties from lack of infrastructure, cooperation, and other benefits of society.

[Figure 2 here]

Once a maximum acceptable probability of individual failure has been selected (P in Fig. 2), the carrying capacity (K) is the corresponding population density above which density-dependent effects cause the combined (density-dependent and -independent) probability of failure to exceed this maximum value. In a case where extremely high levels of risk cause the curve to exceed the maximum acceptable probability of individual failure at all points, a reasonable solution would be to select the minimum probability of failure as the point corresponding to K.

Any strategy for sustainable use of Amazonian rainforest must begin with consideration of human carrying capacity. Each possible sustainable type of forest or land use implies the capability to supply commodities at a given rate and to provide employment to a given number of people. Since we are is assuming that the land-use systems in question are sustainable, we may use these levels of benefit in conjunction with specifications concerning the average, the distribution and the minimum acceptable level of consumption per capita to calculate carrying capacity. However, in reality, no form of land use can be considered sustainable with complete certainty, each form having a given probability of proving unsustainable at some future time. The way this possibility is calculated and weighted will affect the decision as to the best strategy for sustainable use of the forest, and the corresponding carrying capacity.

The different forms of land use also 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 (e.g., MacArthur & Wilson 1967). The role of Amazonian rainforest in the region's water cycle also implies increasing risk with the scale of deforestation (e.g., Salati & Vose 1984): 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 1995a). These thresholds include drought tolerance of individual tree species, and 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 were primary forest, while 12 000 km^2 were selectively-logged forest (Malingreau et al. 1985). In Amazonia, events described as mega-El Niños have caused widespread conflagrations in the forest four times over the past 2000 years (Meggers 1994). The effect of large-scale deforestation would be to turn relatively rare events like these into something that could recur at much more frequent intervals. Droughts would be more frequent because, with reduced water vapor supply, the smaller El Niños that occur more frequently would reduce available water to levels below critical limits for plants. How these dangers are incorporated into land-use decisions greatly influences the carrying capacity of the region for humans. If we assume that the entire region could be converted to agricultural use without unacceptable consequences, then the carrying capacity calculated would be much higher than if we assume that enough forest must remain intact to keep the risk of environmental catastrophes within defined limits.

Land-use decisions and zoning

Decisions on land use will constrain the carrying capacity of the region. These decisions are mostly made by individual actors such as landless migrants, colonists in government settlement areas, ranchers, loggers and land thieves (grileiros). Some influence over this process is exercised by the government through its decisions on road building, financing agricultural and ranching activities, enforcing environmental regulations, and zoning. While zoning can be a valuable tool in guiding land-use decisions towards sustainable options, we cannot expect government decrees to be capable of causing the landscape to evolve toward the patterns recommended through zoning. Understanding social processes involved in land-use decisions is necessary, beginning with an understanding of the dynamics of deforestation.

Ecological-Economic Zoning (ZEE) is being done for the entire region under the coordination of the Secretariat of Strategic Affairs (SAE). As with any zoning, this necessarily embodies value judgments as to what use should be made of different pieces of land. 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. To date, the tendency of zoning methodology has been to evaluate the different restrictions on agricultural choices which are 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 zoning areas for agriculture is illustrated by the question of agricultural expansion in Acre (Fig. 1). Preliminary zoning maps produced by the Brazilian Enterprise for Agriculture and Cattle Ranching Research (EMBRAPA) indicate large areas for agriculture, including the western two-thirds of the state of Acre (Brazil, EMBRAPA-SNLCS 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). Both indicated the western two-thirds of Acre as recommended for agriculture. In Acre this area is commonly known as the 'filet mignon of Amazonia' because its soils are believed to be better than those of most of Amazonia, at least at a very general scale. Probably unintentionally, the 'filet mignon' analogy also reflects the predatory approach to agriculture in the region, perhaps more accurately than it reflects soil quality. Even if the soils were as good as their reputation, it is by no means a foregone conclusion that this particular piece of meat should be devoured. 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 1989a). Brazil's 'extractive reserves' are areas of forest owned by the federal government but managed collectively by rubber tappers, Brazilnut gatherers and other collectors of nontimber forest products.

The question of whether or not extractive reserves should be established in this area illustrates well the conflict between zoning based on maximizing production of commodities from the land and that based on the achievement of environmental ends. Extraction of non-wood forest products is often criticized as an activity only leading to poverty and backwardness. However, I would submit that extractive reserves deserve support, first because the proposal for these reserves comes from the nontimber forest product users themselves rather than being handed down from above to force these populations to remain 'backwards', and, second, because the rationale for government support is based on the environmental benefits of forest rather than on the value of material commodities produced for the market. For this reason, extractive reserves are created by the parks and reserves sector of the Brazilian Institute for Environment and Renewable Natural Resources (IBAMA) rather than by the National Institute for Colonization and Agrarian Reform (INCRA).

Zoning decisions based on permitting the maximum land-use intensity that physical conditions will allow can quickly pass limits in other spheres when the sum of individual zoning allocations is considered together. Zoning is more than the sum of its parts. Misleading results can be expected from methods for zoning that fail to include provisions for limitations of various types on the area that can be allocated for any given land use. We may examine each cell in a grid in a geographical information system (GIS), comparing factors including the soil and rainfall 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 thousand million 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); the study is discussed in the next section.

