Energy Systems
Overview
of the
AMAZON BASIN

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Report to

THE COUSTEAU SOCIETY

ENERGY SYSTEMS OVERVIEW OF THE AMAZON BASIN

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CONTENTS

ABSTRACT

This is a report to The Cousteau Society of results of research studies of the Amazon Basin using energy systems methods and models to gain overviews of the combined economy of humanity and nature. Energy systems analyses were developed for the Amazon, for Brazil as a whole, for tropical forest ecosystems, for tropical forest yield systems, sugarcane-alcohol, oil palm, cacao, and the hydroelectric dam at Tucurui. Energy systems diagrams, energy analysis tables, indices of economic contribution, and simulation models were developed to gain understanding of the processes and trends.

The original patterns of ecological and human settlements organized in a spatial hierarchy around the downstream converging river flows to the east are being complemented by a new hierarchy that includes the network of roads and pipelines converging to upland centers and also connecting with centers and resources of the Andes. The spreading economic development prevails over ancient patterns of nature because of additional energy resources, oil and hydroelectric power, that are brought into use in the region by the new infrastructures. At the current rate of use of the wood and soils, the economic stimulus these storages provide is greater now than will be the case later when virgin storages are gone.

In order to maximize the economic vitality during economic growth and later when resources of the world are not available to stimulate further economic development, the renewable environmental resources of the Amazon can sustain economic yields through a pattern of rotation in which the great species diversity is retained to facilitate the most rapid and inexpensive possible restoration of soils, wood, and other products. Long range patterns for maximum economic vitality may require four land uses: land in yield plantations; land in fallow restoration; small, well distributed areas of high diversity, complex "virgin forest" to supply the automatic reseeding of the restoration phase by plants and animals; and land in hierarchical centers, the towns and cities. As analyzed for the forestry plantation area at Jari, the time required for rotation for restoration depends on the availability of fertilizer and other inputs either from natural processes or from economic purchases.

Because of the many direct inputs from the environment in support of people, currency in Brazil represents more real products than that in developed countries. When this high-value currency is used to purchase fuels overseas, little net energy is obtained. Consequently, development of fuels from biomass is occurring sooner in Brazil than elsewhere. Whereas ethanol meets local needs for motor fuel its effect on the economy is neutral, not stimulating other aspects of the economy the way cheap fossil fuels have done in the past. Export sale of raw products, wood, agricultural produce, iron ore, ethanol, etc. contributes much more to the foreign economies than is received in payment at international exchange rates. Because of the higher buying power of currency, repayment and interest on loans is two or three times what is received initially for development.

CALYPSO
The Cousteau Society

PREFACE

Probably the most important problem humanity faces today is the sound management of natural resources and integration of human and natural processes. We need to understand both the human and natural domains, each in the context of the other, and we need to develop management strategies which acknowledge and promote the vital interconnections between them.

Traditionally we have had a reductionist approach to the study of the natural resources on which we depend, generally focusing attention on small units of living systems. Almost no attention has been given to studying the biosphere at the level of interactions between ecosystems and human systems. We view this as a tragic mistake since it is at this level that humans are presently exerting a major influence on the biosphere. It is at this broad or high system level where we have the most to gain, by designing systems which maximize the benefits from our environment. And it is at this level where we have the most to lose as we can potentially destroy entire ecosystems on which we depend.

Neither economics nor ecology alone are adequate to address the problems we presently face. Ecology per se does not include the human domain. Economics is even more limited in dealing with humanity-nature problems because of its assumptions and because it is totally anthropocentric, attributing value solely in terms of humans, and being unable to assess the total value of environmental processes and resources. The global economy, the consistent overexploitation of natural resources justified by "economic realities", and the regional degradation of the environment bear testimony to the limits of market theory to the human-nature relationship. Money is not an appropriate unifying concept or common denominator which can equate the goods and processes of both systems or deal with their distribution. It is also obvious that economics cannot be excluded from the discussion because of its importance to humans. We are convinced that energy is one entity which flows through and is stored by both systems. Evaluating energy, energy quality, and embodied energy enables us to quantify the flows and storages of energy in both systems. We are thus able to compare various resource uses and determine which strategies of development maximize the energetics of both human and natural systems; the appropriate use is the one which maximizes the flow and storages of energy because it is the strategy which will last the longest.

With a global reduction in available energy eminent, we are going to need careful evaluation of how best to use our energies and how to use more effectively the free services of nature. We will need to evaluate the needs of the human sector, including the economic domain in light of those of the natural system, ecology, to accept the fact that the two are inextricably bound, and then to develop the most appropriate technologies to enhance this mutualism.

Richard Murphy
Director of Science & Education
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I. INTRODUCTION

Increasingly, with new technologies, new concepts, and new attitudes humanity is learning to overview the larger systems of environment and humanity. Through television documentaries everyone is learning to think on the large scale of weather fronts, economic trends, and patterns of human development with nature. Because the water cycles of the earth are so important in the organization of the landscape, river basins form a natural unit for understanding, predicting, and planning for the future. The Amazon River Ecosystem is one of the greatest; important, not only to the nations of the region but increasingly part of the concern of the world consciousness.

Along with the development of films that vividly represent systems at close view and overview, some new scientific techniques help the mind comprehend and facilitate quantitative measurements of the forces and factors at work in growth and change. This study uses energy systems models to improve our overview of the Amazon River Basin System. With more understanding of what is happening, humans can emerge further in their new role as stewards of their own future. Like a zoom camera we have to look at the small processes of the great green system up close and the large mechanisms at a distance. First, we model the geologic, meteorologic, biotic, and economic factors of the basin as a whole. Next we look more closely to see how tropical forests work under natural and economic management. Finally, we back up to see how the world economic trends operating through the national economy are controlling important inputs to the basin.

Many questions are raised concerning development of the Amazon which the energy system models help to answer. How is development accommodated with destruction of resources? How is a balance maintained between humanity and sustainable land uses? How much diversity is necessary? How will international economic trends and decreasing availability of world resources affect the Amazon? What is the meaning of the depressed economy of Brazil of the early 1980's in the longer range trends? What will be the sources of fuels? What is the future of Amazon wood? How will river energies be used? What patterns of spatial development will occur? What infrastructure develops the best economy of nature and of humanity? How can biological species diversity be incorporated in economic development as a symbiotic contributor? What economic policies in world trade and within the Amazon nations will foster a sustained economy that uses environmental resource systems as a contributing partner rather than a temporary consumable to be eliminated.

Perspectives and Previous Studies

The Amazon basin is the largest tropical river system and largest stand of tropical moist and rain forests in the world. The diversity of plant and animal life is so great it is thought that there are many species within the basin yet unknown to modern science.

Brazil's population (approximately 68% of the Amazon Basin is within Brazil) has been growing at a rate of 3.2% per year. In recent years the Brazilian economy has been experiencing inflation at over 100% per year. The international debt of Brazil is the largest in the free world, creating great pressure to increase internal productivity and exports to meet interest payments. As Brazil continues to industrialize and segments of its population enjoy greater standards of living, there is increasing demand for forest products, agricultural land, and other resources found within the basin. Everywhere, there is pressure for conversion of forest land.

Roads are being constructed through out the basin to open lands for development. Enormous hydroelectric projects and mining operations convert large tracts of land to lakes and other uses. Conversion of forest land to pasture is an increasing trend with increased populations relocated from the south.

In all, the pressure to develop the Amazon Basin is great, with worldwide concern over the loss of the tropical forest and its species and the effects of such losses, possibly with effects on global carbon balance or ocean productivity. There is also concern over the extinction of species, some of which remain to be discovered. While the Brazilian government and the world development community are moving quickly to develop the Amazon Basin, the world environmental community asserts that development in the basin should be under tighter controls.

Global Perspectives

Projections for world population indicate an increase of 2.5 billion people by the year 2000. Of this increase, almost 90% is expected to occur in the so called undeveloped countries of the world (Johnson 1976). Projections of world food supply and demand indicate that an additional 2 million km^2 must be put into cultivation before the turn of the century just to maintain the present, largely inadequate, levels of food production in the developing world (Sanchez et al. 1982). In addition to these pressures for food, a doubling in the demand for wood between 1970 and 2000 is expected (Johnson 1976).

