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by

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INTRODUCTION

The types of development that now prevail virtually throughout Brazilian Amazonia are transforming vast areas of forest to other ecosystems. This process is accelerating, and much of it is irreversible. The biome[†] that occupies practically all of Amazonia—tropical rain-forest (TRF)—is believed to be of very great (but inadequately quantified) value. The widespread devastation of this forest biome¹ is so worrisome to significant portions of Brazilian society that it has now become a matter of national controversy.

The controversy arose from the gradual and mostly recent recognition of the fact that some of the prevailing patterns of development in Brazilian Amazonia are dangerously unsound environmentally, and may well be commensurately uneconomic as well. It is also becoming recognized that, for many parts of Amazonia, a development programme which is both economically and environmentally desirable remains largely to be conceived. In recognizing these facts, the outgoing government of President Geisel proclaimed 1979 as the 'International Year of the Amazon', and the incoming government of President Figueiredo has solicited public debate on the issue for an interministerial work-group which was installed on 12 June 1979 and given 120 days to report. All sectors of the population have been called upon to contribute to the formulation of a new policy for Amazonia. The Congress of Brazil will be presented with the conclusions of this federal study, so that guidelines can be legislated for the future development of Amazonia.

The aim of this paper is to indicate some of the possible environmental costs and benefits of the various choices of development projects. Although much has been written on the economic aspects of development, environmental factors have frequently been regarded as 'externalities', if indeed they were considered at all. This paper shows that the environmental impacts of different types of projects vary so greatly that they can be crudely ranked, though such ranking should in no way be construed as promotion of particular development projects. On the contrary, I share the view that Brazil's

limited capital would improve future and present conditions more by allocation mainly outside Amazonia, while preserving the renewable resource-base and keeping options open for the future.

Nowhere in the world is the TRF biome being managed intact on a sustainable basis, except by tribal people such as the indigenous Amerindians. Furthermore, no one knows confidently whether, much less how, sustainability can be achieved at yields that significantly improve social well-being. Indeed, a view recently expressed in *Brazil* was that the only recourse at present is to leave the biome alone until research demonstrates how it can be managed for sustained yield.² Even ardent conservationists do not advocate inviolate protection in perpetuity of every square metre. The issue is to approach the optimal combination of projects over time, given changing human needs, the results of research, and opportunities arising elsewhere. Conversely, how much loss or expenditure of this otherwise potentially renewable resource is our generation willing to accept for future generations?

Although the economic value of the TRF biome may be large, the risks or costs of its destruction are becoming realized as extremely large, onerous, and more immediately tangible. In reality, development projects will continue and some will create adverse environmental impacts. This paper seeks to help choose, design, and locate, projects in such a way as to minimize these adverse impacts.

For both the degree and extent of transformation of the TRF biome, and also the likelihood of irreversible damage, the increase in human well-being or the amount of economic return accruing per unit area transformed, will probably be less in tropical rain-forest than in any other biome in the world. Calculated by orthodox analysis,³ no economically feasible type of development has yet been achieved which is compatible with conservation of the TRF biome. Conservation is here defined as management at a constant value, or for sustainable exploitation for human benefit.

BRAZIL'S STEWARDSHIP OF THE WORLD'S LARGEST TROPICAL RAIN-FOREST

Most (80%) of the world's TRF biome occurs in only about a dozen countries (cf. Table I).⁴ More than half of the area of this biome lies in the Neotropics, and most of

*The personal opinions expressed in this paper do not necessarily reflect the official position of the World Bank.

[†]For explanation of acronyms and contractions, and a glossary of technical terms, etc., see Appendix, which is followed by the numbered footnotes.

TABLE I. World Distribution of 'Intact' Tropical Rain-forest Ecosystems (very approximate figures).

Country	Area of Tropical Rain-forest (km ²)
Brazil	2,800,000
Peru	500,000
Colombia	400,000
Venezuela	300,000
Guyanas (three together)	300,000
Bolivia	162,000
Ecuador	100,000
Africa (mainly Zaire and Gabon)	1,600,000
Southeastern Asia (mainly Malaysia and Indonesia)	900,000
	<u>7,062,000</u>

[Note: All the above data are being revised; the areas include tracts occupied by tribal people, but exclude cut-over ecosystems and open-canopy forests; pers. comm. from Dr Louis Huguet, FAO in Rome 1979].

it is within the 7.8 million-km²-watershed of the Amazon River system (cf. Fig. 1). Of the Amazonian countries, four—Brazil, Peru, Ecuador, and Colombia—lie mainly in the Amazon Basin, 85% of which is primarily covered by the TRF biome or its derivatives (wooded and forested, but not intact). Brazil contains

more of this special set of ecosystems than any other nation. The Brazilian TRF in Amazonia is the focus of this paper.⁵

Under current market signals—such as the prices of beef, land, and labour, etc., and the fiscal incentives of SUDAM—the Amazon forest can quickly yield immense profits when converted to pasture for the production of cattle. This explains why livestock projects were so strenuously encouraged by SUDAM. But these profits, though enormous, are ephemeral. The overgrazed pastures are allowed to deteriorate in a few years in the absence of expensive chemical inputs, so that conversion of further forest becomes more profitable than rehabilitation of existing pasture (Hecht, in prep.). This expenditure of capital resources rather than of interest derived from forest capital, probably creates the lowest level of employment and does this at about the highest cost per job created (US\$63,000, according to Skillings & Tcheyan, in press) of all types of development projects. Since the profits are repatriated almost entirely to southern Brazil, the cattle ranching emphasis has brought no lasting benefits to the people of Amazonia. As this becomes acknowledged, and as the value of wood, of chemicals derived from the forest, and of the forest itself, becomes appreciated, the formula will change.

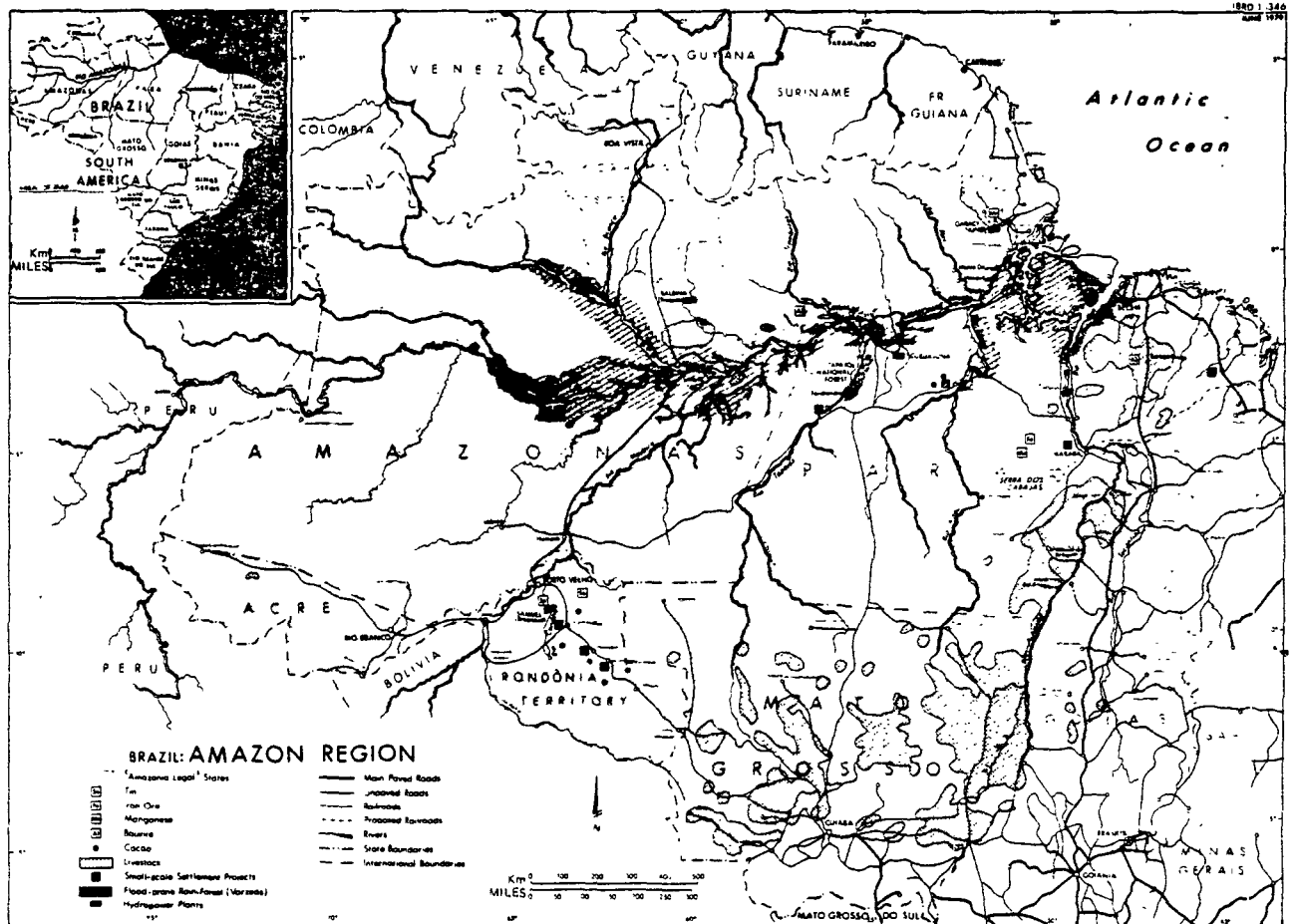


Fig. 1. Map of the Amazon region of Brazil, with inset for orientation.