Problems of scale in carrying capacity estimation

Most studies of human carrying capacity in Amazonia have thus far been at very local levels, such as studies of shifting cultivation by indigenous tribes (e.g., Carneiro 1960) or by traditional non-indigenous (*caboclo*) farmers (Gourou 1966, p. 45). In a study of small farmers in government colonization areas, a stochastic model was developed which took into account the probability distributions associated with the various climatic, soil, behavioural and other factors affecting crop yields and land use (Fearnside 1986*a*). While this approach demonstrates the importance of variability, a factor omitted from previous methods of carrying capacity estimation, the KPROG2 model developed for these estimates (Fearnside 1979*b*) is too demanding of site-specific data to be readily transferred to much wider areas. It nevertheless serves as a starting point for work at other scales. More general models are needed for setting regional policies on population and development. It also shows that agriculture in Amazonia is not likely to form the basis for supporting dense populations.

To date, what has been done at a regional level contains substantial distortions which arise from much oversimplification. The FAO/UNFPA/IIASA study estimated carrying capacity in 117 countries throughout the tropics (FAO 1980, 1981, 1984; Higgins *et al*. 1982). It is worthwhile to examine the study in some detail, as the illusion embodied in it that Amazonia can be turned into a major 'bread-basket', an idea that long pre-dates the FAO/UNFPA/IIASA carrying capacity estimates, is a persistent and pernicious one in Brazilian planning for the region. The study's results (Higgins *et al*. 1982) contain numerous significant 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, including fertilizers, mechanization and an optimal mix of rain-fed crops. These calculations lead to the conclusion that Brazil could support 7.1 thousand million people if high levels of inputs are applied (Higgins *et al*. 1982, p. 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, phosphate requirements quickly enter 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 pertaining to the intensive agriculture suggested make this a cruel illusion (see Fearnside 1990*a*). These limits are best illustrated by the inviability of applying to any significant part of Amazonia the 'Yurimaguas technology' for continuous cultivation that has been under test in the Peruvian Amazon (Nicholaides *et al*. 1985; Sánchez *et al*. 1982; see Fearnside 1987, 1988; Walker *et al*. 1987).

Input limitations set strict bounds on expansion of all fertilizer-demanding agricultural systems, including agroforestry systems (Fearnside 1995b). Markets for the products would restrict 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 environmental advantages of cacao 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. When drawing conclusions about carrying capacity, we must not only consider the limits to sustaining population per unit area of land use implanted, but also the extent to which each land use can be expanded within the limits imposed by macroeconomic effects, physical resources for inputs, and climatic and other environmental impacts.

One of the assumptions leading to the high carrying capacity values the FAO/UNFPA/IIASA study ascribed to Amazonia is 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, p. 43). Unfortunately, as is true in most parts of the earth, the best land is brought into cultivation first, with land quality progressively declining in new settlement areas until only very marginal lands remain. In Rondônia, 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).

RESEARCH PRIORITIES

Studies of different systems and at different scales

Detailed work on carrying capacity needs to be done in areas where different land-use systems predominate. In addition to the agriculture of small farmers that has received the most attention so far, important land-use systems include ranching, extractivism, logging and forestry management, perennial crops, silviculture, soybeans and charcoal manufacture. Mining, an inherently unsustainable activity, also needs to be better understood.

At the same time that detailed information is needed, much progress needs to be made on linking models at this level of detail with more general models for larger geographical areas. The problem of scale is crucial, as expanding population and agriculture have different effects when they reach the point where environmental impacts become more than local, and where agricultural output affects prices and other factors in the wider economy.

Limits to support of urban populations

Carrying capacity analyses need to be extended to include urban populations. The Amazonian population is already 58% urban (Brazil, IBGE 1992, p. 207). In addition to the need for agricultural and other products from the surrounding countryside, analyses of industrial societies inevitably point to strict limits linked which are to energy supply and use efficiency in the urban sector (e.g., Gever _et al_. 1986; Odum 1971, 1983). Brazilian Amazonia is fortunate in having tremendous potential for hydroelectric generation, although this potential is very unevenly distributed over the region. In addition, most planned dams are intended for transmission of power to cities outside Amazonia. The dams listed in Brazil's 2010 Plan would have a total installed capacity of 85 900 MW if all were constructed, independent of the projected year of completion (Brazil, ELETROBRÁS 1987; see Seva 1990, pp. 26-27). However, the impacts of many of the individual proposed dams would be tremendous, and their combined impact would be catastrophic (see Fearnside 1989_b_). They would flood 10 million ha, or about 2.5% of the forest directly, and roads built to them would threaten wide swathes of additional forest. Among other impacts, the dams would make significant contributions to global warming (Fearnside 1995_c_).