Several land resource studies indicate that the greatest potential for agricultural expansion into virgin or underutilized lands lies in the humid tropics (Brown and Eckholm 1975; Kellman 1980; Alvim 1977; Dalley and Hudson 1977; and Sanchez et al. 1982). The humid tropics is that part of the world with a variation of less than 5° C in mean monthly air temperature between the three warmest months and the three coldest months, and no more than a 4-month period in which potential evapotranspiration exceeds precipitation (Sanchez et al. 1982). They cover approximately 18 million km^2 or one tenth the continental land surface (Brown and Lugo 1981). For the most part the native vegetation is tropical forest.

Tropical Forests

Tropical forests account for about half the world's forest area, 46% of the world's living carbon pool, and 11% of the world's soil carbon pool (Brown and Lugo 1981). They exhibit tremendously high biological productivity, yet tremendously low economic potential. Goodland (1980) suggests that the increase in human well being or the amount of economic return accruing per unit area transformed will probably be less in tropical forests than in any other biome of the world. From an ecological point of view, the main limiting factors are low soil fertility and excessive rainfall (Alvim 1977).

The high levels of production in such depauperate nutrient environments are enabled by extremely efficient nutrient conserving structures and associations. Of these, perhaps the most important is the sponge-like character of the dense mat of roots and humus. Direct physical adsorption of nutrients occurs. Stark and Jordan (1978) found that, in rain forests in the Amazon territory of Venezuela, 99.9% of all Ca 45 and P 32 sprinkled on the root mat was immediately adsorbed. Mycorrhizal fungi provide an avenue for transfer of nutrients from a decomposing leaf to roots. Algae may take up dissolved nutrients from the rainfall that reaches the forest floor. Microorganisms in the root mat may fix nitrogen. The canopy leaves in the Amazon forests, with their associated cover of algae and lichens, scavenge nutrients from the rainfall. Thick, long-lived leaves reduce vulnerability to insect damage and reduce the need for additional nutrients to replace or rebuild lost or damaged leaves. Translocation of the more mobile nutrients occurs prior to leaf shedding. Toxic compounds are typically produced to inhibit herbivory (Jordan 1982).

Natural Rotation in Rainforests

Gaps occur in forests due to treefalls caused by natural mortality, wind, loss of structural integrity due to herbivory or disease, and other disturbances. The rain forests of the world exhibit an efficient self-regeneration system through the process of secondary forest succession (Gomez-Pompa et al. 1972). Regeneration of trees following disturbance depends on a source of seeds or seedlings. Sources include seeds that were dispersed and remain viable in the soil prior to disturbance, seeds dispersed into the disturbed area following destruction, and shade tolerant seedlings of young plants of many of the primary tree species. These dormant seedlings, upon exposure to increased light following disturbance, continue to grow but at greatly increased rates. At the same time, the secondary species begin to grow from seeds. After several years the primary species outgrow the secondary opportunists, and the major step in regeneration is accomplished (Gomez-Pompa et al. 1972; and Ewel 1980b).

The removal of large groups of trees results in relatively large changes in light intensity, humidity, air temperature, and soil temperature. Shade tolerant tree seedlings often cannot survive these abrupt changes in microclimate. At the same time, the greater sunlight in these large canopy openings allows fast-growing, shade intolerant species to colonize (Uhl 1982). These secondary communities derived from the tropical rain forest are gradually replaced by primary forest species provided seeds, animal vectors, and microbes are near (Harcombe 1980).

Up to 80 to 90 % of nutrients in tropical forests are bound in the plant biomass (Russell 1983). These are consumed or lost to the system when the forest is cut and used for agricultural purposes.

Shifting Agriculture

Shifting agriculture by primitive cultures with few economic inputs has been a natural way to use the regenerative properties of the rain forest for the benefit of man. It is the predominant farming method on roughly 30% (3 million km^2) of the exploitable soils of the world and supports over 250 million people (Uhl et al. 1982). The strategy employed in shifting cultivation of short-term land use followed by longer periods of fallow, ecosystem succession provides for adequate nutrient accumulation in the fallow periods to support annual crops during cultivation. The threshold beyond which such a strategy cannot be successful is surpassed when clearings are made too close together or repeated on the same place without sufficient time for regrowth (Sioli 1980). Such a strategy of land use shifting cannot be sustained beyond 10 individuals per km^2, a figure which has already been exceeded at current levels (Goodland 1980).

Under intensive and extensive use of the land, sources of seeds of primary tree species for regeneration become less and less available because of the short-range dispersal characteristics of those species and because of the scarcity of individuals of most of the tree species. The only species available that are preadapted for continuous disturbance are secondary species (Gomez-Pompa et al. 1972). Regeneration of the native forest is impeded. Nutrient conserving mechanisms are lost and nutrient limitations quickly result in declining productivity.

As development increases in intensity and extent, regeneration capabilities with regard to nutrient status, resistance to pests and disease, and species richness decline rapidly. Major trends in agricultural land use in the tropics are clearly moving towards more frequent and intensive agricultural manipulation of increasingly extensive areas. Resultant selection for weed species of short life cycles, high fecundity, and seed dormancy capabilities is to be expected. Secondary succession taking place on such sites is a much reduced version of tropical forest succession. In many areas, the invasion of primary tree species may never occur. The result could be extensive parts of the tropics covered by "floristically depauperate and quasi-stable communities of grasses, forbs, and shrubs" (Kellman 1980:39).

This view of permanent destruction of forest resources is not shared with equal vigor by all. Harcombe (1980:11) states that, while human influences on seed sources certainly will slow succession, "there is little doubt that the climatic climax would ultimately re-establish itself, though probably only after a very long time." A long time is later judged to be probably less than a few hundred years. Ewel (1980a:1) states that, "Just as successional communities reflect human destruction, they also signify high productivity and potential for net yield . . . Nature abhors a vacuum, so sites laid bare by human activity are quickly covered by some kind of community."

Deforestation of Tropical Forests

The issue of regenerative capability of tropical forests after large scale disturbance remains unresolved. Consequences of large scale deforestation may include:

1) loss of top soil structure;
2) loss of scarce nutrients;
3) extinction of numerous species;

4) climatic changes, particularly rainfall distribution; and
5) erosion of soil base, especially in areas of more extreme topography (Sioli 1980; Medina 1982).

Estimates for rates as well as definitions of deforestation vary widely. Forest conversion can range from marginal modification to fundamental transformation, i.e., highly selective timber extraction to shifting agriculture with maintained potential for primary forest regeneration to transformation or total forest destruction (Myers 1980). Rates of conversion are estimated at between 100 to 200 thousand km^2 per year (Myers 1980) and 70 thousand km^2 per year (Lanly 1982) in the two most recent major analyses of tropical deforestation rates. Yearly percentages are calculated at 0.75 - 1.09% (Lugo and Brown 1982) compared to the figures of 1.2 and 3.5 % for the rates quoted above.

Whatever the actual rate, it is a vastly significant portion of our globally huge reserves of topical forests. Small scale slash and burn type shifting agriculture receives the blame for the majority of deforestation (Uhl 1983), but the natural system's ability to revegetate is much greater in disturbances of small size because of the availability of seeds and animal activities. When a forest opening of one hectare or less is made, no permanent damage occurs (Herrera et al. 1978). Destruction for the purpose of establishing pastures and tree plantations is on a larger scale and may revegetate much more slowly.

Development in Amazonia

The Amazon basin of South America, along with sub-Saharan Africa, provides the only region of the tropics with sizable portions of well watered, potentially arable land. Development there accounts for a large proportion of global deforestation.

"Ultimately, Brazil may need to look no further than the Amazon for all the financing it could possibly use." (Meadows 1981). Such statements are indicative of a prevalent notion about the potential for economic development in the Amazon. In contrast, the premise of "an Amazon full of rich potentialities awaiting development to yield copius and abundant profit and lasting benifit has only recently emerged as being tragically false." (Goodland 1980).

Legal Amazon, that part of Amazonia within Brazil, covers approximately 5 million km^2, one third the area of the continental United States (Sioli 1980). While far from being a homogeneous stand of tropical forest, it is still the largest continuous mass of tropical forest in the world (Palmer 1977; Klinge et al. 1981).