All formulae that are employed to design development programmes are inevitably complex. This paper emphasizes only one of the many factors comprising such formulae, namely the environmental. Special environmental factors and constraints are emphasized *inter alia* because they are possibly more influential in the management of TRF than in that of other biomes or their component ecosystems.

TABLE II. *Amazonia: Summary of Environmental Options.*

1. Deflection of development elsewhere: e.g. cerrado*
2. Promote projects small in area but high in return: e.g. mining
3. Develop non-forested portions: e.g. aquaculture, capoeira*
4. Energy sources: e.g. hydroprojects and biomass
5. Use of the forest itself: e.g. intact-forest use, tree plantation, agri-silviculture.

*Such non-English terms are defined in the Appendix to this paper.

Although the opportunities listed in Table II are powerful for improving the environment in Amazonia, they are not amplified further in this paper. The sections which follow largely concern the less-well-recognized development choices within Amazonia—a variously-defined area of which a map is attempted in Fig. 1.

DEFLECTION OF DEVELOPMENT

Resolution of Amazonian issues will be achieved only by considering them in a context wider than Amazonia:

the resource-base may be maintained and the options preserved open to the extent that development is deflected away from Amazonia (Table II). Such prudence will buy time for the results of research into sustained-yield practices. Compared with Amazonia, promotion of development in the vast adjacent (1.1 million km²) under-utilized cerrado⁶ poses fewer environmental risks and offers major economic advantages (Table III). Similarly, development sited on the already extensive—and expanding—areas of secondary vegetation or ‘capoeira’ and abandoned pasture creates much less damage than do projects in the intact forest biome. Allocation of resources to existing development projects, such as improvement of agriculture on land that is already in production, further lessens the pressure on Amazonia. Deflecting development away from TRF and towards these three alternatives—cerrado, secondary vegetation, and existing projects—can be achieved by modest adjustments of incentives, and by avoiding unintended incentives such as the construction of highways and other means of facilitating access.

In my judgment, deflection of development away from Amazonia as outlined above promises to be more effective than any of the alternatives for improved development within Amazonia that are mentioned below. The cerrado environment is robust, resilient, and more familiar to people than the forest. The Amazon forest is fragile, intractable, and essentially unknown. The production of ethanol, beans, soya beans, rice, and even wheat, is successfully practised in the cerrado.

TABLE III. *Environmental Preferences for Agricultural Development in Cerrado Rather Than in Tropical Rain-forest.*

Characteristics	Cerrado	Amazon Forest
Size (approx.)	1.1 million km ²	2.86 million km ²
Location	Near consuming markets	Distant from consumption
Rainfall	Adequate for 9 months	Generally excessive
Insolation	Propitious	Sometimes limiting
Dry season	Decreases pest and plant growth	Absent or short
Erosion risk	Medium to severe	Greater with deforestation
Nutrient leaching capacity	Less	Greater
Pest diversity	Lower	Greater
Pest risk	Medium or lower	Higher
Fire risk	High	Low
Soil type (mainly)	Oxisols, ultisols	Oxisols, ultisols
Soil fertility	Generally poor	Generally poor
Soil structure	Generally acceptable	Generally worse
Access to fertilizer	Reasonable	Poor
Response to fertilizer	Slightly better	Slightly worse
Prevailing land-use	Extensive ranching	Shifting cultivation
Infrastructure	Better	Inadequate
Social, Government services	Better	Inadequate
Transport, accessibility	Reasonable	Inaccessible, expensive
Communications	Good to medium	Difficult, expensive
Electricity supply	Widely available	Mainly not available
Availability of labour	Medium	Very low
Indigenous occupation	Little	Significant tracts inhabited
Value of intact ecosystems	Less	High
Species diversity	Low	Very high
Knowledge of biota	Medium	Very incomplete
Human disease risk	Medium	Very high
Suitability for colonization.	Suitable (with precautions)	Less suitable (with exceptions)

(Note: Generalizations encompassing such vast expanses of heterogeneous ecosystems perforce contain exceptions.)

AMERINDIANS

The new constitution of Brazil, as promulgated and adopted by the military Government in 1969, commendably and unequivocally provides that lands inhabited by indigenous forest dwellers (Amerindians) are inalienable. The right of permanent possession of these lands belongs to the Amerindians, including the exclusive use of the natural resources therein contained (Article 198; Titulo V).

Amerindians in Brazil and elsewhere have been decimated and even obliterated by conflict with, and disease from, exogenous society.⁷ This anguishing and continuing process is well documented. As the problem is less ecological or environmental than ethnological, it is hoped that anthropologists and others will work to resolve the issues. Suffice it to say that the Government is criticized from both sides. State officials, agencies, and developers, feel that the Government has allocated disproportionately more land than the tribal numbers justify. On the other hand, criticism is growing that the Government does too little to protect the Amerindians' welfare, and that soon there will be no Amerindians and consequently no problem.

The urgently needed zonation recommended later in this paper can make development compatible with Amerindian rights. At present, development and Amerindian rights are incompatible forces where they coincide, and, under the constitution of Brazil, no project can be sited where irrevocable and serious violation of tribal lands could result.

Meanwhile, controllers of any project in any way related to Amerindians must take special precautions for all staff engaged on the project to be free from infection and thoroughly immunized. FUNAI, the federal agency administering Amerindian policy, must, if necessary, be strengthened so that the project impacts and the nearest Amerindians do not conflict.

INDUSTRIAL PROJECTS

Development projects within Amazonia itself fall into two distinct categories: those largely independent of the ecosystems, such as mining or hydroprojects, and those manipulating or depending on the general biome or particular ecosystem, e.g. forestry or livestock projects. The biome/ecosystem projects, listed in Table IV, are taken up later.

Projects which do not depend fundamentally on the general biome, and those in which the particular ecosystem is removed, occur primarily in the industrial, mining, transportation, and hydropower, sectors. As with all projects, dependence on environmental factors exists: water supply for river transport and for hydroprojects is an obvious example.

General Industry

In Amazonia, industry accounts for only 1%, by value, of the total Brazilian industrial output, while

over 90% of extant Amazonian industrial enterprise occurs in the two cities of Belem and Manaus (cf. Fig. 1).⁸ Of the fairly wide distribution of industry among the sub-sectors, the largest employer is wood processing. Food products are the largest single group by value of output, while mining is the most important in adding revenue (Skillings & Tcheyan, in press). The environmental dimensions of wood and food processing projects include limited pollution of water and land from improper effluent disposal and lack of recycling. In general, though, these points are now relatively minor and so are not amplified here.

Bauxite Mining

Aluminium, tin, manganese, iron, kaolin, gold, and diamonds, are major economic resources of Amazonia. Mining in general can be one of the most appropriate forms of development that are compatible with the environment of Amazonia. This holds where the economic return per unit area of forest destroyed is greater than in other projects, and applies to most deep mines and even to opencast mines to a lesser extent.

Environmental precautions are being integrated increasingly into such projects in Amazonia. The bauxite project on the Trombetas River some 80 km above its confluence with the Amazon is a case in point (cf. Fig. 1). This reserve contains an estimated 600 million tonnes of superior-grade ore (av. 51% available Al_2O_3). It is low in the common impurities iron and silica, and is expected to last for a minimum of 65 years at an initial production rate of 3.35 million tonnes per year, starting in 1979, with a subsequent increase to 8 million tonnes per year. This enormous tonnage will be extracted, all by opencast mining, from the relatively small area of 72 hectares per year (including port, beneficiation (see below), and ancillary facilities). The Trombetas bauxite project sets an important precedent, being the first in Amazonia and now thought to be one of the world's major repositories of easily-recoverable bauxite, with over 900 million tonnes in all proven and 3.2 thousand million tonnes of probable reserves.

The Brazilian company Mineracao Rio do Norte (MRN), aware of the potential for significant environmental impact of the plan, promptly engaged the full-time services of an experienced Amazonian ecologist, formerly of FAO, who now heads the company's environmental defence department on the site. After arrangements had been made for botanical, zoological, archaeological, and forestry inventories, and for appropriate scientific collecting in the forest covering the ore body, the commercial woods were extracted, and the usable remaining areas were converted for housing and other purposes. Unusable cut trees were arranged parallel to contours on the slopes, in order to reduce erosion risks. A sawmill was one of the first components to be set up, and has since expanded to make maximal use of the wood.

Wherever the ore body was covered by a layer of recoverable soil, this was carefully removed and stockpiled. The overburden, which varies in depth from 5 to

30 m, was also removed and stockpiled separately. As each sub-area is quarried out, the overburden is replaced, covered with the stockpiled topsoil, augmented where necessary with black organic earths from near the residential area, and revegetated as soon as practicable and in any case before the onset of the next wet season. The sequence of deforestation, soil stockpiling, overburden removal, mining, and restoration, has been carefully planned serially to minimize the area and duration of disturbance. Erosion-preventive measures were implemented early on and these will be maintained throughout the project, as will the railroad and residential area. Eventually, the reforested tract will become long-rotation tree plantations.

Beneficiation in this case includes crushing the ore, then washing and drying it. The environmental division is concerned also with ways to minimize pollution by dust and effluent. Prevailing winds were studied in order to site the dryer and to adjust stack height (now 45 m) appropriately with respect to the residential and operating site. A series of filters (to 80-mesh), dust cyclones, and precipitators, are being installed and are expected to reduce dust problems.