Amazonian cities have widely differing means of support (Becker 1995). Manaus, the region's second-largest city after Belém and with a 1992 population of about 1 million, has a highly artificial economy which is based on the incentives for industries offered since 1967 in the Manaus Free Trade Zone (SUFRAMA). Most of the industries produce electronic or other equipment which is assembled from components imported free of importation taxes, after which the products are shipped to southern Brazil for sale as domestically-produced merchandise. Economists are forced to conclude that 'except for the incentives and, to a much lesser extent, the supply of cheap labour, other reasons are hard to find to justify these companies staying on in Amazonia' (Pinto 1992, p. 132).

A more common pattern is one of cities which are dependent on exploitation of the surrounding agricultural land or forest. A good example is Itacoatiara in Amazonas (1992 population _c_. 60 000)(Fig. 1), which processes wood that is floated to the city's plywood and veneer industries from the Madeira River and from the Solimões (Upper Amazon) River and its tributaries. When considered in terms of 'emergy', which is embodied energy or energy memory (Odum 1988), the wood exported is worth 31 times more than the money received in return (Comar 1994). In effect, Brazil is being bled of its energy capital through international trade, a feature that also characterizes the country's economy as a whole (Odum & Odum 1983). The unsustainable nature of the harvest of raw materials makes the urban economies which it supports unsustainable as well. Replicating and strengthening analyses such as that of Itacoatiara would represent an important research contribution towards the eventual adoption of changes in the economic system such that rewards lead to maintaining population in sustainable ways with a minimum of environmental impact. Brazil has considerable diplomatic weight to press for such changes, and research can both help convince Brazilian authorities to use their influence in this way and increase the effectiveness of doing so.

The use of energy today indicates clearly that supporting urban populations in Brazil, and particularly in Amazonia, is not a priority in development decisions. Almost two-thirds of the power generated by the Tucuruí Dam is supplied at heavily subsidized rates to the largely foreign-owned aluminium industry in Barcarena, Pará, and São Luís, Maranhão. Tucuruí's 4000 MW installed capacity generates 2059 MW (18.03 tWh) annually (Brazil, ELETRONORTE no date [1992], p. 3); the 1985 energy use for aluminium manufacture was 625 MW in São Luis and 630 MW in Barcarena (Gitlitz 1993). Expansion of the mill's capacity at Barcarena (CVRD 1997) implies an energy use of 677 MW by 1996. Assuming 2.5% transmission loss (see Fearnside 1997a), 65% of the available output is used for aluminium. The tariff charged in 1985 was US$0.010/kWh (Lobo 1989), about one-sixth the rate charged to residential consumers. The quantity of employment generated by aluminium processing is minimal: there are 1200 jobs in Barcarena and 750 in São Luís. In 1986, the aluminium plant in Barcarena used 49.5% of all of the electricity consumed in the state of Pará (Brazil, ELETRONORTE 1987, pp. Amazonas-32 and Pará-12). The 'workers town' in Barcarena, including dependants and shopkeepers has a population of only 5000 people; this town consumes more energy than Belém, Santarém, and all of the other cities of Pará together. Construction of the Tucuruí Dam cost a total of US$8 thousand million when interest on the debt is included, according to the calculations of Pinto (1991, p. 158). Considering that two-thirds of the power produced is used for aluminium, Tucuruí alone, which is only a part of the infrastructure supplied by the Brazilian government, cost US$2.7 million per job created. Virtually any other use of electricity would bring greater benefits to Brazil (see Fearnside 1989b).

Limits to environmental impacts

The limitations posed by environmental impacts are a key factor influencing the type of development implanted and the carrying capacity of the area in question. Keeping environmental impacts within acceptable, often unspecified, bounds is a part of most definitions of 'sustainable development', such as that used by the Brundtland Commission (World Commission on Environment and Development 1987). A key problem is that, in practice, when the limit this implies is finally encountered, the decision is frequently to ignore or redefine the environmental limit such that whatever 'development' project is proposed can go ahead unhindered. Rhetoric concerning the necessity of development projects paying for their own environmental costs is usually rendered meaningless in the same way. The pig iron smelters in the Grande Carajás area, which cause a major impact, but produce a product of such low value that the smelters would be uneconomic except for government fiscal incentives have been a case in point. When asked about the smelters after a speech in which making development projects pay for their environmental impacts was called for. The answer of a former head of Brazil's Central Bank was quite clear: if paying for environmental costs would make an operation unprofitable, then the project would simply be allowed to continue destroying the environment for free rather than being shut down (C.G. Langoni, public statement 20 June 1989). The political reality revealed in the reply undermines any attempt to achieve sustainable development.

Environmental services

At present, economic activities in Amazonia almost exclusively involve taking some material commodity and selling it. Typical commodities include timber, minerals, the products of agriculture and ranching, and 'extractivist' products like natural rubber and Brazil nuts. The potential is much greater, both in terms of monetary value and in terms of sustainability, for pursuing a radically different strategy for long-term support: namely finding ways to tap the environmental services of the forest as a means of both sustaining the human population and maintaining the forest (Fearnside 1997b).