Sustainability of Amazon Soils

The soil is probably the most crucial factor in the outcome of development projects in the Amazon basin (Sanchez 1981; and Alvim 1977). 75% of the Amazon basin is dominated by soils classified as oxisols and ultisols. They are deep, well drained red or yellowish with favorable physical properties, but are very acid and deficient in plant nutrients

(Sanchez et al. 1982). In spite of widespread soil infertility, both biomass and production levels of the Amazon rain forest exceed substantially those of humid temperate forests. High annual production is matched by sustained litterfall. Decomposition is rapid. Nutrients in organic debris promptly become available for uptake and storage by plants, and rapid recycling occurs (Eden 1979).

Phosphorus deficiency is found in 90% of the soils. Fortunately, only 16% have the tendency to immobilize large quantities of phophorus into insoluble forms. Other limitations include soil acidity, associated aluminum toxicity, deficiency of Ca, Mg, S, Zn, and low cation exchange capacity. The well publicized problem of laterization (Goodland and Irwin 1975) is less important since only 4% of the soils in the basin have the potential for laterite formation upon loss of topsoil. Limited laterite formations have been useful for road building materials (Sanchez 1981).

Jordan (1982a:398), referring to low nutrient soils of central Amazon, states "Amazon forests cannot be clear-cut over large areas, burned, and then expected to produce crops for more than a few years." Further, most upland soils are unsuited to continuous agriculture when intensive fertilization is not available (Jordan, 1982a). In early work by Duke and Black (1953:3), the result of crop use of cleared forest soils might be "scraggly second growth which will never return to true climax forest." Sioli (1980:712) states that "eventual substitution of lost nutrients by mineral fertilizers is illusory, because of the low adsorption capacity of the kaolinitic soil."

Sanchez (1982) draws the conclusion that production of food crops is possible in oxisols and ultisols of the Amazon basin with correct agronomic practices. Economic, apparently sustainable, agricultural projects have been demonstrated in the western Amazon, where soils are regularly renewed by flood deposited sediments from the Andes. Finally, Harcombe (1980:10) states that although native fertility of the tropical soils may decline rapidly, "there seems to be a growing concensus that in most cases they respond well to fertilization and can sustain permanent agriculture if proper precautions are taken to prevent erosion." Apparently, soils in most areas lose quality with use eventually requiring land recycle and/or expensive inputs such as fertilizers to maintain economic production.

Transamazonian Highway

In 1970, the Brazilian government announced plans to integrate the Amazon region with the rest of the country. The forest was to be criss-crossed with a web of pioneer highways. From 1972-1974, the whole of Brazilian Amazonia was covered systematically by radar and color infrared and multiband photography. The 330 km trans-Amazon highway was completed in 1975 (Palmer 1977). The anticipated development of the region has failed to materialize (Palmer 1977, Eden 1979; Goodland 1980; Henley 1982).

Initial goals of the development scheme were to 1) provide access to new areas for the drought and poverty stricken families of the northeast; 2) help fill a demographic void in a region occupying half of Brazilian territory but only 4% of the population; and 3) create access to mineral and timber reserves within the basin (Smith 1981). Development along the highway has occurred in three phases: initial attempts at small tract colonization; primarily large scale cattle ranching operations; and slackening of operations due to low productivity and lack of governmental incentives (Henly 1982).

By 1973, after only 8,000 of the anticipated one million families settled along the highway and half of the original land purchases had already been resold, the highway was opened for large scale entrepreneurs, mostly cattle ranchers. Reasons for the dismal failure of most of the colonists included poor soils, poor crop choices, innaccessability to markets due to road traversability problems, and innappropriate financing schemes to assist farmers. Quite simply, it was not enough to open up frontier areas with highways, divide the land into parcels, provide credit with dubious restrictions, and expect largely illiterate farmers with few capital resources to flourish (Smith 1981).

Cattle ranching became the most widespread form of land use. By 1977, an estimated 15000 km^2 had been transformed into pasture use. In addition, 150,000 km^2 of natural grassland and 15000 km^2 of varzea (floodplain) grasslands were being used for cattle operations (Fearnside 1983). Fiscal incentives by the Brazilian government were prevalent, including forgiving up to 50% of income tax, low interest loans for development, and duty free imports of machinery and equipment (Management 1976; Dalley and Hudson 1977). This phase of development was even more damaging. As outrage and awareness, both within Brazil and internationally, grew over the loss of huge amounts of forests, conservationist ethic and environmental movements raised the controversy to a level adequate to affect the policy makers.

By 1979, the government declared a moratorium on SUDAM (Superintendent of Development in Amazonia) approval of fiscal incentives for new ranching projects in classified rain forest lands. Cerrado (scrublands) and transition lands continue to receive incentives (Eden 1979). Coupled with rising interest rates in the United States, large scale cattle ranching investments declined in the region of the highway (Goodland 1980; Henley 1982). Elsewhere in the basin, cattle ranching and wood extraction for charcoal and timber continue to expand (Fearnside 1983).

Tree Plantations

Ecologically, the situation for forest plantations in the Amazon is somewhat better than for annual crops. The use of soils of the humid tropical regions for the production of perennial tree crop production is the best known and least controversial of agricultural uses (Sanchez 1981). They are considered the most appropriate type of land use for tropical regions (Eden, 1979; and Alvim 1981). The productivity of Amazon ecosystems may not decline immediately after cutting. Burning of the cut forest usually consumes only a small proportion of the felled trees, root systems, and other biomass left after clearing. The remaining debris, or slash, releases nutrients through decomposition. If the first crop following conversion is a tree plantation, vegetation often becomes established before the slash is completely decomposed and thus can take advantage of the leaching nutrients (Jordan 1982b). When the trees are established they mimic the nutrient cycling capabilities of the rainforest they replaced (Sanchez 1981). Sustaining plantation monocultures may be precarious requiring weeding, fertilization, and pest control (Eden 1979).

JARI

In the mid 1950's, United States shipping magnate Daniel Ludwig financed and developed a system of tropical forest plantations and an associated pulpmill on the Jari River in northeastern Brazil. Criteria for site selection were 1) an apparently stable government receptive to foreign investment, 2) a large uninterrupted block of land at a reasonable price, 3) a moist or wet tropical climate, and 4) a deep water port (Briscoe 1983). The resulting location was to become both the largest individually owned tract of land and the world's largest tree farm, Jari Florestal e Agropecuaria, hereafter referred to as Jari (See Figure 1). Price for the 1967 purchase was 3 million dollars or about $1.90 per hectare (Kinkead, 1981). The 16,000 km^2 tract of land is larger than the state of Connecticut. It lies on both sides of the Jari River, the last major northern tributary of the Amazon River, at 0 50' S and 53 W. Original access was restricted to occasional river boats from the closest city, Belem, some 300 km away (Briscoe 1983).

Annual rainfall averages 2,300 mm, with October and November being the driest months; April and May the wettest. Normal daily temperature range from 22-26°C (Briscoe 1983). Soils vary tremendously from deep organic to sand dune alluvium and deep kaolinitic clays (Russell 1983). Over half of the estate, however, the soils are loamy clays with a relatively high proportion of exchangeable bases (Greaves 1979).

The first species planted was *Gmelina arborae* Roxb., an exotic from India, hereafter referred to as Melina. The same characteristics that make it successful within its natural range (rapid growth, prolific seed production, high competitiveness) enable it to become a successful naturalized exotic, especially in heavily disturbed areas (Ewel 1980b). It is frequently praised for the ease with which it can be established in plantations and the readiness with which it coppices (sprouts basally) to give second and later rotations. It grows best in loamy clay soils (Greaves 1979).

In 1969, large-scale land clearing and planting of Melina was begun as part of the proposed silviculture, pulp manufacture, rice growing, mining, and logging project. Initial forestry development called for the clearing and replanting of 2,000 km^2 by the mid 1980's (Greaves 1979). Native timber was originally burned on site. In later years, 50-65% of the above ground biomass was removed for railroad ties, pulp, saw timber (less than 2%), and primarily fuelwood to supply the boilers in the electrical generating process (Russell 1983; Fearnside and Rankin 1982).

As management officials quickly realized, the choice of land clearing methods is the first and probably most crucial step affecting the productivity of farming in the tropics (Sanchez et al. 1982). Mechanized land clearing techniques were abandoned after compaction and topsoil loss problems became evident in low growth rates in the initial two or three seasons of plantation establishment (Briscoe 1983). Upon switching to labor intensive clearing methods, 2000 laborers were brought in. Initially, they were managed by local contractors. Government inspectors required improved housing and wages. That was the start of the city of Monte Dourado and the six million dollars per year social costs required from the project to maintain it (Kinkead 1981).