Effluent disposal was considered in detail long before the washing plant was constructed. The expected chemical composition was determined first and was found to be inert and more innocuous than possibly any other industrial effluent, as it consists of oxides of aluminium with traces of iron, titanium, and silicon, oxides. After filtration to 0.65-mesh, the effluent will be disposed onto a riprap area of stones which avoid erosion. The very watery remains (12% suspended fines) will seep through the earth and down a 10-metres-long gentle (2%) slope at the foot of which it enters a seasonally dry creek. Any effluent that remains unfiltered and unpercolated will seep another 3,500 m to a large (2,200 ha) and deep (5–20 m) lake. The lake-shore is uninhabited by humans and the lake contains no special organisms (according to IBDF and SOPREN) and moreover is one of very many such lakes occurring along the length of the Trombetas River. Any fines entering the lake are expected to settle or be diluted in its 14 km length to the seasonally-open connection with the River. The situation is being carefully monitored, and contingency plans for decantation weirs or retention dams are being held in readiness. Studies are in progress on migratory fishes and turtles.⁹

The guidance of all appropriate government agencies was sought by MRN from the start, and even non-government environmental groups are collaborating to make this a model project. The federal environment agency, SEMA, screens all proposals, regularly inspects the site, and would like to strengthen these procedures. The environmental division supervises water quality, safety, preventive medicine, and vector habitat control, and stringently enforces a no-hunting policy. Furthermore, a 37,000 ha tract, and some lesser ones, have been set aside as preservation areas. MRN collaborates with IBDF and the Trombetas Biological Reserve which is situated across the river (Nogueira-Neto & Carvalho, 1979).

For the next few years, all the bauxite will be transported from Amazonia by ship. In 1983, when the large Tucuruí hydroproject generates enough power, alumina plants and smelting capacity are expected to be installed 50 km SW of Belém. The main environmental problems of such facilities, namely proper disposal of cooling waters and of 'red mud' containing sodium hydroxide, are already being considered.

Much of the food needed for the company's personnel both here and at Jari is produced through cultivation *in situ*, with MRN-contracted horticulturists and market gardeners of Japanese origin raising food-crops on the concession, using inputs mainly of local origin. Cattle from Jari graze on the grass between the pine trees, to the mutual benefit of both the cattle and the trees.

Other Mining Projects

Cassiterite, a tin-containing mineral, occurs in large deposits in Rondonia, southern Para, and elsewhere in Amazonia, whence it had long been extracted by small-scale prospectors with minimal environmental damage. Most of this was prohibited in 1970 in order to encourage capital-intensive extraction. The reserves are variable in extent and in tin content. It seems possible that Rondonia's production may rise to 15,000 tons (tin content) or more by 1990, worth US\$145 millions, which would make a significant contribution to Brazil's balance of payments (Skillings & Tcheyan, in press). Although the area of ecosystem destroyed may be small, experience in Malaysia and elsewhere shows the need for early environmental precautions similar to those incorporated by MRN.

Iron ore extraction from the Serra dos Carajas presents by far the largest potential project in Amazonia. This gigantic deposit contains an estimated 15.7 thousand million tonnes of high-grade (av. 66.7% Fe) ore of which 1.7 thousand million tonnes have already been fully confirmed. The vegetation on the Serra dos Carajas, consisting largely of depauperate scrub, is far less rich in species than the TRF, and little would be destroyed by the mine, although the occurrence of endemics should be checked. The planned 876-km-long railway from the projected mine to Itaqui near São Luiz in Maranhão (see Fig. 1) will, however, create an impact that will exceed its 70-m width. The impact of noise, dust, and erosion, arising from twelve 160-gondola trains daily, should be assessed. Even more important will be the routing of the right-of-way to avoid sensitive areas such as Amerindian territory and biological tracts (Nogueira-Neto & Carvalho, 1979).^{*} Careful environmental planning and management, such as has been achieved at the Trombetas bauxite mine, could prevent major adverse consequences of this project, making it environmentally preferable to prevailing developments of upland rice and agro-industrial cattle-ranching.

^{*}In answer to our question as to how these 'biological tracts' (later revised to 'biologically important tracts') may be related to the 'ecological stations' of these last-cited authors, Dr Goodland replied that the latter are 'only of SEMA; however IBDF and SUDAM have designated too.'—Ed.

NON-FOREST PROJECTS

Not all of Amazonia is covered with TRF, the valuable biome which this paper seeks to preserve. The ecosystems involved would be conserved, and development projects improved, to the extent that the latter were sited on the non-forested areas of Amazonia.

There are about 150,000 km² of savanna in Amazonia—mainly in the territories of Roraima and Amapa, but including large tracts around Humaita and elsewhere (cf. Fig. 1). These natural grasslands with scattered trees and shrubs can be grazed and cropped with far less damage than is liable to be caused through conversion of intact forest. The periodically-flooded *varzea* grasslands, and the flooded or sedge meadows, can also be exploited with less damage than results from the prevailing course (see section on Varzea Rice Projects, pp. 17–8). Many commercial fish species feed exclusively in varzea rice-fields or on fish that feed therein. Any alternative development must take account of the concomitant risks to commercial fisheries.

Development is also favoured on the already extensive, and expanding, areas of secondary vegetation or 'capoeira'. There is so much capoeira that pragmatic research to find sustainable uses for it is badly needed. Meanwhile, soil surveys show that from 2% to 4% of Amazonia may be endowed with relatively fertile soils. Many of the areas of fertile soil occur as small, isolated, diffuse pockets, often on more continuous alluvial plains. Nevertheless, this 15-million-ha area could be exploited for agricultural projects with less risk of failure and environmental damage than on other, less fertile sites. Recent RADAM studies reveal that possibly 10% of the area of upland, non-flooded *terra firme* forest may be developed on relatively fertile soil.

Finally, the other most significant area of non-forested Amazonia is the water itself. Aquaculture, including the management of fish, floating and other crops, indigenous aquatic or amphibious fauna, etc., clearly is a most promising course for Amazonia.¹⁰ It is probable that aquaculture could be developed on a sustained-yield basis with less difficulty than the TRF. INPA in Manaus, and Professor Harald Sioli's Max Planck limnology group (Sioli, 1968, 1975; Sioli *et al.*, 1969), are actively working on this most significant and promising opportunity. But although fully acknowledged as having great potential importance, it is not considered further here.

INTACT FOREST

Use of TRF as intact ecosystems heads the list of environmental ranking (Table IV) as it seems sustainable over the long term in Amazonia. As the environmental value of intact TRF is unknown and cannot at present be calculated, it has been largely ignored. It could be argued that irreversible climatic modification, demise of Amerindians, and extinction of native plant and animal species, which would mainly affect future

generations of mankind, do not significantly increase discounted present values, and could safely be ignored (Skillings & Tcheyan, in press). Ecologists do not find cost-benefit analysis particularly useful in this case, as it rarely provides meaningful guides further than ten or sometimes twenty years into the future.

Most fortunately, the great values of intact TRF, and the onerous risks associated with its destruction, are at last becoming acknowledged by economists and planners (Reis, 1978). Brazil has provisionally proposed twelve protected forest research tracts in Amazonia, totalling 40 million ha for IBDF (the federal forest development agency).¹¹ SEMA has established four biological stations (totalling 937,000 ha and representative of diverse ecosystems) ranging more or less throughout Brazilian Amazonia, and more are being actively incorporated (Nogueira-Neto & Carvalho, 1979). INPA has four small tracts, too. The system of national parks and equivalent areas is being worked on and partly adopted, but the only actively managed tract at present is the ca 1,000,000-ha Amazonia National Park on the Tapajos River (cf. Fig. 1).

Only time will tell if these restricted areas are adequate samples of the whole, and whether they can be maintained under increasing pressure to convert them to less sustainable exploitation. The results of the national Amazon planning code are expected shortly. Such important questions as how much should be preserved, in what size of tract and where, remain to be answered fully (Brown, 1979; Lovejoy, in press; Lovejoy & Oren, in press).

In concluding this section, I would like to express an opinion which should be of significance for developers: any project that modifies an ecosystem in Amazonia should compensate for this by somehow strengthening or augmenting the nearest protected tract, including SEMA's Ecological Stations, and no project should be sited where it could damage a special tract. Because these goals are felt to be of such fundamental importance, they have recently been adopted as World Bank policy (World Bank, 1978).

FOREST ACTIVITIES AND PROJECTS

Shifting Cultivation

Shifting cultivation, which is probably the most widespread activity in tropical forested regions today, supports some 250 million people practically throughout the tropics. About 300 million ha of forest lands are under such cultivation, which is a technically viable form of land-use that has sustained much of humanity for millennia without destroying the resource-base. However, as this system can be sustained only for a population density of up to about ten people per square kilometre, which has been exceeded world-wide where it is practised, shifting cultivation cannot continue to alleviate population pressures indefinitely, and has become a system which 'mines the soil and ruins the resource'.

TABLE IV. *Environmental Ranking of Possible Utilization of the Amazonian Tropical Rain-forest.* (Note: This is *not* an economic ranking.)

Tropical Rain-forest here is taken to mean tropical perhumid forest occurring on oxisols, ultisols, or red-yellow latosols. This *environmental* ranking runs in general from the top (preferred), gradually descending through all five categories, with the least desirable at the bottom. Examples at the top anticipating sustained-yield¹² (certainly over fifty years) are thus preferred on environmental criteria over the non-renewable, degradative examples at the bottom. Within each of the five categories a ranking has also been attempted such that the environmentally preferred precede the less desirable activities. There is much overlap, both vertically and horizontally. The actual mix of utilization methods adopted may be expected to be closely site-specific, given the enormous heterogeneity of Amazonia. The most rational land-use pattern will, however, probably be almost as diverse as the environment on which it depends.