Among the environmental services provided by Amazonian forests, only three will be considered here, namely biodiversity maintenance, carbon storage, and water cycling. The magnitude and value of these services are poorly quantified, and the diplomatic and other steps through which such services might be compensated for are also in their infancy. These facts do not diminish the importance of the services nor of focusing effort on providing both the information and the political will needed to integrate these into the rest of the human economy. This integration should be conducted in such a way that financial forces act to maintain, rather than to destroy, the forest.

Biodiversity has many types of value. There are financial values associated with selling a wide variety of products. There are also use values of the products, because the value to humanity of a drug, for example, is usually much more than the profit that will be obtained by selling it. There are also existence values which are unrelated to any direct 'use' of a species and its products. People disagree on what value should be attached to biodiversity, especially those forms of value not directly translatable into traditional financial terms by today's marketplace (Meijerink 1995). While some may think that biodiversity is worthless except for sale, it is not necessary to convince such people that biodiversity is valuable; rather, it is sufficient for them to know that a constituency exists today and is growing, and that this represents a potential source of financial flows intended to maintain biodiversity (Ruitenbeek

1992).

Carbon storage, in order to avoid global warming through the greenhouse effect, represents a major environmental service of Amazonian rainforests. The way that this benefit is calculated can have a substantial effect on the value assigned to maintaining Amazonian forests. As currently foreseen in the Framework Convention on Climate Change (FCCC), maintaining carbon stocks is not considered a service, while only deliberate incremental alterations in the flows of carbon are. Even considering only this much more restrictive view of carbon benefits, the value of Amazonian forests is substantial. In 1990, Brazil's 13 800 km^2 y^{-1} rate of deforestation was producing net committed emissions of 274-285 million metric tonnes (t) of CO_2-equivalent carbon per year, and the benefit of slowing or stopping this emission is, therefore, substantial (Fearnside 1997c). For comparison, the world's 400 million automobiles emit 550 million t of carbon annually (Flavin 1989, p. 35).

Although a wide variety of views exists on the value of carbon, already enacted carbon taxes equivalent to US$45 t^{-1} in Sweden and the Netherlands, and US$6.10 t^{-1} in Finland indicate that the 'willingness to pay' for this service is already substantial (Schneider 1994). This willingness to pay may increase significantly in the future, when the magnitude of potential damage from global warming becomes more apparent to decision-makers and the general public. At the level indicated by current carbon taxes, the global warming damage of Amazon deforestation is already worth US$1.6-11.8 thousand million y^{-1}. The value of the global warming damage from clearing a hectare of forested land in Amazonia (US$1200-8600) is much higher than the purchase price of the land today.

Water cycling, the third category of environmental service, is different from biodiversity and carbon in that impacts of deforestation in this area fall directly on Brazil rather than being spread over the world as a whole. Several independent lines of evidence indicate that about half of the rainfall in the Brazilian Amazon is water that is recycled through the forest, the rest originating from water vapour blown into the region directly from the Atlantic Ocean (Salati et al. 1978, 1979; Villa Nova et al. 1976). Because recycled water is 50%, the volume of water involved is the same amount as flows in the Amazon River, which is by far the world's largest river in terms of water flow--over eight times larger than the second largest river, Africa's Congo River. Because of the earth's rotation, part of the water vapour is transported to Brazil's Central-South region, where most of the country's agriculture is located (Salati & Vose 1984). Brazil's annual harvest has a gross value of about US$65 thousand million, and dependence of even a small fraction of this on rainfall from Amazonian water vapour would translate into a substantial value for Brazil. Although movement of the water vapour is indicated by global circulation models (GCMs), the amounts involved are as yet unquantified (Eagleson 1986).

On many fronts, one of the major challenges to finding rational uses for Amazonian forest lies in gathering and interpreting relevant information. Making environmental services of the forest into a basis for sustainable development is perhaps the area where information is most critical. When comparisons are made among options for combating global warming, avoiding deforestation is much less frequently the approach chosen than, for example, planting trees in silvicultural projects. Even though the potential benefit of avoiding deforestation may be many times higher and the cost per tonne of carbon much lower than in tree-planting schemes (Fearnside 1995d), the latter is more convincing to those who make the choice, in part because of the greater certainty associated with plantations. Past experience allows reasonable assurance that investing a given amount in tree planting will sequester the promised amount of carbon, whereas no such assurance can be had that after investing in trying to slow deforestation there will be a given number of hectares less clearing in Amazonia. Providing better understanding of deforestation dynamics, as well as understanding deforestation's impacts on biodiversity, carbon storage and water cycling, is a necessary starting point on the long road to turning environmental services into a basis for sustainable development in Amazonia.

MAIN OBSTACLES TO SUSTAINABLE MANAGEMENT

Social obstacles

Social obstacles of many kinds reduce the likelihood of planned development strategies proving sustainable. One problem is the lack of discipline of the occupation process. Although we may imagine, for example, a scenario of farmers following an approved management plan of agroforestry and extraction of forest products, which might theoretically include sustainable harvests of timber, the reality is unlikely to unfold in this way for social reasons. This follows from a tradition which is over 400 years old in Brazilian Amazonia of complete disregard for any law designed to preserve the flora and fauna of the area (Sternberg 1973). Throughout Brazil there is also the problem of a system where the law is considered to be something which is only to be applied to 'enemies', and which can always be avoided by means of the omnipresent *jeito*, an informal bypass of the formal legal system (Rosenn 1971). There is a tradition dating from colonial times of maintaining thousands of laws technically in force, and only applying a few of them (Rosenn 1971). These problems make it difficult to formulate effective laws to control deforestation or to mandate sustainable management practices, and it is not reasonable to expect that this context of the problem will change in the near future (Fearnside 1979c).