When it was found that Melina was not suited to the sandy oxisols and ultisols, Pinus caribaea Morelet var. hondurensis Barr and Goff was planted in place of Melina on the sandier sites. Since 1979, Eucalyptus spe. have also been planted widely on marginal soils. In 1980, approximately 65% of the Jari plantations were on sandy oxisols and ultisols (Russell 1983).

In 1976, a Japanese firm was contracted to build a 250 million tonne per year capacity pulpmill and supporting wood-fired electric generator. The complex of barges was floated across three oceans to Jari and, in early 1979, the first pulp was produced. Original estimates for the cost of the project's capital investment were in the vicinity of 300 million dollars, but soon were approaching one billion dollars. In 1978, after already laying the foundation for a second paper mill, attempts to find financial assistance for that mill and support for a dam to generate electricity to run the mills faltered (Kinkead, 1981). The electrical plant currently runs on virgin forest wood. The project, excluding rice operations, was sold to a Brazilian consortium of 27 firms in 1982 for 280 million dollars, just over one quarter of the total investment in the project (Kinkead 1981 and Fearnside and Rankin 1982).

When the author visited in April, 1983, operations were continuing with the area of plantations at 1,000 km^2 and still expanding. The trees continue to grow. Outbreaks of pests such as a 300 ha, 12 week long epidemic of lepidopterous larva in 1977 have collapsed. Examination of the dead larvae indicated local pathogens caused the collapse (Briscoe 1983). Soil nutrient studies have shown little nutrient loss due to leaching and in some cases actual accrual of nutrients has been observed. However, net loss of plant nutrients accompanies the harvests of both native forest and plantation wood (Russell 1983).

Methods

Overviews and understanding of the Amazon Basin were sought with energy systems methods that use models to analyze and synthesize knowledge about the systems of humanity and nature on three scales of size: (a) the larger national economies, to which the river basin contributes, (b) the river basin itself, and (c) component land use systems, the forests and agroecosystems. Model diagrams were used to organize and express structure and relationships. Aggregated versions of these models were computer-simulated to learn the temporal consequences of resources, relationships, and policies built into the models. After aggregated diagrams were developed, embodied energy analysis was used to measure the economic importance of various inputs, processes, and accumulations. From the embodied energy tables various ratios and indices were calculated to provide perspectives on trends and preferred policies.

Energy Diagrams of Models

Energy systems diagrams were drawn using symbols and language conventions provided in a number of texts (Odum, 1971, 1983). Some explanations of the main symbols are given in Figure 1. After a boundary of the system is indicated with a rectangular frame, outside influences are shown with source symbols (circles) arranged from left to right in order of increasing energy transformation ratio (See definitions in Table 1). Within the frame main components such as producers, consumers, storages, and interactions are shown again arranging symbols from left to right according to energy intensity. Then pathways are connected between symbols. The way the pathways are joined to each other and to the symbols indicates the mathematical relationships such as adding, multiplying, integrating, etc. The energy diagram provides a visual overview of the system. The diagram represent hierarchy from numerous smaller items on the left converging to fewer larger-territoried items on the right. Flows of money are included as dashed lines and related to other flows by prices. After a diagram is produced, a simpler version may be developed by aggregating (combining) some units that were shown separately in the first inventory.

Computer Simulation

The mathematical relationships are readily inferred from the diagram since each pathway has a characteristic mathematical term that goes with each kind of symbol-pathway pattern. Thus a set of differential equations may be written by inspection, one equation for each unit in the diagram that has storage properties. From the equations microcomputer simulation programs were written in Fortran or Basic. To calibrate the coefficients of the model's equations, values of storages and flows were written on the energy diagram pathways where it is easy to compare and check numbers. For example, flow of money in and out of a system could be set equal, thus calibrating at steady state to simplify calculations of coefficients. After substituting a number for each flow and storage in a mathematical term in an equation, it was solved for the coefficient value. Then the coefficients

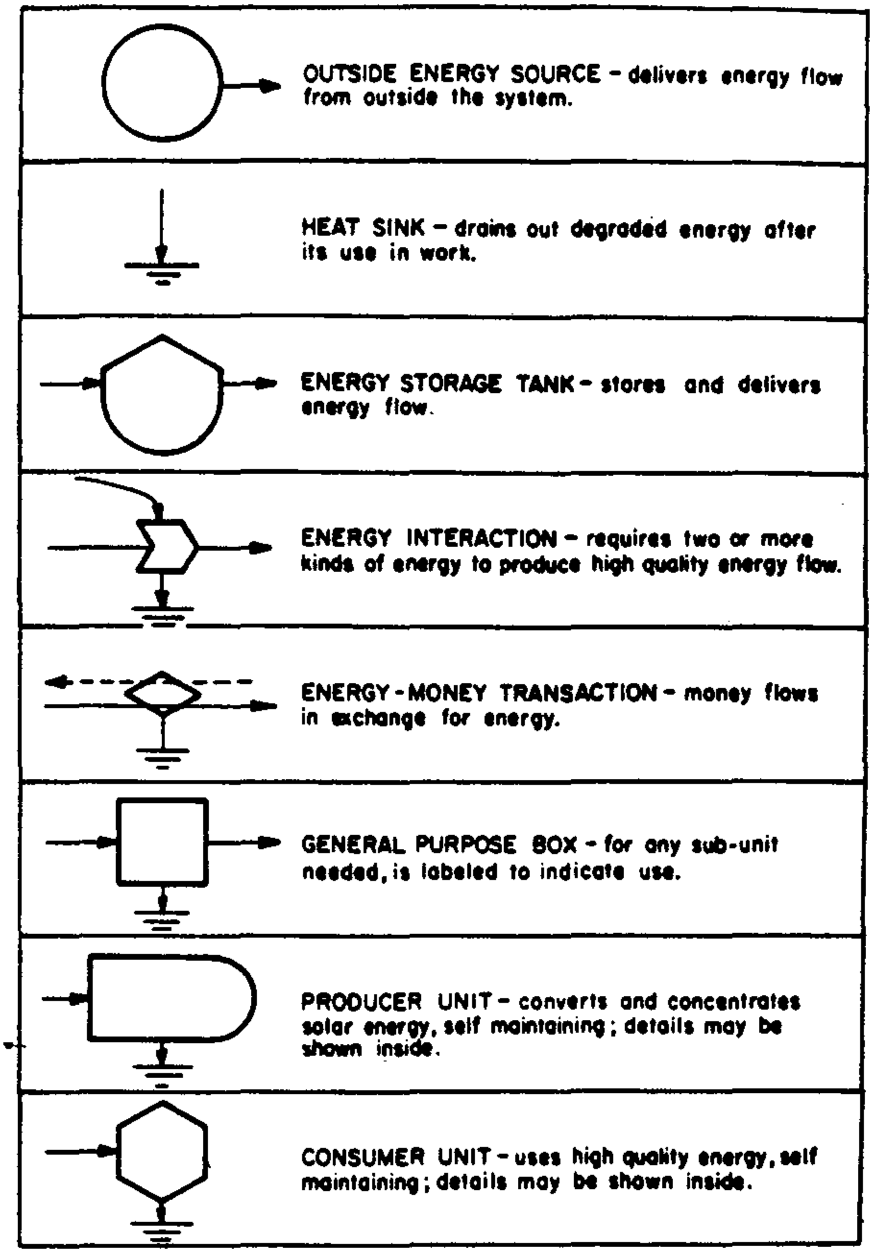


Fig. 1. Energy language symbols.

Table 1. Definitions.

Embodied energy *	Energy of one type required to generate a flow or storage of matter, energy, information, or whatever
Energy transformation ratio*(theoretical)	Energy of one type required to generate a unit of energy of another type in a system adapted for optimum efficiency and maximum power
Energy transformation ratio*(practical)	Energy transformation ratio observed in a surviving real system
Solar energy transformation ratio*	Embodied solar energy per unit of energy of a particular type
Net energy yield ratio	Ratio of embodied energy yielded per embodied energy of the same type of energy fed back from the economy
Energy investment ratio (Economic-environment ratio)	Ratio of embodied energy purchased from the economy to the input of embodied energy of the same type from the environmental resources
Gain from sales	Ratio of embodied energy in the buying power of currency recieved to the embodied energy of the same type in a product sold

*Names being considered for these measures:
embodied energy = emergy; energy transformation ratio = transformity

were entered in the computer program. Graphs were generated by the computer run showing the nature of growth, leveling, oscillation, etc. that the set of assumed relationships and values generates.