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1. *Intact Forest*
 - 1.1 Biological reserve; scientific repository; gene-pool, germ-plasm storehouse; phytochemical and ethnobotanical resources.
 - 1.2 Environmental protection services: climatic buffer, watershed protection, protection of downstream activities.
 - 1.3 Indigenous peoples and reservations based on natural, legal, and moral criteria; also for knowledge of indigenes.
 - 1.4 Collecting, gathering, tapping, game- and fish-culling.
 - 1.5 National park development; national and international tourism; recreation.
 2. *Utilization of Natural Forest*
 - 2.1 Dynamic sustained-yield management (as in Nigerian and Malaysian Shelterwood forestry).
 - 2.2 Leaf protein, leaf chemicals, other chemicals.
 - 2.3 Selective felling with careful removal.
 - 2.4 Bole removal with slash, roots, stump, bark, and branches, left *in situ*, rather than whole-tree removal.
 - 2.5 Enrichment planting, refining, liberation, reconstitution management, or directed regeneration.
 - 2.6 Clear-cutting small tracts, leaving regeneration foci in strips or environs.
 3. *Tree Plantation*
 - 3.1 Mixed-species polyculture products (e.g. rubbers, oils, nuts, resins), rather than monoculture products.
 - 3.2 Mixed-species polyculture timber plus synergistic species and products; mixed-species timber; oligoculture timber.
 - 3.3 Monoculture timber: veneer, dimension lumber, plywood, particle-board, timber, chips, fuel-wood, hogfuel.
 4. *Agri-Silviculture*
 - 4.1 Multiple-dimension forestry, '3-D' forestry of timber, products, synergists, browse, understorey components, or graze.
 - 4.2 Polycropping and intercropping, e.g. rubber and synergists with understorey and annuals.
 - 4.3 Taungya: annuals and perennials planted simultaneously, eventually becoming a tree plantation; chena.
 - 4.4 Treed pasture: wood and products plus synergists; browse and multispecies graze (legumes, forbs, grasses).
 - 4.5 Subsistence rotational gardens, e.g. Mayan home garden, Kandy garden, chinampa, etc., of trees, perennials, and annuals, with small livestock, fishponds, etc.
 5. *Agriculture*
 - 5.1 Long fallows, small areas, multi-varieties of some species, breed tolerance of pests and infertile soils, rotations.
 - 5.2 Varzea management; naturally irrigated crops, Water Buffalo, capibara, turtles.
 - 5.3 Perennial crops in preference to annuals; subsistence crops in preference to export and cash-crops (such as tobacco or sugar).
 - 5.4 Oligotrophic exports (e.g. hydrocarbons, carbohydrates) in preference to eutrophic exports.
 - 5.5 Multispecies pasture for mixed herbivores; e.g. small livestock and solitary stabled cattle.
 - 5.6 Oligoculture pasture for monospecific herbivores (extensive ranching for cattle export): the worst option under prevailing low-management practices.
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Nor is there any prospect of this trend being reversed in the future. This important topic has, however, been so well documented already that it will not be treated further here.¹³

Native Forestry Projects

By careful selective extraction, the intact native forest can be exploited on a more usefully sustainable basis than can well be maintained by any other directly economic use. Hence 'Utilization of Natural Forest' ranks second in the environmental listing of the five general categories (cf. Table IV). On this basis alone, careful forestry projects of this type are the best way of creating a sustainable livelihood for people within the Amazonian forests.

However, as too often is the case, economic factors dominate the equation. Despite the fact that Brazil has over 200 million ha of untouched TRF, transportation costs to the markets are so great that it is economically preferable to establish two million ha of fast-growing pine or eucalyptus industrial plantations on more expensive land closer to the consuming centres of the south-

east. The inference follows that large areas of Amazonia remain inaccessible, protected by distance—except for the highest-value 'quality' veneer logs. Promotion of plantation forestry in those parts of Amazonia that are served by cheap transportation, especially to nearby markets which are situated outside Amazonia, thus helps to preserve the intact Amazonian forest.

Hardwood Plantations

Productions of the more valuable, quality hardwoods in plantations reduces the pressure to exploit native forest. The demand for, and price-increases of, these hardwood products have been carefully projected by several independent agencies which reveal that acceptable rates of return (greater than the usual cost of capital for the country concerned) can be expected from investment in such plantations. But whereas such projects are economically feasible and environmentally preferable, they are technically uncertain. Growth-rates and yields may not produce a log large enough for veneer in, say, 25 or even 45 years. During this long trial, the monocultures are susceptible to fungal and

TABLE V. Amazon Timber Production, 1974 (from Skillings & Tcheyan, in press).

	Amazon Production (millions of cu.m)	% of Total Brazil	Value (millions of US\$)
Logs	3.4	13%	40
Sawnwood	2.5	23%	[not available]

insect attacks, as well as to soil deterioration. Even so, existing pilot plantations of *Triplochiton*, *Terminalia*, *Maesopsis*, Teak (*Tectona grandis*), and *Aucoumea* or 'Gaboon Mahogany', have been judged promising in the West African TRF.

Perennial Crops

Perennial crops such as rubber, palm oil, coconuts, and Brazil nuts, are derived from trees that can protect the fragile soils of Amazonia while providing a reasonable quality of life for small farmers. The products are largely oligotrophic, so that such forms of land-use can be sustainable. They are therefore strongly preferred on environmental criteria. Throughout the tropics, more than 25 million ha of agricultural tree-crop plantations have been established, mainly on better-than-normal soils, and many of them are in sustained production after more than 50 years of continuous cropping. Minor environmental improvements, such as soil enrichment with legumes and other synergists, increasing the number of varieties of each species, and breeding for tolerance of pests, nutrient deficiencies, and aluminium toxicity, could make this a most appropriate system. This form of agriculture deserves major emphasis.

However, because of three constraints, perennial crops are no panacea. The first is that possibly as much as one-half of the remaining moist tropical soils are so infertile, acidic, and severely leached, that nutrient-demanding perennial crops cannot be sustained without costly agricultural inputs and careful technological management. Promotion of less-demanding species and varieties, enrichment of the mineral nutrient-cycle where practicable by periodic flooding with fertile or silty water, retrieval of leached nutrients, and addition of locally available nutrients, can extend the time-span and productivity of appropriate sites.

The second constraint is economic rather than environmental. The markets for some of these products are fairly inelastic, many are sumptuary, i.e. limiting private expenditure in the interest of the State, and most are distant from the areas of production: people cannot be induced to buy much more than enough to satisfy their basic needs, though what they consume may include some luxuries (e.g. chocolate), which are therefore of uncertain demand in times of recession. The price is controlled largely by the consumers and is unrelated to the holistic costs of production (including mining of the soil and loss of ecosystem). Increasingly diversified cropping that emphasizes the more basic commodities (e.g. cooking oil), and also strengthens trade-relations, would improve the system. However,

these economic considerations lie outside the scope of this paper.

The third major constraint throughout the tropics more than elsewhere is imposed by diseases or pests. The longevity and sustained cultivation of these crop-trees allows time for one or more of the uncounted thousands of potential pests to find the plantation and counter the natural defences even of so-called resistant or tolerant varieties. The disparity in generation-cycling between a bacterial or other pest and a tree—minutes, hours, or at most weeks, *versus* from five to fifty years or more—when considered as an evolutionary factor, is too great for reliance on this agricultural system alone. The Witches'-broom Fungus (*Cripinellis pernicioso*) of Cocoa (*Theobroma cacao*), the *Fusarium* wilt of pepper (*Piper* sp.), and the Leaf-blight (*Microcyclus [Dothi-della] uliei*) of Rubber (*Hevea brasiliensis*), have all but shattered the respective crop industries at various times in recent history. Integrated pest management will help to the extent that it can be elucidated and afforded, but time will always exert pressure against tree-crops in Amazonia.

Assuming that some of the foregoing could be achieved by the year 2000, without serious marketing problems, Spears (1979) calculates that a further two million ha of perennial agricultural tropical tree-crop plantations world-wide could improve the livelihood of significant numbers of families. This represents less than 2% of the tropical forest that is likely to be destroyed in any event. In my judgment, however, such conversion is greatly preferable to prevailing patterns of use, and is an attractive choice for suitable soils and sites in Amazonia.

Plantation Forestry

The destruction of vast tracts of natural mixed forest in order to plant a few species of exotic trees provokes strident clamour. Seeing a pure stand of eucalyptus where a luxuriant forest once teemed with life is indeed saddening.

The paradigm is the huge 1.4-million-ha Jari project on land which was bought in 1967, nearly 500 km WNW of Belem and less than 1° south of the Equator.¹⁴ Criticism of this project has been loud and wide, and was fully shared by the present writer until recently. Although the complaints are anguished, they are to a certain extent misdirected because few people have visited the site and, even to them, reliable facts were not divulged. Fundamental and possibly avoidable errors were indeed perpetrated. Bulldozing the forest, burning the trees, levelling the ground, scraping off the thin topsoil, planting a clay-soil tree on sand, or a sandy-soil species on clay, then having to cut the mistake and switch to something else, may contain more than a grain of truth. The other widely documented accusations are, however, largely irrelevant environmentally.

The empirical, trial-and-error start to this scheme gave way during the intervening 13 years of the project to the much more thoughtful and scientific approach which prevails today. Now the errors have largely—and at admittedly inordinate expense—been corrected.

About 100,000 ha of the two species *Gmelina arborea* (65%) and *Pinus caribaea* (35%) have been planted, and the oldest plantations have now reached harvest size to the extent of 750 tonnes per day of bleached kraft-mill pulp. The whole project creates direct employment for about 13,000 workers, most of whom arrived from depressed areas of Brazil with their families and are now indisputably better off as a result of their migration.