Deforestation is the most ubiquitous land-use transformation in Amazonia today, and this process largely occurs outside government control (Fearnside 1997d). Deforestation precludes sustainable use of the rainforest, including use of its environmental functions. Contrary to the common view that clearing is the result of the poor trying to feed themselves, about 70% of Brazil's Amazonian deforestation is attributable to medium (100-1000 ha) or large (>1000 ha) ranchers (Fearnside 1993a). Because cattle pasture is by far the most common land uses replacing forest, and pastures on this scale are not sustainable, any strategy for sustainable development must include measures to halt deforestation (Fearnside 1990b). Obvious measures include levying and collecting heavy taxes on speculative profits from land sales, ceasing to recognize clearing, i.e. pasture, as an improvement (benfeitoria) for purposes of establishing land tenure, and removing various government incentives that still remain in effect despite a 1991 decree placing restrictions on new incentives (Fearnside 1989c, 1993a).

Another social obstacle to sustainable development is the inextricable linkage of certain kinds of production to intolerable injustices. For example, the charcoal industry for manufacture of pig iron in the Grande Carajás area of eastern Amazonia (Fig. 1) and in the state of Minas Gerais is based on a form of debt slavery that must sooner or later come to an end, even if the system were technically sound. Brazil's charcoal industry has provoked a national and international scandal following charges brought before the International Labor Organization in 1994 (Pachauski 1994; Ribeiro 1994; Sutton 1994; Pamplona & Rodrigues 1995). Such injustices surely make the system neither 'development' nor 'sustainable'.

Economic obstacles

Sustainable development proposals for Amazonia often focus on plans for sustainable management of forest for timber. These run up against fundamental economic obstacles that are inherent in the logic of the proposals. Brazil has been an active participant in the International Tropical Timber Organization (ITTO), and, like ITTO, its national policies have emphasized plans for sustainable management of tropical forests. IBAMA requires 'forestry management plans' as a condition for granting logging permits. Effectiveness of the programme is hindered by lack of guidelines as to what constitutes sustainable management, and by frequent differences between stated plans and field practices. Insufficient as they are, the management plans are better than the unfettered exploitation that would result from the proposals of logging interests intent on abolishing the requirements.

The underlying logic of increasing profits to loggers as a tool to encourage sustainable management is not supported by observed behaviour. Rather than restraining harvest intensity with a view to long-term returns, cutting is increased to capture short-term profits. The explanation of the lack of interest in commercial application of sustainable management systems lies mainly in the existence of alternative investment opportunities that pay higher returns on money invested than does waiting for future cycles of a long-term management system. The key comparison is between forest management and other possible uses of money, not between forest management and other uses of land. This is because money obtained by cutting all saleable timber from the forest as quickly as possible can be freely invested elsewhere in the wider economy (Fearnside 1989d).

The number of sawmills and level of timber extraction activity has increased dramatically in recent years, but is still much less than in forest areas in Asia (Browder 1989). This is because South-east Asian forests are characterized by a higher density of commercially-valuable trees (Nectoux et al. 1991). South-east Asian forests are dominated by a single plant family , namely the Dipterocarpaceae, making it possible to group the vast number of individual tree species into only a few categories for purposes of sawing and marketing. In addition, most Asian woods are light in colour, making them more valuable in Europe and North America where consumers are accustomed to light woods such as oak and maple. Amazonia's timber is generally dark coloured, hard to saw, and extremely heterogeneous; it has therefore been spared the pressure of large multinational timber corporations (Fearnside 1989d). Asian woods are usually of lower density than Amazonian ones, making them more suitable for peeled veneer (Whitmore & da Silva 1990). The approaching end to commercially significant stocks of tropical timber in Asia (Grainger 1990) can be expected to change this situation radically. FAO data (WRI 1994, pp. 310-11) indicate that, as of 1991, only 4.5% of internationally-traded roundwood came from all of South America, versus 38.2% from Asia. By the year 2000, Asian forests are expected to be depleted to the point where they can supply less than 10% of global markets (Grainger 1990); it seems likely that technologies would be developed to use Amazonian woods, whether consumers like them or not. In 1996, entry of Asian firms into Amazonia began in earnest: Brazil's Central Bank registered the entry of foreign capital totaling US$300 million during the first 10 months of 1996 for investments in the logging industry in Brazilian Amazonia, including land purchases (Anon. 1996a). Logging firms from Malaysia and China have purchased a total of 4.5 million ha of forest land in the state of Amazonas (Anon. 1996b). While I view increasing timber demand as a major threat to Amazonian forests, an alternative view holds that world demand for tropical forest timber may decline due to substitution from plantations (Vincent 1992).