Embodied Energy Analysis

After the initial energy diagram was simplified by aggregation to show the main inputs and flows, embodied solar energy was calculated for the main flows and storages of interest. The embodied solar energy is the solar energy that would be required to be used directly and indirectly in the process of generating a flow or stored quantity. The procedure for calculating the embodied solar energy is to set up a table in which the first column has the energy of the flow, whatever the type of energy.

Then in the next column energy intensities are given as derived from other studies. Solar energy embodied per unit energy (solar energy transformation ratio) is the ratio between the solar energy required and the energy of the type in the pathway. For example, about 40,000 Joules of solar energy are estimated as the necessary amount to generate a Joule of coal (Odum and Odum, 1983).

Finally, the energy values in the first column are multiplied by the energy intensities in the second column to obtain the solar embodied energy in the third column. Using the diagram to avoid double counting, sums and ratios can be calculated. By expressing inputs or production in units of solar embodied energy, flows of entirely different type may be expressed in units that can be added to determine the total contribution that has gone into a product. The solar embodied energy is a common denominator that is believed to evaluate the amount of one commoditiy that is substitutable for another.

Embodied Energy Criteria for Economic Evaluation

Useful indices that use embodied energy for inference are included in Table 1. The embodied energy measures the contribution to an economy of nature or of humans. By proportion a dollar equivalent may be estimated. The percentage that the embodied energy of a process is of the total economy's budget of embodied energy is the percentage that that process is of the gross national product.

Fuels may be evaluated with the net energy yield ratio which is the ratio of yield to the inputs supplied by the monied economy. If a source of fuel has a lower net energy yield ratio it means that it uses too much input to be economically competitive with sources with higher ratio.

The embodied energy investment ratio is the ratio of the inputs from the economy to the free inputs from the environmentals resources. The ratio is useful for determining the relative contribution of free inputs. A process to be competitive must have as much free input as competitors. The ratio also measures environmental loading. A high ratio means that the environment is loaded with economic inputs.

By analyzing the main embodied energy inputs of a whole country and dividing by the gross national product an energy to dollar ratio is found for that country. This can be used to estimate the embodied energy that goes with paid services. The embodied energy per person is a useful measure of total contributions to the person's existence. Rural people receive more embodied energy basis for their existence directly without money payment than city people. In this case money does not measure their relative standard of living.

The benefits from buying and selling may be inferred from the relative magnitudes of The embodied energy in the trade. The balance of embodied energy is very different from the balance of money payments. Money evaluated the human services. The embodied energy includes all inputs including those of human service, of fuels, and environment.

Policy Criteria

The embodied energy concept is used to choose between alternative plans and policies. Alternatives with higher embodied energy inputs to an economy increase its vitality and competitive position. It may be expected that in the trial and error process of open markets and human individual choices, the pattern that generates more embodied energy will tend to prevail and be copied. Recommendations for the future likely to be successful are those that go in the direction of the natural tendencies as predicted by selecting that which maximizes embodied energy.

II. AMAZON BASIN

Our efforts here to overview the Amazon Basin with models begins with a systems diagram of the Amazon's environmental and human components and the main driving forces of the surroundings and the external world economy. In the first section the main flows responsible for the economy of humanity and nature are evaluated in units of embodied energy, an analysis that suggests future trends and shows the position of the Amazon among world regions in the scale of world hierarchy and economic development. The second and third sections consider the western Amazon and the development of hierarachical organization relative to the Andes. A computer simulation of the patterns of spatial development in the Amazon shows visually the consequences of the assumptions about external available energy and investment couples with the principles of hierarchy.

ENERGY SYSTEMS OVERVIEW OF THE AMAZON BASIN

M.T. Brown, R.A. Christianson

Introduction

The Amazon Basin (Figure 1 and Figure 2) is a region of vast environmental resources comprising approximately 700 million hectares and "belonging" to five countries (Brazil, Bolivia, Colombia, Ecuador, and Peru). Over 68% of the basin is within Brazil, yet the greatest density of development is found in the Andean parts of the basin in Bolivia, Ecuador, and Peru. There is significant development at Manaus and Belem on the Amazon River in Brazil. The Carajas Mountains on the south contain seemingly vast mineral resources and recent major discoveries have been made. The Trans-Amazon Highway crosses the basin south of the river and has opened much of the southern basin for development. Homesteading and conversion of forests to agricultural uses is evident along the entire length of the highway. There are hydroelectric installations on the Araguari and Vatum rivers, with seven others in various stages of construction on other rivers throughout the basin. To the north of the Amazon River on the Jari River is the Jari Florestal project, first developed by Daniel Ludwig and most recently owned by a consortium of Brazilian companies. In the very remote areas of ~~the~~ basin shifting cultivation is still the predominant land use, although wherever roads and railroads are built, allowing homesteading, more permanent agricultural cultivation is attempted. The most dominant aspects of the basin are the Andes in the west, which contribute a constant supply of eroded materials to the basin, and the dendritic pattern formed by the river and its tributaries.

Energy Value Tables

An evaluation of the inflows of energy to the basin is given in Table 1. The embodied energy in the inflow of chemical potential energy inherent in rainfall is the largest. The physical work of flowing water in streams is second largest, but when evaluated as hydroelectric energy (line 14) currently being generated, it suggests that the potential has not been developed. When

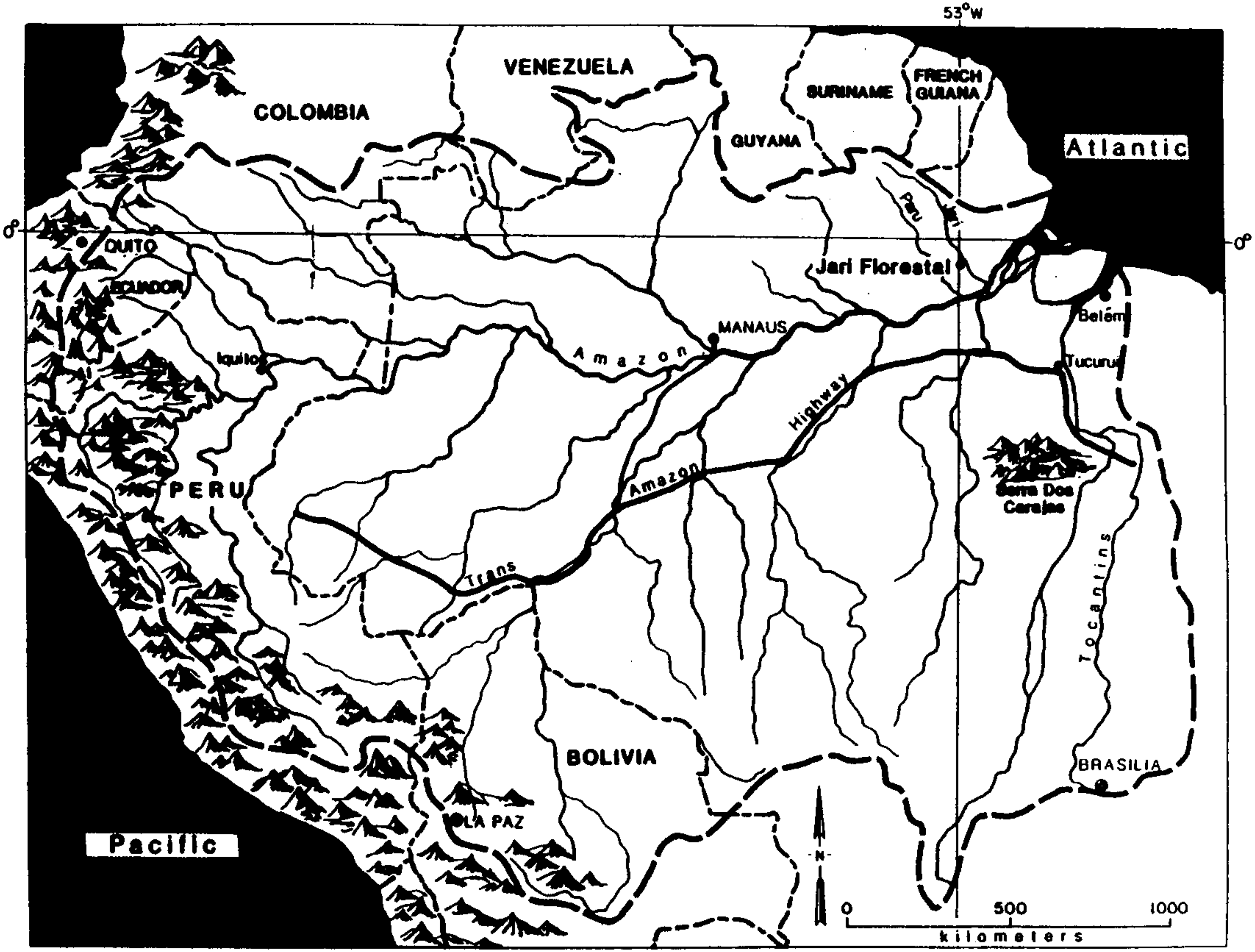


Figure 1. Map of the Amazon Basin showing main features and cities and the locations of Jari Florestal and the Tucuruí hydroelectric dam.