In view of the fact that plantation forests can be up to twenty times as productive as native forests, plantation forestry is greatly preferred over the two main development models now prevailing in Amazonia—namely forest conversion to annual crops and cattle pasture. The Jari plantation product, pulp, is oligotrophic, so that the nutrient cycle is only minimally disruptive, while the more eutrophic parts—leaves, branches, roots, and some bark—are left on the site. Loss of nutrients is thus kept to a low level.

Whether second and subsequent yields will fall significantly remains a risk of unknown gravity. The highly atypical 'terra roxa' clay soils are fortunately among the richest and most appropriate ('A' horizon pH 6.3, mean of 10 samples) in Amazonia, and there is said to be a possibility that soil pH may increase as *Gmelina* litter decays, as it is less acidic than the general forest litter. Similarly, the pine plantations are inoculated with mycorrhizas which improve the nutrient cycle. Another optimistic possibility is that, on the sandier soils where it is now planted, the pine's deep tap-roots may recover nutrients that have been leached from above. At all events, no economically attractive responses to the many and detailed fertilizer trials have been demonstrated.

It is to be feared, and for compelling reasons, that the above two exotics, introduced into a clearing surrounded by literally thousands of species of insects, Fungi, Bacteria, and weeds, may be damaged unless protected with biocides. However, so far there have been only three or so attacks by leaf-eating moth larvae, and these were self-limiting. The occurrence of a usually marked dry season, during which *Gmelina* is deciduous, doubtless helps.

My point of view is that plantation forestry is much less damaging than most alternatives, and that the Jari experience may reveal the extent to which this model can be sustainable. In a way, Brazil will benefit from this experience at no direct financial cost to the country—but with significant financial benefits to set against the irrevocable loss (of unquantified value) of the original forest which was destroyed in all its largely undocumented complexity.

AGRICULTURE

Subsistence Agriculture

Throughout Amazonia it is the exception for people to produce enough food to support themselves. Sus-

tainable Amerindian shifting cultivation is dependent on a low level of exploitation and a detailed understanding of the environment, so that it is too difficult and labour-intensive to be attractive for others. Even if peasants managed to practise it successfully, it would not support many more people than it does today.

It is now generally conceded that over most—say, three-quarters—of Amazonia, soils without agricultural inputs will not support continuous annual cropping for much longer than five years, or often less, and never much more than ten. Decreasing yields, aggravated by increasing weeds and pests, make the clearing of more forest more rewarding. As this is the process that is destroying the forest so rapidly almost throughout Amazonia, any improvements in permanent subsistence agriculture will alleviate the pressure to convert intact forest.

In my judgement, improving subsistence methods should be addressed as a priority issue by agricultural agencies, although large numbers of people can never be supported sustainably in Amazonia—even with likely improvements. Such improvements include the Mayan system, the Indonesian Home Garden system, Chinampa, integration of agoutis or rabbits, small fish-ponds, fowl, bees, leak-proof nutrient recycling—especially of faeces, ash, and organic matter—and the use of intact forest products to the extent that this may be possible. Gerardo Budowski of CATIE in Costa Rica, Stephen Gliessman in Cardenas, Mexico, Otto Soemarwoto in Bandung, Indonesia, and the Eco-development Center in Mexico, are regrettably rare examples of people and groups who are now moving in this direction.

Success in such eco-agriculture could do more for the people of Amazonia, while reducing the rate of destruction of the ecosystems, than any other programme. In the interest of the people there, promotion of successful subsistence agriculture rather than prevailing expectations of surplus or cash-cropping, should receive priority in establishing pertinent models. Spoilage of surplus, high transportation and marketing costs, and unpredictable climatic and harvest fluctuations, combined with the low yields inherent in any sustainable system, cannot be conducive to annual cash-cropping in most of Amazonia *without chemical inputs*.

Varzea Rice Projects

Varzea, comprising the seasonally-flooded portions of Amazonia that are situated adjacent to rivers, supports mainly a forest ecosystem that is arguably less vulnerable and less valuable than the 'terra firme' or upland forest. Subjected naturally to major perturbations by occasional and unusually damaging floods, this ecosystem supports fewer species per unit area than does terra firme. As varzea always occurs near major river transportation routes, it can be viewed as more appropriate for development than other types of area. With judicious planning, large tracts of the varzea habitat can be preserved, while other varzea areas can produce food and support people.

Depending on definition, there are more than five million and possibly over thirty million ha of varzea in

Amazonia, the soils of which are generally more fertile than those of the terra firme. Varzea can yield a wide variety of products, at least in places—including timber, rubber, jute, beans, fish, fowl, turtles, and, most significantly, Water Buffaloes and rice. In this overview, only rice projects will be considered.

Rice was seen as the penultimate panacea for Amazonia, the mainstays of the ambitious federal programme to integrate Amazonia in the early 1970s having been rice and roads. As these two are largely incompatible with each other environmentally, rice needing wet conditions but roads preferably dry ones, both failed to produce the expected results and have been curtailed. Indeed one of the tragedies of the transamazonian highway scheme was that it focused attention and resources on the upland or terra firme and largely unflooded portion of Amazonia, while neglecting the seasonally fertilized lowlands or varzea, endowed as they are with a pre-existing communications system of rivers.

As production of rice, the most widely-planted crop in Amazonia (ca 200,000 ha), can be sustained for only one or two years, and is mainly on terra firme at present, it is responsible for more deforestation than any other crop. Rainfed rice yields on terra firme are transitory and meagre, possibly averaging less than one tonne per hectare, and failing to fulfil even regional demands.

Rice production from irrigated varzea can yield ten times that from terra firme, and on a permanent basis (Norgaard, 1979a, 1979b, 1979c). Defection of rice from upland to lowland cultivation would help to preserve the forest and improve the nutritional and economic status of the region, while promoting the more rational and less damaging system of fluvial transport.

The varzea is also more attractive than terra firme environmentally, assuming that it is desirable to produce plentiful food in Amazonia. Seasonal deposition of silt improves the fertility of the soil, while flooding decimates pests and pathogens. Two major constraints to Amazonian agriculture—infertile soils and pests—are thus reduced to minor proportions by working with the environment rather than against it. This has been widely known even from the time when the first exogenes saw many indigenous people living along varzeas; but it was forgotten or disregarded in recent development planning. Diking, draining, and levelling, are all expensive, but far less so than the largely unproductive transamazonian highway system.

Successful, sustainable rice production on varzea can be labour-intensive and provide acceptable livelihoods for much larger numbers of people, whether small farmers or cooperatives, than where rice is currently grown. Alternatively, varzea rice production can be extremely capital-intensive, requiring high technology and employing few people, as is the case at Monguba (see Fig. 1) in the Jari project. Here rice is grown almost hydroponically, being germinated in nurseries and sown as a seedling from an aeroplane on a carefully levelled, diked, and drained, substrate. This rice receives periodic aerial doses of fertilizer and biocides, and is harvested mechanically. The possibility of

fish-kills from biocides must be countenanced as a direct cost. The difference between the two extremes is economic—capital *versus* people—as the environmental effects are similar. Consequently, any mix of these two approaches should be calculated largely by economists.

Because of my recent involvement with transmigration in Indonesia—one of the world's biggest environmental modifications—I cannot resist an opinion which is more economic than biological. Intensive rice cultivation on exceptionally fertile soils in Indonesia helped to produce the highest population-density in the world, but in harmony with the environment. Alien influences—invaders, antibiotics, biocides, and the Green Revolution—helped to shatter this harmony. Now, 500,000 government-sponsored families and as many unsponsored families are expected to move in the next five years largely to forested sites on soils that are frighteningly similar to those of Amazonia. The people are expected largely to subsist as well as to export rice to Java. The environmental risks are practically the same in Indonesia as on rice-deforestation areas in Amazonia. Indonesia recently bought over 50% of the world's marketed rice; Brazil imports over 80% of its petroleum needs. Long-term agreements between Brazil and Indonesia (and other OPEC rice-consumers) to exchange rice for petroleum would greatly improve the environmental and TRF status in both countries (Norgaard, 1979a).

Although significant, the environmental costs of varzea rice production are much less than all comparable alternatives. The main cost is the irrevocable loss of habitat, as the varzea forest is rich in species with circumscribed ranges. The many economically significant animals which depend on varzea for food, reproduction, refuge, etc., would markedly decline—including many commercial fish, fowl, and turtles. The risk of diseases such as malaria, schistosomiasis, and cholera, would intensify. Although careful management could reduce all these environmental costs, the cumulative costs suggest that irrigated rice may well be more appropriate for cultivation in extra-Amazonian Brazil.

Livestock Projects

As soon as the yields of rain-watered rice and other crops officially promoted along the length of the transamazonian highway system began to plummet, land-use policy switched to large-scale livestock ranching. However, the new policy was disastrous both financially and environmentally.¹⁵ Over US\$1 thousand millions will have been invested on implementation of all the 1965–78 projects (Mahar, 1979; Skillings & Tcheyan, in press). Between 1965 and 1978, SUDAM invested US\$391 millions in subsidized livestock projects on behalf of corporate investors holding tax-credit deposits. The 187 assisted projects and 100–150 livestock credit projects were larger in number and total cost than all other sectors combined (cf. Table VI).

Conversion of tropical rain-forest ecosystems into pastures for cattle rates the worst, environmentally, of all the conceivable alternatives, as indicated in Table IV. The reason why extensive cattle pastures rate so low in

TABLE VI. SUDAM Fiscal Incentives: 1965-79 (from Skillings & Tcheyan, in press).