Recognition of environmental services faces economic obstacles different from those facing timber management. Lack of progress on valuation of environmental services seriously limits the ability of this potential income source to serve as a means of supporting the population in Amazonia. Progress is needed both on research and diplomatic fronts, as well as in building public support for paying for environmental costs.

Biological obstacles

The environmental services must be estimated and included in the zoning decision algorithms. Services both of the forest and of the planted landscape that replaces it must be included. Spatial factors are important in this, both in terms of the location of each cell and in terms of the cumulative effect of other allocations.

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 (Fig. 3*a*), 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. 3*a*) is not a scientific question, but rather a moral and political one that needs to be debated and decided in a democratic manner.

[Figure 3 here]

Unlike the relation of acceptable risk to magnitude of impact (Fig. 3*a*), the relation of risk to deforestation (Fig. 3*b*) 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 that are adapted to a relatively stable climate.

The maximum permissible amount of deforestation can be calculated from Figure 3*a* and *b*. Starting with the size of the impact that would be provoked by perturbation from deforestation, we can determine the corresponding maximum acceptable level of risk to society from Figure 3*a*. We can then determine from Figure 3*b* the percentage of the forest that could be cut and still stay within the bounds of this acceptable level of risk.

One of the impacts of deforestation is contribution to global warming (Fearnside 1991, 1992). Global warming is one of the most serious problems facing the planet today (Houghton *et al*. 1990, 1992). Brazil's official estimates indicate that the country's deforestation contributes 1.4% of the global total of carbon dioxide entering the atmosphere (Borges 1992). However, this estimate omits a large portion, approximately 70%, of the emission from deforestation that occurs from decay of unburned biomass or from burning of biomass that is not combusted at the time of initial clearing (Fearnside *et al*. 1993). Inclusion of this and other factors omitted in the official estimates approximately triples Brazil's contribution to over 4% of the global total (Fearnside 1996*b*). By underestimating the global warming impact of deforestation, Brazil's official estimates understate the relative advantage of slowing deforestation versus planting eucalyptus. Expansion of silviculture is currently Brazil's principal proposal for contributing to the fight against global warming (e.g., USP-IEA 1990).

CONCLUSIONS

There is no such thing as sustainable development for an infinite number of people. Any strategy for sustainable development must therefore include recognizing and respecting the limits of carrying capacity. There is also no such thing as sustainable development if the area is all converted to non-sustainable land uses like cattle pasture. Halting the transformation of forest to pasture, which in the case of Amazonia is essentially the same as halting deforestation, is therefore a prerequisite. The process of deforestation needs to be better understood and should be a top research priority. However, no further research is needed to identify a number of obvious actions that need to be taken immediately, such as removing the motives for deforestation for speculative purposes, establishing land tenure, and the incentives that still remain.

One of the most promising means of long-term support for the population in Amazonia is by tapping the value of environmental services of standing forest. In order to do this, environmental services need to be assessed and their values incorporated into planning and zoning decisions.