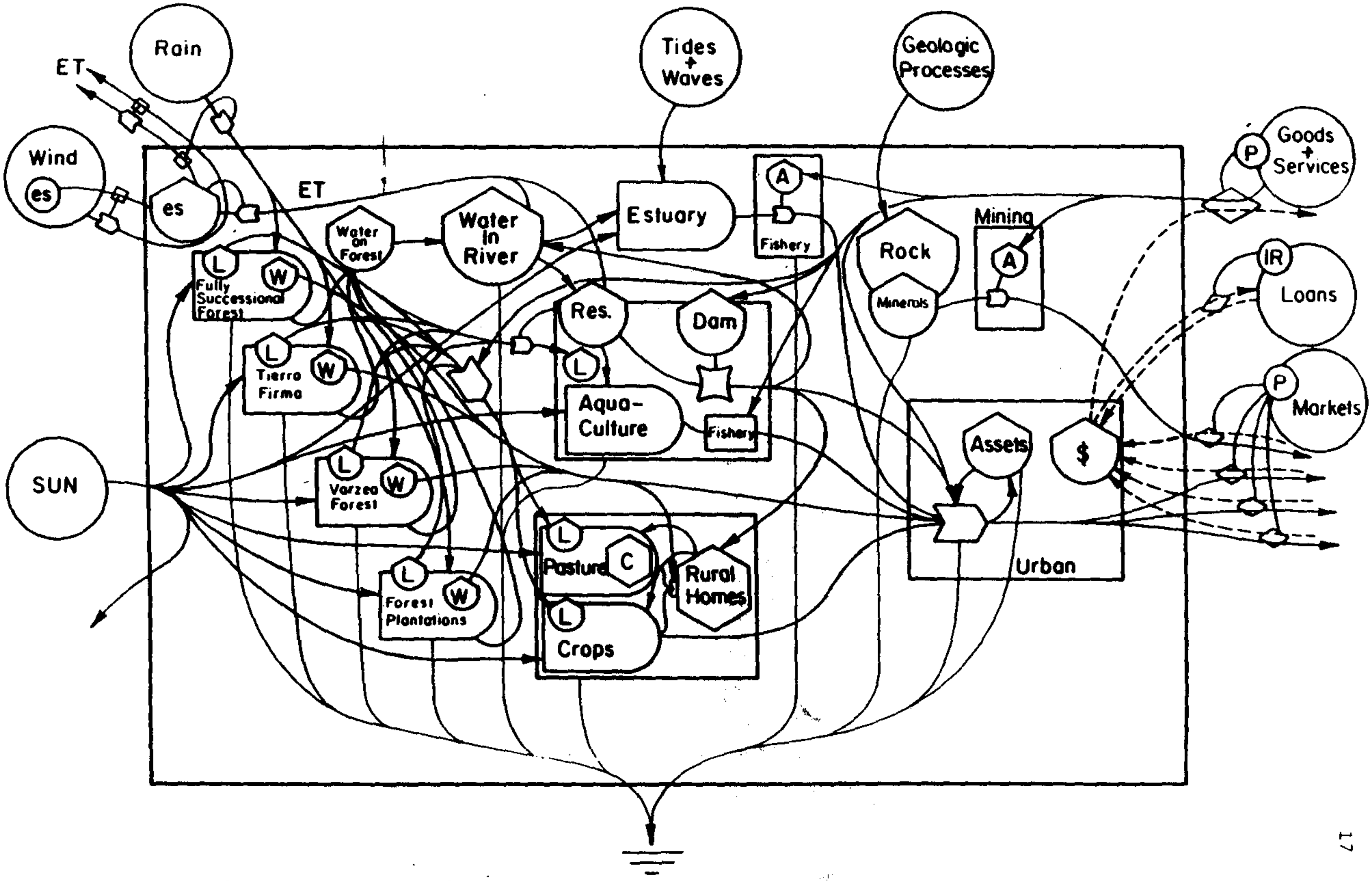


Figure 2. Energy diagram of the Amazon Basin showing forest areas, hydroelectric dams, rural land uses, and urban lands. Letters in symbols are the following: ET = evapotranspiration, L = land, W = wood, C = cattle, A = assets, P = price, IR = interest rate.

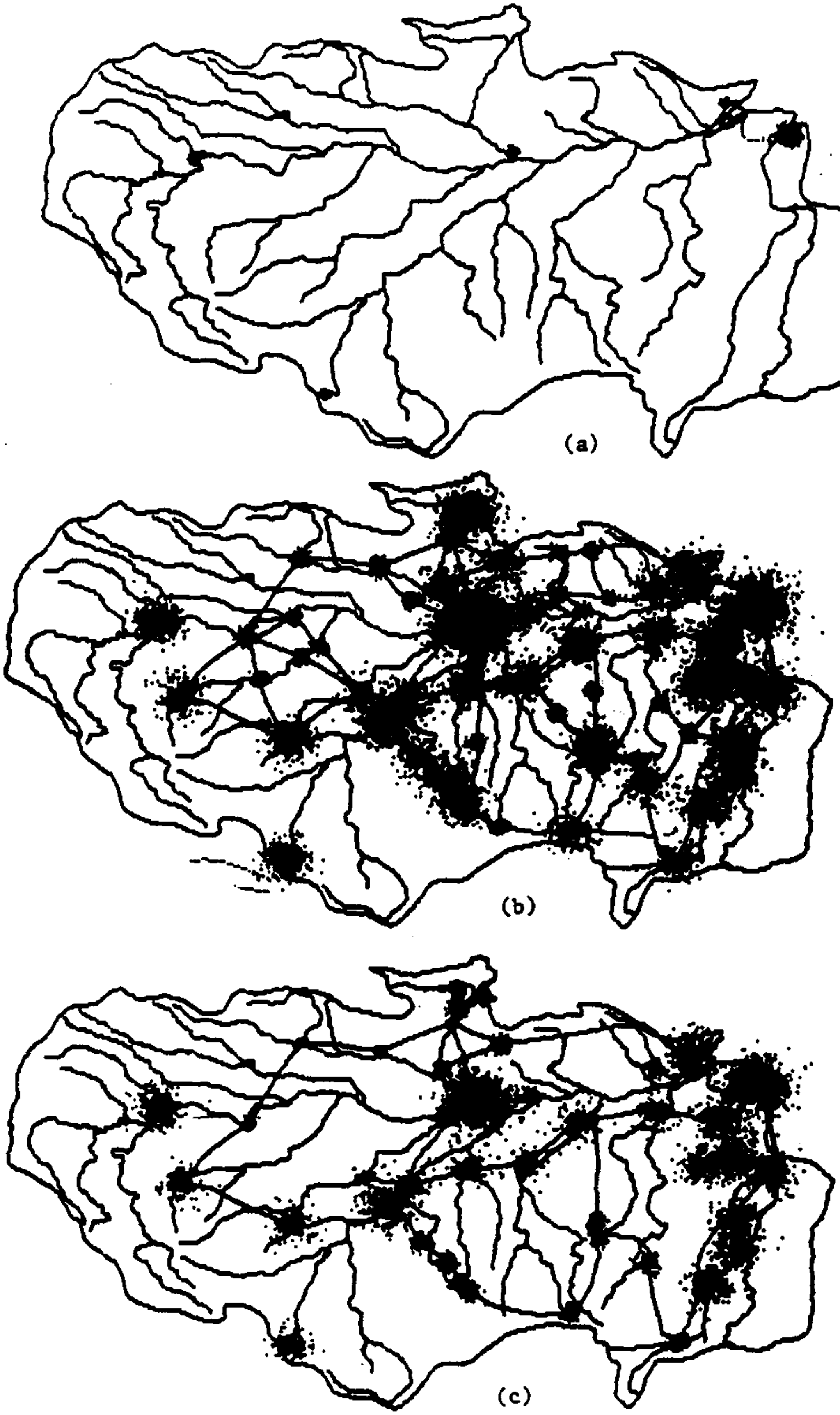


Figure 3. Computer generated maps of development. (a) Solar based economy; (b) unconstrained growth 2100; (c) level of development achieved after halt in external trade.