Sector	Number of Projects	Total Investment in Approved Projects (million cruzeiros)	Fiscal Incentives (million US\$ equiv.)
Livestock	337	9,715	391
Industry	182	14,801	348
Other	51	7,647	97
Total	570	32,163	836

(NOTE: 'Other' includes agro-industry, energy, education, telecommunications, transport, and tourism. Cruzeiro values at current prices; US\$ values derived by converting annual cruzeiro values at annual average exchange rates.)

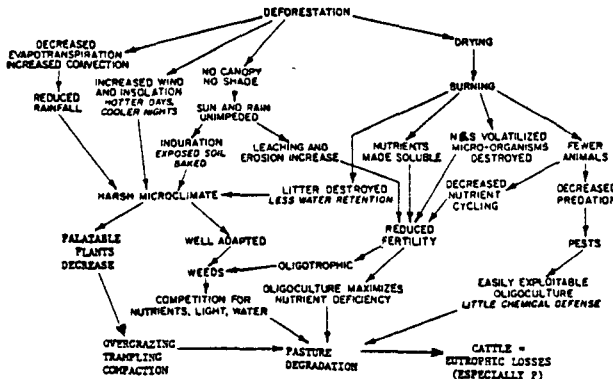


Fig. 2. Schema showing some environmental relations of cattle pasture created from tropical forest.

the environmental ranking is that the area of biome lost is large in relation to the short-term benefits and low employment-creation. Fig. 2 outlines some of the relationships of this conversion. The carcass leaving the ecosystem is eutrophic—rich in the nutrients that tend to be in short supply and, consequently, tightly recycled by the intact ecosystem involved. The top of the food-chain is occupied by a single species of herbivore; the bottom of the two-link chain is normally a few, usually inappropriate, species of grass. Overgrazing, trampling, and compaction of the soils, their oxidation and induration by the unattenuated force of the sun, and their leaching and erosion by the untrammelled force of ca three metres annually of warm solvent rain, soon leads to degradation. Highly tolerant weeds, many of them poisonous to cattle, are much better adapted to these new edaphic conditions, and shortly outcompete the pasture grasses.

In addition, the timber initially cleared is usually wasted by fire, and the employment created by this ranching is the least of all sectors. The area of forest biome irrevocably lost is greater per unit value of the product, beef, than in other more intensive products. To environmentalists it will come as no surprise that nearly all of these projects have been abandoned. Hecht (in prep.) reports that 85% of the cattle ranches around Paragominas, formerly Capital do Boi Gordo, were out of business by 1977. Livestock projects, particularly emphasizing Water Buffalo (*Bubalus bubalus*), are more appropriate for the vast natural grasslands of Marajo,

Amapa, varzea, and cerrado, than is pasture created from Amazonian forest.

Other Agricultural Aspects

Successful tropical agriculture is proving to be vastly more complicated than temperate agriculture, in which all biological systems and chemical reactions abruptly halt during the winter or are at least dramatically reduced. Temperate agriculture on highly mechanized high-input farms, is not a sustainable activity, for *inter alia* it depends almost entirely on supplies of imported oil, which are finite. Much has been said concerning the perils of extrapolating temperate methods for the tropics, which are incomparably more heterogeneous, and in which the ideal will be similarly heterogeneous. In the humid tropics, small-scale, attentive owner-management and diversity are more likely to be successful than large, uniform agro-industrial projects based on alien technology and alien economics.

Every chemical pest-control programme selects 'factors' for its own failure. Where winter or a dry season does not aid the farmer by decimating pest populations, where humidities are higher, temperatures in general warmer, and generation-times shorter, than in temperate regions, and where there are thousands of potential pests rather than a few, factors for failure will tend to be selected sooner rather than later. Biocides therefore are much less useful for Amazonia than is widely the case elsewhere, and reliance on them is dangerous indeed.

In principle, synthetic chemical fertilizers in temperate countries can top-up the nutrient reservoir—the soil—and thus restore the nutrient cycle after harvest. The fertilizer is held by the soil for the next crop, and in winter largely 'stays put' owing to marked decrease in chemical and biological activity. Soils are not the major reservoir for nutrients in Amazonian TRF ecosystems to any comparable degree: instead, most nutrients there are stored in the biomass. Fertilizers (mainly N and K) added to such TRF soils are rapidly leached out and wasted because of the three metres or so of annual rains reacting with the soil. The very low absorption-capacity of the predominantly kaolinitic-clay soils cannot store many nutrients. Furthermore, the iron and aluminium soils, so inextricably sequester practically all of the phosphatic and other nutrients that plants cannot extract them at useful rates.

Fertilizers also promote the growth of large numbers of species of indigenous plants to the extent that they become weeds which compete all-too-successfully with the crops in Amazonia. On infertile Amazonian soils, continued fertilizer dressings will eventually create nutrient imbalance, trace-element deficiencies, or degradation to low levels of organic matter. As currently formulated and applied, synthetic fertilizers are not as useful in Amazonia as in temperate croplands—even if the increasingly onerous transportation costs are overcome.

I conclude this topic with an anecdote from Jari's rice project, which tends towards hydroponics. Succes-

TABLE VII. Brazil: Amazonian Hydroprojects.*

Project Name	Year of Completion or present stage	River	Location	Megawatts	Reservoir Surface km ²	Kilowatts per Hectare
1. Paredao (or Coaracy Nunes)	1975	Araguari	80 km NW of Macapa	40+	23	17
2. Curua-Una	1977	Curua Una	70 km SW of Santarem	20+	86	2
3. Tucuruí	1983	Tocantins	300 km SSW of Belem	3,960+	2,160	18
4. Itapeuara	1986?	Jari	Just NE of Mt Dourado	252	1,800	1
5. Balbina	Feasibility	Uatumã	150 km NNE of Manaus	250	2,000	1
6. Cachoeira Samuel	1985?	Jamari	52 km SE of Porto Velho	216	645	3
7. Couto Magalhaes	Constr. starts 1985?	Xingu	SSW of Bananal	220	?	?

*Located in Fig. 1.

Note: All of these data are approximate. Kw/ha, a crude environmental ratio, ranks benefit (power) gained to area flooded. There are many more medium-to-large potential sites identified throughout Amazonia, but distant from demand. Tucuruí is now under way; construction started in 1976, and five more dams are planned upstream. Curua-Una and Paredão are functioning on one or more turbines each, with room for additions when the need arises. Cachoeira Samuel is likely. Balbina is needed for Manaus but has problems to surmount, including a large shallow reservoir in forested land for modest power (low kw/ha ratio). Magalhaes is a most attractive site hydraulically, but distant. The new generation of environmentally benign, run-of-river axial tube turbines may intercede before long.

sive declines in rice-yields worried the best rice research workers that money could attract, and all sorts of experiments failed to reverse the declines. On one occasion a shipment of nitrogenous fertilizer (urea) was delayed, so the scientists borrowed another source of nitrogen from a different division of the company. The accidentally-used nitrogen was ammonium sulphate. The rice yields soared to previous levels—a fortuitous discovery of sulphur deficiency!

ENERGY PROJECTS

Hydroprojects

The hydropower potential of Amazonia, although unknown, is enormous, and significantly exceeds the estimated installed capacity in the rest of Brazil. Eletronorte conservatively estimates the Amazonian potential to exceed 85,000 MW, whereas the total installed capacity in all Brazil was 25,000 MW in 1978. This is expected to grow to 55,000 MW in 1990, by which time the economically justified sites are likely to have been developed. Present consumption of electricity is approximately indicated by the figure of only 1,555 kWh in 1976 (Skillings & Tcheyan, in press).

The first two Amazonian hydroprojects are complete: the 40+ MW Paredão project in Amapa, and the 20+ Curua-Una project near Santarem. Construction of Brazil's biggest hydroproject, Tucuruí, started in 1976, and is due to generate nearly 4,000 MW by 1983. The existing and likely hydroprojects are indicated in Table VII and on the map of Amazonia (Fig. 1).

Hydropower can be environmentally benign, representing a means of harnessing solar energy on a sustainable basis. Much careful planning is necessary from the earliest stages, including the selection of the site. Environmental monitoring throughout the life of the project can reduce further impacts.

Eletronorte is well aware of the necessity for such environmental management, and created a department of environmental assessment in 1975. Eletronorte commissioned a far-reaching environmental assessment of

the Tucuruí project in 1977–78, many of the recommendations of which are now being implemented.¹⁵

Since the controversial Egyptian Aswan Dam saga was publicized, there have been comprehensive conferences, books, and studies, on the environmental impact of hydroprojects, so that any concomitant major environmental problems can now be predicted and avoided or largely mitigated. The major environmental costs may include the involuntary resettlement of people, the loss of habitat, the risk of waterborne diseases, and the deterioration of water quality. So much has been written on these topics that they are not further elaborated here.¹⁶

Judiciously planned hydroprojects are environmentally more appropriate for Amazonia than most of the energy alternatives—particularly nuclear. To the extent that hydrodevelopment reduces over-reliance on foreign oil and nuclear technology, Brazil will benefit from it both environmentally and economically.

With hydroprojects, as with so many other development projects, the environmental impact is directly related to the size of the project. The low population density of Amazonia, combined with the abundance of suitable rivers, strongly suggests that more relatively small hydroprojects would create less impact than a few mammoth ones. Axial tube (low-head) turbines cause practically no environmental problems, as little or no reservoir is needed for them (Cals, 1977). These cheap, low-maintenance, sparkless sources of power can be totally manufactured in Brazil in the 100-KW to 1,000-KW range. Even 20 MW to 100 MW sizes create less impact than comparable conventional projects.