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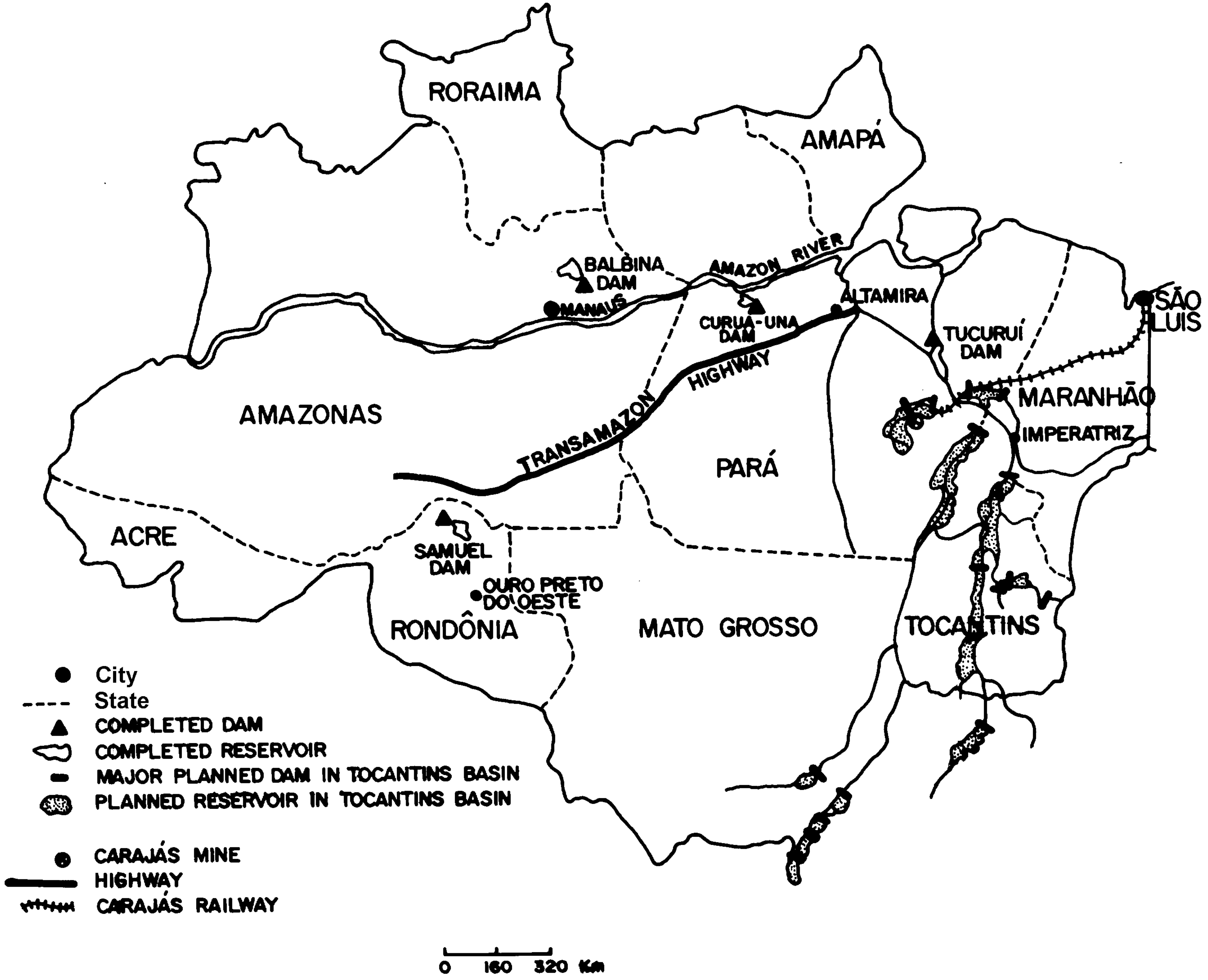
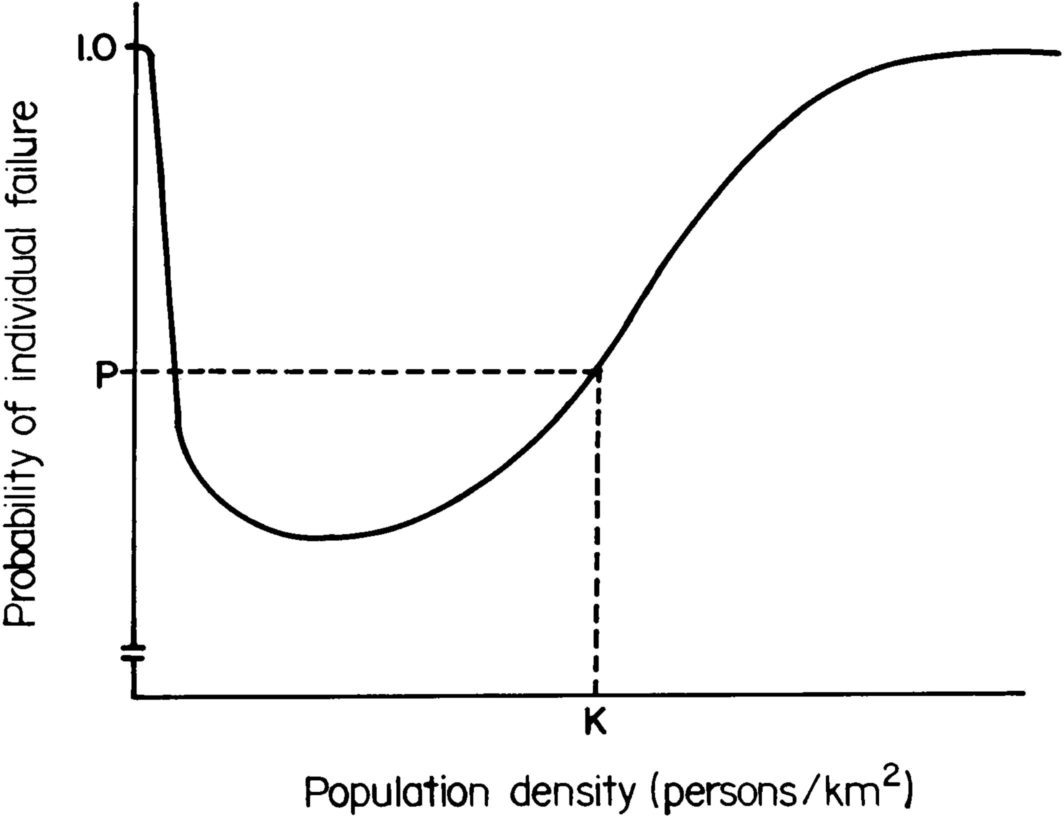
FIGURE LEGENDS

Figure 1 Brazil's Legal Amazon region.