Table 1. Inflowing energy sources and outflowing energy exports for the Amazon Basin.*

Foot-Note	Item	Actual Energy, Cal/yr	Energy Trans-formation Ratio,† global solar Cal/Cal	Embodied Solar Energy,* E19 SEC/yr
1	Sun	1.4 E19	1	1.4
2	Rain (kinetic energy)	1.25 E14	5.3 E5	6.6
3	(gravitational potential)	1.37 E16	8.9 E3	12.2
4	(chemical potential)	2.2 E16	1.5 E4	33.9
5	Tide	9.9 E11	2.4 E4	0.002
6	Waves	8.39 E12	2.6 E4	0.02
7	Streams (physical energy)	6.8 E15	2.4 E4	16.0
8	(chemical potential)	7.4 E13	4.1 E4	0.3
9	(physical potential of material)	5.5 E11	5.1 E7	2.8
10	Wood harvested	4.3 E15	3.2 E4	13.7
11	Exports			
	Iron ore	1.9 E5 tonne	2.0 E11 Cal/g	0.004
	Bauxite	1.3 E6 tonne	2.0 E11 Cal/g	0.03
	Lumber	4.5 E6 tonne	1.3 E11 Cal/g	.06
	Paper	2.2 E5 tonne	8.3 E11 Cal/g	0.02
12	Fuels imported	4.0 E13	5.3 E4	0.2
13	Fuels consumed	4.7 E13	5.3 E4	0.25
14	Hydroelectricity generated	3.93 E10	1.6 E5	0.0006
15	Import Services	$5137.0 E6	9.1 E8	0.05
16	Export Services	$2467.0 E6	1.6 E9	0.04

@The Amazon Basin includes the Brazilian states of Rondonia, Acre, Amazonas, Roraima, Para, Amapa, and parts of the following countries; Bolivia (47.2%), Colombia (0.4%), Ecuador (2.6%), and Peru (34.9%). Most import and export data for the Brazilian portion of the Basin were given by state, while the data for the other countries were calculated from percentages of the total imports and exports for individual countries. The percent of each country within the Basin was determined from geographical population distribution where population of all cities within the Basin was divided by the total population of each country.

†Energy Transformation Ratio: estimate of global solar Calories incident on earth required to generate Calories of actual energy (Odum et al. 1983).

*Embodied Energy: energy embodied in the flows of actual energy, calculated by multiplying the actual energy by the energy transformation ratio.

FOOTNOTES TO TABLE 1.

[1] Average absorbed solar energy (incident minus albedo) was determined from a map of the basin (adapted from: Global Map of Total Albedo [Figure 2, Vonderhaar and Suomi 1969] and Incident Solar Radiation [Figure 7, Sellers 1965]). Solar insolation was calculated by multiplying the average absorbed insolation by the area of the basin.

$$\text{Solar Insolation} = E_S = I_A \cdot A \qquad (1)$$

where I_A = Insolation absorbed = 195 $\text{Cal/cm}^2 \cdot \text{yr}$;
A = Area = 7.05 E12 m^2 (1 E4 cm^2/m^2) (Sioli 1975);

$$\begin{aligned} ES &= (195)(7.05\ \text{E}12)(1\ \text{E}4) \\ &= 1.4\ \text{E}19\ \text{Cal/yr}. \end{aligned}$$

[2] Kinetic energy in rain. Total rainfall was determined by taking the mean of the following reported numbers (several reported numbers were averaged):

2083 mm/yr	Averaged from rainfall map (C.I.A. 1982)
3000 mm/yr	(Rzoska 1978)
2500 mm/yr	(Sioli 1964)
2650 mm/yr	(Eden 1979)
3000 mm/yr	(Klinge et al. 1981)
2250 mm/yr	(Goulding 1980)

MEAN = 2580 mm/yr

The kinetic energy due to the velocity of falling rain was calculated by using equation 2 below.

$$K_e = \text{kinetic energy} = P(0.5 \quad v^2)(2.38\ \text{E-}7) \qquad (2)$$

where P = rainfall = 258 cm/yr;

= density of rainwater = 1 g/cm^3;
v = average velocity of raindrops = 762 cm/s (Odum et al. 1983, E35) 2.38
E-7 = ratio of Cal/erg x cm^2/m^2.

$$K_e = (258)(0.5)(1)(762^2)(2.38\ \text{E-7})$$

$$= 1.78\ \text{E1 Cal/m}^2\cdot\text{yr} \times 7.05\ \text{E12 m}^2$$

$$= 1.25\ \text{E14 Cal/yr.}$$

[3] Gravitational potential of rain over land. Gravitational potential of rainfall was based on the potential energy of the water falling from the average elevation of basin to sea level. The average elevation of land was calculated by estimating percent area at different elevations based on a topographic map of the region (U.S. Department of Defense 1971).

Elevation = 322 m

Gravitational potential of rainfall was calculated using equation 3 below.

$$G = \text{potential energy} = P(\ gh)(2.38\ \text{E-7}) \qquad (3)$$

where P = rainfall = 258 cm/yr (see footnote 2);
= density of rainwater = 1 g/cm^3;
g = acceleration due to gravity = 980 cm/s^2;
h = average elevation = 3.22 E4 cm;
2.38 E-7 = ratio of Cal/erg x cm^2/m^2.

$$G = (258)(1)(980)(3.22\ \text{E4})(2.38\ \text{E-7})$$

$$= 1.94\ \text{E3 Cal/m}^2\cdot\text{yr} \times 7.05\ \text{E12 m}^2$$

$$= 1.37\ \text{E16 Cal/yr.}$$

[4] Chemical potential of rainwater. The chemical potential of rainfall was based on the gradient of concentration of dissolved solids between rainwater and seawater. It was calculated based on equation 4 below.

$$F_r = \text{chemical potential of rain} = P(nRT)(C_2)\ln(C_2/C_1) \qquad (4)$$

where P = rainfall = 2.58 m/yr (see Table 1, footnote 2);
n = number of moles of water = 1/18 mole/g;
R = Universal gas constant = 1.99 E-3 Cal/°K·mole;
T = temperature = 300°K;
C_1 = seawater concentration = 1,000,000 - 35,000 ppm = 965,000 ppm;
C_2 = rainwater concentration (assumed 10 ppm) (Odum et al. 1983: E42)
= 1,000,000 - 10 ppm = 999,990 ppm.

$$F_r = (2.58)(1/18)(1.99\ \text{E-3})(300)(999{,}990)(\ln 999{,}990/965{,}000)$$

$$= 3.05\ \text{E3 Cal/m}^2\cdot\text{yr} \times 7.05\ \text{E12 m}^2$$

$$= 2.2\ \text{E16 Cal/yr.}$$

[5] Physical energy in tidal absorption. The energy in tides was calculated by dividing the area of tidal influence into three zones: 1. the continental shelf (to approximately 150 m depth, which corresponds to the 35‰ salinity isopleths): 2. the zone between 1.0 and 2.5 m tidal fluctuation (approximately Rioxingu to Macapa); and 3. the zone between 0.0 and 1.0 m tide.

Total energy in tidal absorption was then calculated by summing that of each zone using equation 5 below.

$$E_t = \text{energy of tidal absorption} = N\ A\ (0.5\ \ gh^2)(2.38\ \text{E-}11) \qquad (5)$$

where N = number of tides per year = 705 (Odum et al. 1983: E50);
A = area of tidal influence (see table below);
= density of seawater = 1.025 g/cm^3;
g = acceleration due to gravity = 980 cm/s^3;
h = tidal range (see table below);
2.38 E-11 = ratio of Cal/erg.