Zonation for Amazonian hydrodevelopment will become increasingly important in order to ensure optimal use of natural resources. Thus, for example, fish migrations should not be impeded in areas of fishery projects, while oligotrophic water is preferred for hydroprojects—leaving eutrophic water for irrigation or nutrient enrichment.

Other Energy Projects

Brazil's vast natural resources include more sunshine than most countries, and large tracts of productive land

with generous rainfall. Thus it is not surprising that Brazil leads the world in the development of biomass energy. Biomass, chiefly in the form of wood, supplies most of the total energy in Brazil, as in most developing countries. The sugar-cane and cassava sources of alcohol, that are now being used more and more in Brazil to replace fossil fuels *inter alia* in automobiles, can be derived better outside Amazonia—in cerrado, for example.¹⁷

Within Amazonia, wood steam, charcoal, wood alcohol, and anaerobic fermentation of organics to methane, producer gas, and water-gas, are all appropriate on a small scale. These systems can be environmentally advantageous to the extent that they recycle materials which would otherwise be wasted (e.g. sawdust) or produced sustainably (e.g. village fuel-wood lots). There is a compelling case to be made for a mobile or floating steam-sawmill to be the first centrepiece of all projects in Amazonia.

Amazonia is unlikely to be the source of significant amounts of biomass energy for export elsewhere, but all local projects can be made self-reliant in energy. In my judgment, there is less scope for multiple-use energy tree-plantation projects in Amazonia than in the cerrado to the south.

TRANSPORTATION PROJECTS

The colossal geographic size (5,057,490 km²) of Amazonia, compared with its minute economic significance (4% of the income and 7% of the population in 57% of the national area of Brazil), stresses the transcending economic influence of transport factors. The environmental impacts of transportation are similarly influential.

The domination of petroleum-based roads through upland forests—the federal Transamazonian Highway programme of the early 'seventies—increased Brazil's dependence on foreign oil (now 85%), opened vulnerable ecosystems to inappropriate peasant agriculture, and deflected attention away from fluvial transport and varzea potentials.¹⁸

Wood-based fuels can be sustainably produced in Amazonia, as was previously mentioned. River navigation consumes less energy per kilometre-tonne than road, rail, or air, transport. Use of the 80,000 km of existing navigable waterways which are provided and maintained virtually free-of-cost, is environmentally and energetically preferable to the use of highways, which are very expensive to construct, more expensive to maintain, expensive to utilize, and open large areas to damage.

On energy and environmental criteria, rail is intermediate in choice between road and river transportation, and several railroads functioned successfully in Amazonia until addiction to petroleum-based highways left them to fail by default. Promotion of trackside fuel-wood plantations and even diesel rail systems using charcoal* is preferable to that of highways.

The vast distances in Amazonia, the perishability of some of its products, and the feeling of haste shared by many people today, combine to create a role for air transport. Airships, blimps, or balloons, designed to work with the environment, are fitted with small motors which use considerably less energy per tonne per km transported than the unnecessarily fast and expensive jets that are so widely relied on today. Airships use something of the order of 35% less fuel than trucks to transport the same goods over the same distance. Wood-based fuels (e.g. alcohols, gases) are appropriate for such motor units, and for hot-air *plus* gas airships. As, moreover, airports and roads are less necessary for airships than for aeroplanes, etc., the promotion of airships over jets is environmentally desirable. These variables, *plus* considerations of distance, speed, payload (weight and volume), infrastructure, and maintenance, make airships preferable to highways in many Amazonian circumstances. Harvesting the forest canopy, and fine-tuned manipulation of the forest by dangling from cables suspended from balloons and airships, would be much less damaging than most alternatives.

Clearly, terrestrial projects will need feeder roads or rail service to the riversides, and people want mobility. The choice from among walking, bicycles, draught animals, traction engines, and canal barges, will be determined largely by distance, weight, speed, etc. Avoidance of an automatic recourse to petroleum-driven automobiles will be environmentally beneficial. As much as 80% of Brazil's internal freight shipments are carried by trucks, which accounts for much of Brazil's reliance on oil imports.

The aim of this section has been to show that the choice of mode of transportation (road, rail, fluvial, or air), and of power source (e.g. petroleum, biomass energy, or animals), involves major environmental differences. This has been overlooked in Amazonia, and at great environmental cost. Consideration of these aspects will improve all Amazonian development in the future.

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The personal opinions expressed in this paper do not necessarily reflect the official position of the World Bank.

*A mixture of powdered charcoal and used oil-slurry.—Ed.

SUMMARY AND CONCLUSION

The premise of an Amazonia full of immensely rich potentialities awaiting development to yield copious and abundant profit and lasting benefit, has only recently emerged as being tragically false. The most important environmental consideration in Amazonian discussions has been to convince the controllers of the enormous risks of the prevailing course of development.

People in Brazil and elsewhere who were concerned with various foreseeable dangers, intensified efforts to persuade the Government about them when the Transamazonian Highway programme was announced in June 1970. This programme, and the associated colonization scheme in 100-km strips on either side of the road network, subsequently was largely abandoned or postponed, as the harvests failed and roads deteriorated. The next development thrust—agro-industrial livestock—was even more damaging, and so the environmental movement in Brazil grew. Almost simultaneous announcements towards the end of the Geisel Government, of accelerated emancipation of Amerindians and risk-contracts to extract timber on unprecedented scales with no limit placed on area, were shelved with the change in government early in 1979 (cf. Schmitzhusen, 1978).

Now the situation appears to be improving.¹⁹ SUDAM has ceased promoting financial incentives for cattle pasture development, while accelerated emancipation and timber risk-contracts have been postponed indefinitely. The Government has involved a representative cross-section of Brazilian society in the design of an overall Amazonian development programme. This is expected to mandate nearly all the area to remain in trees, to reinforce meaningfully the system of parks and preserves, and to require complete zonation so that all land-use becomes compatible with the environment and all projects with one another. To the extent that this may be expected to succeed, the future prospects for Amazonia should brighten.

Overall zonation and judicious land-use planning preceding implementation of development projects can increase ecological compatibility and decrease environmental risk. Agencies responsible for managing the zonation and controlling the land-use, will succeed only to the extent that they are accorded adequate authority. For example, it is virtually impossible to prevent settlement in a tract that has been assigned as a national park if another agency constructs a road through or adjacent to it. IBDF's '50% rule'—that one-half of each land-holding shall be retained as reserve forest—should be enforced for projects as well as for properties. Moreover, examples of a conserved tract of an important ecosystem or other feature may, on occasion, be better preserved elsewhere—e.g. adjacent to already-preserved tracts.

The overall development programme for Amazonia will be improved to the extent that the environmental dimension is integrated from the start. Environmental and ecological views should be adequately represented in

all management and implementive agencies if the onerous environmental errors of the recent past are to be avoided in the future.

All major individual development projects can minimize environmental costs by establishing an environmental unit from the start. This unit should assist from the earliest planning choices right through to implementation of the project and monitoring thereafter. The unit should also ensure that all those agencies which are able to mitigate environmental impact would be invited to work on the project and encouraged to see their roles expedited. Any deforestation that is judged inevitable can be palliated by taxonomic salvage, reforestation, and the establishment of compensatory preserves.

In general, the tighter the nutrient recycling is, or the higher it stands in the ranking list (Table IV), the less damage will the project create. Time for required research can be bought through choice of the preferences in Table II—particularly deflection of development elsewhere (such as the cerrado) or promotion of projects occupying small areas or of those not destroying the forest.

Economic policies and incentives have been responsible for most environmental impacts in Amazonia. Without the Government financing 70% of livestock projects' costs—almost half of the Government's total Amazonian funding in the last decade—livestock development would have been insignificant, for example. For such reasons, the environmental implications of all new economic proposals should be elucidated *before* any change is made or project embarked upon.

Most important is research and education in living sustainably within the renewable resource-base in a non-expanding economy. *The whole world must learn this in the future.* Countries with a fragile resource-base such as that of Amazonia, and those nations which have let themselves become totally dependent on foreign non-renewable energy imports, must learn to live in a steady-state economy as a matter of ever-increasing urgency. The choice is between careful planning to mitigate the inevitable as smoothly as possible, or letting the inevitable dictate the suddenness and extent of the break.

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- Biome - A characteristic major form of vegetation with its attendant animals and microbiota
- Capoeira - Secondary growth after the original forest has been felled and abandoned
- Cerrado - The Brazilian variant of Savanna; the 1.6 million km² of natural grassland with trees in Central Brazil
- CNPq - Conselho Nacional de Pesquisas
- Cr - Cruzeiro(s)
- Ecosystem - A characteristic unit of a biome: the physical components, plants, and animals, characterizing a particular area so far as it remains essentially uniform
- ELETROBRAS - Centrais Electricas Brasileiras S.A.
- ELETRONORTE - Centrais Eletricas do Norte do Brasil S.A.
- EMBRAPA - Empresa Brasileira de Pesquisa Agropecuaria
- EMBRATER - Empresa Brasileira de Assistencia Tecnica e Extensao Rural
- Entisol - Soils of such slight or recent development that only one simple horizon occurs
- Eutrophic - Nutrient-rich (in this context)
- FAO - Food and Agriculture Organization of the United Nations.
- FBCN - Federacao Brasileira de Conservacao da Natureza
- FUNAI - Fundacao Nacional do Indio
- ha - Hectare(s) = 10,000 m² = 2.471 acre
- Hogfuel - Ground-up wood used for fuel
- IBDF - Instituto Brasileiro de Desenvolvimento Florestal
- IBGE - Instituto Brasileiro de Geografia e Estatistica
- INPA - Instituto Nacional de Pesquisas da Amazonia
- IPEA - Instituto de Planejamento Economico
- IUCN - International Union for Conservation of Nature and Natural Resources
- km - Kilometre(s)
- kw or KW - Kilowatt(s)
- Latosol - A tropical soil that has been leached red or yellow; a laterite
- MRN - Mineracao Rio do Norte
- MW - Megawatt
- Oligotrophic - Nutrient-poor (in this context)
- OPEC - Organization of Petroleum Exporting Countries
- Oxisol - Well drained, red or yellow acidic soils, very low fertility but good structure
- RADAM - Radar para a Amazonia
- SEMA - Secretario Especial do Meio Ambiente
- SPREN - Sociedade de Preservacao dos Recursos Naturais e Culturais da Amazonia
- Spodosol - Podzolic sandy soils
- SUDAM - Superintendencia do Desenvolvimento da Amazonia
- Synergist - An agent that increases the effect of another agent when combined with it
- Taungya - see Table IV, 4.3
- Terra Firme - Upland forest of most of Amazonia; never flooded
- TRF - Tropical Rain-forest (Biome), generally included in 'tropical moist forest', 'tropical damp forest', 'tropical humid forest', and 'tropical wet forest', but scarcely 'tropical swamp forest'.
- Ultisol - Soils with low but better fertility and poorer structure than oxisols
- Varzea - Low, seasonally-flooded lands, usually forested