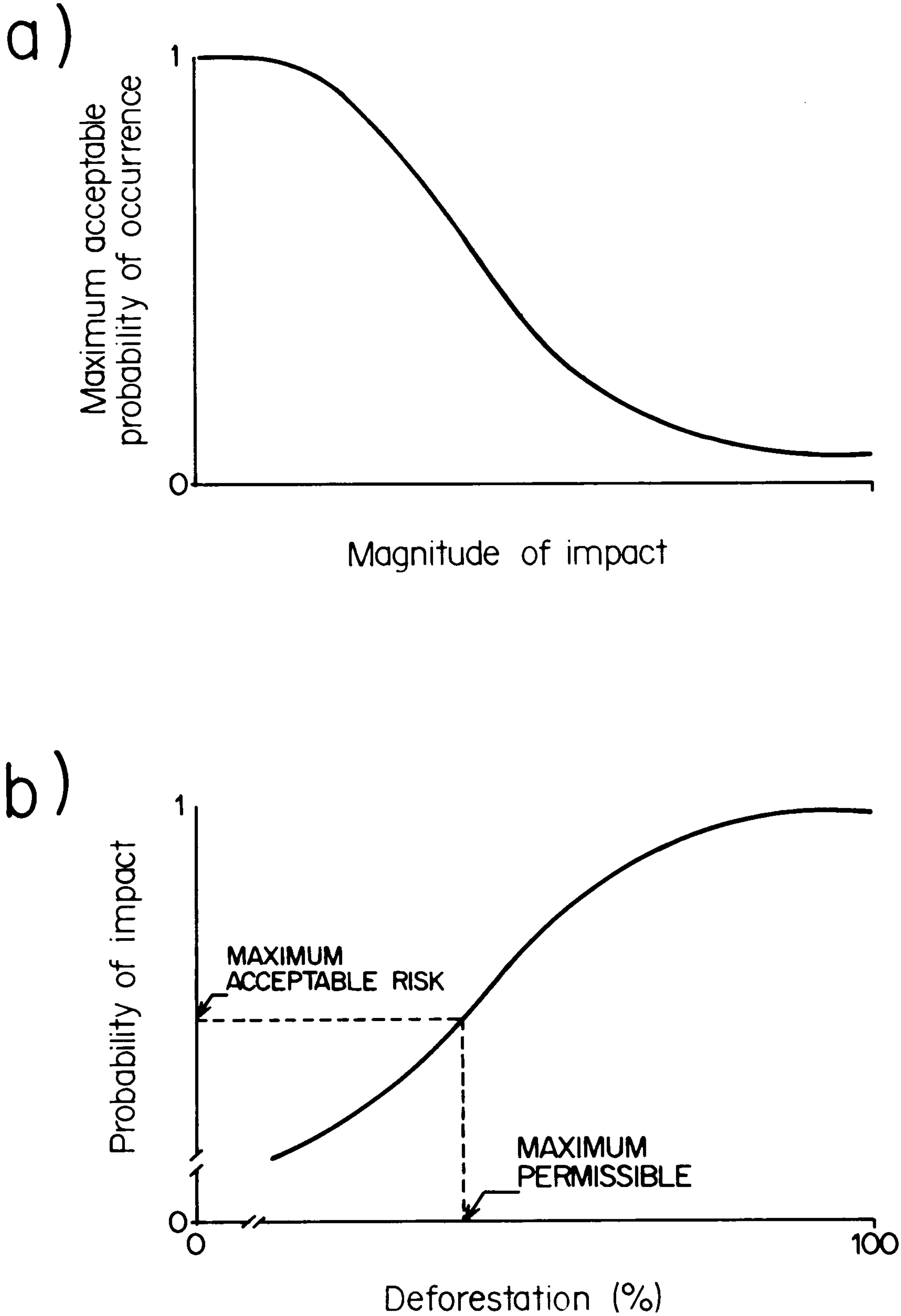
Figure 2 Carrying capacity, *K* as determined from the gradient of increasing probability of individual failure with human population density. Note that this hypothetical curve rises at low densities due to lack of infrastructure and other benefits of society. Carrying capacity (*K*) corresponds to the point where density-dependent increase in failure probability results in failure rates exceeding the maximum acceptable probability of individual failure ("P") (Source: Fearnside 1985*b*).

Figure 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 that these impacts should occur should be low (Source: Fearnside 1993*b*). (*b*) The maximum percentage of deforestation permissible as determined from the maximum acceptable risk (this probability is determined from part A) (Source: Fearnside 1993*b*).


RORAIMA
AMAPÁ
BALBINA DAM
AMAZON RIVER
MANAUS
CURUA-UNA DAM
ALTAMIRA
TUCURUÍ DAM
SÃO LUIS
MARANHÃO
IMPERATRIZ
AMAZONAS
TRANSAMAZON HIGHWAY
PARÁ
ACRE
SAMUEL DAM
OURO PRETO DO OESTE
RONDÔNIA
MATO GROSSO
TOCANTINS
City
State
COMPLETED DAM
COMPLETED RESERVOIR
MAJOR PLANNED DAM IN TOCANTINS BASIN
PLANNED RESERVOIR IN TOCANTINS BASIN
CARAJÁS MINE
HIGHWAY
CARAJÁS RAILWAY
0 160 320 Km



1.0
P
K
Probability of individual failure
Population density (persons/km2)


a)
1
0
Maximum acceptable probability of occurrence
Magnitude of impact
b)
1
0
Probability of impact
MAXIMUM ACCEPTABLE RISK
MAXIMUM PERMISSIBLE
0
100
Deforestation (%)