APPENDIX

ACRONYMS, ABBREVIATIONS, AND GLOSSARY

- Alfisol - Soils like ultisols but much more fertile (more than 35% base saturation)
- Amerindian - American indigene especially of Latin America
- Ultisol - Soils with low but better fertility and poorer structure than oxisols
- Varzea - Low, seasonally-flooded lands, usually forested

FOOTNOTES

¹The tropical rain-forest (TRF) biome refers to most of the low-elevation forested part of Amazonia, which receives approximately 2–3 metres of rain annually, with little or no dry season. The forest is composed of large evergreen trees with a closed canopy, and more different species per unit area than, possibly, any other biome in the world. About 70% of the soils are of the poor oxisol and ultisol types, with some alfisols and entisols (somewhat more fertile), and spodosols (even less fertile).

²'Leave TRF alone until research demonstrates sustained yield': Director of the Aerospace Technical Center, Brigadier-Major do Ar Pedro Frazao de Madeiros Lima, CETESB conference, 1979.

³'Orthodox analysis': as calculated by most national governments, international development agencies, investors, etc.—'economically feasible' in the traditional, conventional sense. This excludes the non-establishment economics which is environmentally greatly more meaningful, such as steady-state economics and 'improvement rather than growth'—as expressed, for example, by K. Boulding, H. E. Daly, N. Georgescu-Roegen, E. J. Mishan, *et al.* While this is more significant to society, it is not the topic that is addressed in this paper.

⁴World distribution and general information of the disappearing TRF: Bastos *et al.* (1974), Persson (1974), Brunig (1975), Moraes (1975), Bene *et al.* (1976), Schubart *et al.* (1976), Sommer (1976), Schubart (1977, 1978), UNESCO (1978), Brown (1979), and U.S. Interagency Task Force (1979). Pires (1974, 1978) outlines the distribution of Amazon forest types.

⁵Estimates vary widely, depending on what is considered Amazonia; the difference between intact, logged-over (creamed), cut, and burned; which satellite or radar imagery photographs are used; total of tracts purchased, concessions allocated (but not necessarily cut), etc.; and many other variables, pointing to the need for reliable monitoring. Five disparate estimates are provided: (*vide* Kerr, 1979) (1) '... nearly all tropical wet lowland forest will have been cut within one generation...' Warwick E. Kerr, Director of INPA, in 1976; (2) Agricultural Commission of Senado Federal '... within 27 years ... there will exist no more trees [?forests] in Amazonia ...' in 1976; (3) Rene Antonio Novaes, Director, National Space Research Institute, Sao José dos Campos (São Paulo, at the first Brazilian Symposium of Remote Surveying (Jan. 1979): four million hectares deforested of the 55-millions study area (borders of Mato Grosso, Para, and Goias) (comprising 25% of Amazonia) covered by the 32 Landsat photos; (4) Same symposium projected that possibly '10% of the total area of Amazon rain-forest could have been cleared by now'; (5) Deforestation of 25% of the original forest area is the highest estimate. Those are put in perspective by Mahar (1979), who estimates that 30,000 km² may have been deforested and the wood largely wasted during implementation of SUDAM projects (a total social cost of US\$1,000,000,000). Kerr (1979) cites two estimates for the 'duration' of the Amazon forest assuming continuation of present trends; 30 years by Harald Sioli and 60 years by FAO.

⁶Cerrado is well-documented by four detailed symposium proceedings (Ferri, 1963, 1971, 1976; Labouriau, 1966), and an annotated bibliography (Briquet, 1976). Cerrado ecology is outlined in Goodland (1975) and Goodland & Ferri (1979), and compared with forest by Goodland & Irwin (1977a, 1977b). The best description remains that of Warming & Ferri (1973). Cerrado soils and potentials are described in IPEA (1973) and by Lopes (1975).

⁷Location, description, and demise, of Amerindians can be found in Dostal (1972), Brooks *et al.* (1973), Davis & Mathews (1976), Davis (1977), Bourne (1978), and Goodland & Irwin (1978).

⁸Most of the economic data in this paper are taken from the useful studies of Skillings & Tcheyan (in press) and Mahar (1979). Mineral resources in Brazil are described by Abreu (1973). Other economic and general information is from Klein-

penning (1975, 1978), Sioli (1975), Katzman (1976), Kohlepov (1976, 1978), and Cardoso (1977).

⁹The migratory turtle (*Podocnemis expansa*) and the Trombetas Biological Reserve (IBDF) are described by Alho *et al.* (1979). This turtle is being commercially and successfully bred in captivity at Juriti.

¹⁰Amazonian fish potential can be found in *Acta Amazonica* and in *Amazoniana*. The best sources are Smith (1977, 1978a, 1978b, in press) and Goulding (1979, in press). Sioli (1968, Sioli *et al.* (1969), Lowe-McConnell (1975), Bayley (1978), Bayley & Moreira (1978), and Goulding (1978) provide further details.

¹¹The major sources on preserved areas are IBDF (1978) and Wetterberg *et al.* (1976, 1978). SEMA's ecological reserves are noted in Minter (1977) and Reis (1978). Barrett (1976) and Pandolfo (1978) amplify, and Jorge (1978) notes that the IBDF goal is to preserve 18,500,000 ha in Amazonia. The Amazon's National Park will cover one million ha. The fact that atmospheric carbon dioxide concentration is rising, its relation to deforestation, and predictions for the future, can be found in Woodwell (1978) and Woodwell *et al.* (1979). Other possible climatic and oceanic changes are not dealt with here.

¹²The best paper on tropical sustained-yield agro-ecosystems is Janzen (1973). Parts of this Table are amplified by Barr (1968), King (1968, 1975), Pitt (1969), Budowski (1974), Kirby (1976), Schubart (1977), Smith (1978a), Goodland (1978c), and Goodland *et al.* (1978).

¹³Most of the forestry and tree-crop information is from Lanly & Clement (1979) and Spears (1979). Pandolfo (1964, 1972, 1979a, 1979b), Dubois (1971), Groulez (1975), and Volatron (1976), provide more background.

¹⁴Jari and related information is from Palmer (1976, 1977), Briscoe (1978), Fearnside & Rankin (1979), Norgaard (1979a, 1979b, 1979c), personal observations, and discussions with company staff.

¹⁵Livestock: Hecht's doctoral dissertation (in preparation) will be a primary source. Jesus & Santos (1977) wrote about pasture monitoring from Landsat. The RADAM reports are published (*Science*, 1977) but scarce and not easily available. Nutrient depletion is outlined in Brinkmann & Nascimento (1973), Parsons (1976), and Irion (1978). Mahar (1979) explores the economic implications.

¹⁶Environmental dimensions of hydroprojects are detailed in Ackermann *et al.* (1973), Baxter (1977), and Goodland (1978a). Environmental aspects of the Tucuruí project are discussed by Goodland (1978b). 'Low-head' and 'unconventional' perspectives are admirably provided by Cals (1977).

¹⁷Other energy projects are noted by Berutti (1976) and Uhart (1976), vegetable oils by Pandolfo (1964), and charcoal by Guerra (1973) and Earl (1975).

¹⁸Transportation: the ill-fated trans-Amazonian highway programme is documented by Goodland & Irwin (1975), Goodland & Bookman (1977), and Smith (1977, 1978a), and its overstrained carrying capacity by Moran (1976) and Fearnside (1978, 1979a, 1979b). Fluvial transportation literature is conspicuous by its absence; airships have scarcely yet been considered (Beier & Cahn-Hidalgo, 1973).

¹⁹Environmental aspects received increasingly strong support by the creation, in 1974, of the Special Environment Secretariat (SEMA), within the Ministry of the Interior, led by Dr Paulo Nogueira-Neto. SUDAM's department of natural resources, led by Dr Clara Pandolfo, improves SUDAM's activities. Lutzenberger's seminal 'Brazilian Ecological Manifesto' (1976) codified positions. SOPREN (based on Belem), a non-governmental environmental group, greatly assists in Amazonia, and FBCN (based on Rio) helps matters nationally. King (1977) assisted the Amazonian land-use and zonation movement. The timber 'Risk Contract' concessions are outlined in Schmithusen (1978) and Pandolfo (1979b). Nicholls (1973) provides support for the establishment of compensatory preserves. IUCN (1975) provides guidelines for development in humid tropical forest. Rumours of the Government's Amazonian policy engender guarded optimism.

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