Zone	Area,* cm^2	Tidal Range, cm
1	8.0 E14	375†
2	7.5 E13	175§
3	3.2 E13	50§

*National Geographic Society 1981 and U.S. Dept. of Defense 1971.
†Klinge et al. 1981
§Sioli 1964.

$$E_t = (705)(0.5)(1.025)(2.38\ \text{E-}11)[(8.0\ \text{E}14)(375^2)$$
$$+ (7.5\ \text{E}13)(175^2) + (3.2\ \text{E}13)(50^2)]$$
$$= 9.9\ \text{E}11\ \text{Cal/yr}.$$

[6] Waves. The energy in breaking waves is the product of energy per unit area of wave front and the velocity of waves striking the shore. It was calculation using equation 6 below.

$$E_w = \text{energy of waves} = 1/8\ \ gh^2 \cdot C \cdot 2.38\ \text{E-}7 \qquad (6)$$

where = density of seawater = 1.025 g/cm^2;
g = acceleration due to gravity = 980 cm/s^2;
h = mean wave height = 160 cm (Assumed similar to other trade wind region);
C = wave celerity = $(gd)^{1/2}$,
where g = acceleration due to gravity = 9.8 m/s^2 and
d = shoaling depth = assumed 10 m (Odum et al. 1983: E52) =
$[(9.8)(10)]^{1/2}(3.15\ \text{E}7\ \text{s/yr}) = 3.12\ \text{E}8\ \text{m/yr}$; and

2.38 E-7 = ratio of Cal/erg x cm^2/m^2.

$$Ew = (1/8)(1.025)(980)(60)^2(3.12\ E8)(2.38\ E{-7})$$

= 3.36 E7 Cal/m·yr x 2.5 E5 m (perpendicular distance at mouth of estuary [U.S. Dept. of Defense 1971])
= 8.39 E12 Cal/yr.

[7] Physical energy in streams. The physical energy in streams was calculated by considering the runoff from rainfall (= rainfall - evapotranspiration = 1.29 m/yr [see notes on evapotranspiration]) and the average elevation from which this runoff occurs. Calculation was based on equation 7 below.

$$G_q = \text{physical energy in streamflow} = \underline{\ \ }q \cdot gh\ 2.38\ E{-7} \qquad (7)$$

where q = average runoff = 1.29 E2 cm/yr;
= density in rainwater = 1 g/cm^3;
g = acceleration due to gravity = 980 cm/s^2;
h = drop in elevation = 3.22 E4 cm;
2.38 E-7 = ratio of Cal/erg x cm^2/m^2.

$$G_q = (1.29\ E2)(1)(980)(3.22\ E4)(2.38\ E{-7})$$

$$= 9.69\ E2\ Cal/m^2 \cdot yr \times 7.05\ E12\ m^2$$

$$= 6.83\ E15\ Cal/yr.$$

[8] Chemical potential of sediments in stream. Chemical potential energy of sediment in streamflow was calculated by multiplying reported organic matter content in the streamflow times the caloric value of that organic matter based on equation 8 below.

$$F_O = \text{chemical energy in sediments} = O \cdot J \cdot Q \cdot K \qquad (8)$$

where O = percent organic matter in sediments = 2% (Gibbs 1975);
J = average streamflow = 175000 m^3/s (Sioli 1964);
Q = sediment loading = 125 g/m^3 (Sioli 1964);
K = caloric value of organic matter in sediments = 5.4 Cal/g (Odum et al. 1983a).

$$F_O = (0.02)(175{,}000)(3.15\ E7\ s/yr)(125)(5.4)$$

$$= 7.44\ E13\ Cal/yr.$$

[9] Physical potential energy in materials in streamflow. Physical potential energy in materials in streamflow was based on the elevation of the streams and the density of materials suspended and dissolved in them based on equation 9 below.

To determine average density of materials in the stream, we used

DOC = 5.0 g/m^3
POC = $\underline{8.8}$ g/m^3
TOC = 13.8 g/m^3

and average percent organic matter = 10.44% (Richey et al. 1980),

thus, = (13.8/0.1044) = 133 g/m^3.

$$G_m = \text{physical potential of materials} = J \cdot gh(2.38\text{ E-11}) \qquad (9)$$

where J = average streamflow = 175,000 m^3/s;
= 133 g/m^3 (see above);
g = acceleration due to gravity = 980 cm/s^2;
h = average elevation = 3.22 E4 cm;
2.38 E-11 = ratio of Cal/erg.

$$G_m = (175{,}000)(133)(980)(3.22\text{ E4})(2.38\text{ E-11})(3.14\text{ E7 s/yr})$$

$$= 5.5\text{ E11 Cal/yr.}$$

[10] Wood harvested. Based on a deforestation rate of 0.8% per year (Lugo and Brown, 1982) standing wood biomass (5.4 E17 Cal)

Energy in harvested wood = .008 * 5.4 E17 Cal = 4.3 E15 Cal.

[11] Energy value of exports was determined from data for six Brazilian states that make up the Brazilian part of the Basin (Fundacao Instituto Brasilero de Geograficae Estatistica 1980).

The total export of materials was as follows:

Iron ore	1.9 E5 tonne
Bauxite	1.3 E6 tonne
Lumber	4.5 E6 tonne
Paper	2.2 E5 tonne

[12] Energy value of imported fuels was determined from data on imports for six Brazilian states that make up the Brazilian part of the Basin (Fundacao Instituto Brasilero de Geograficae Estatistica 1980) and import data for Bolivia, Colombia, Ecuador, and Peru (Organization of American States 1982).

The total import of fuels in 1980 was as follows:

Brazil	3.9 E13 CE Cal
Bolivia	1.0 E12 CE Cal
Colombia	8.9 E10 CE Cal
Ecuador	5.5 E10 CE Cal
Peru	2.3 E11 CE Cal
TOTAL	4.716 E13 CE Cal/yr

[13] Fuels Consumed. Consumption by country in 1980 is as follows:

Brazil	3.9 E13 CE Cal
Bolivia	6.6 E12 CE Cal
Columbia	5.3 E11 CE Cal
Ecuador	8.0 E11 CE Cal
Peru	2.3 E11 CE Cal
TOTAL	4.716 E13 CE Cal/yr

Data for Brazil are from Fundacao Instituto Brasilero de Geograficae Estatistica (1980). Data for other countries are from Organization of American States (1982).

[14] Hydroelectricity generated. Value relfects the installed generating capacity within the Basin of Brazil (5900 KW) and an estimate of installed capacity in Bolivia, Colombia, Ecuador, and Peru. In those other countries the combined total generating capacity was 5029 KW, and an estimate based on population distribution was used to allocate a percentage of the total to the basin (627 KW).

Total generating capacity 6527. Assume 80% load factor.

Actual energy = 6.527 E3 KW x 8760 Hrs/yr x 0.80 x 860 Cal/KWH

= 3.93 E10 Cal.

[15] Embodied energy in services imported is calculated from the dollar costs of imports. Import data were from Fundacao Instituto Brasilero de Geograficae Estatistica (1980) and Organization of American States (1982) and are as follows:

	IMPORTS
Brazil	3173.3 E6 US $
Bolivia	582.4 E6 US $
Colombia	25.0 E6 US $
Ecuador	92.1 E6 US $
Peru	1266.2 E6 US $
TOTAL	5137.0 E6 US $

Conversion factor to convert dollars to energy was derived as a world average by dividing total world flux of energy by world GDP (UN 1979). Conversion Factor = 9.08 E8 Cal/$.

compared with the renewable energies of the basin, the imports of fuels are fairly insignificant, suggesting that the basin is still very much dominated by renewable processes of forest growth and the hydrology of the rivers.

An evaluation of the long-term storages within the basin is given in Table 2, showing the enormous storages in proven reserves of iron ore and bauxite. Given for comparison are the storages of soils and biomass. The energy in the storage of urban structure is evaluated and shown to be insignificant.

Discussion

The population density of the Brazilian Amazon Basin is only 1.1 people/km^2 as compared to the southeast region around Sao Paulo where the population density is greater than 100 people/km^2. While the Amazon Basin represents about 54% of Brazil's land area, it accounts for only about 6% of the fuel use in the country; thus, 94% of the fuel use within Brazil is concentrated on 46% of the area.

Table 3 lists the populations and fuel use of the five countries that make up the Amazon Basin. By far, Brazil is the largest in land area, but second largest in population within the basin. Brazil's fuel consumption is largest as is the consumption of goods and services. Population density is greatest in the Peruvian and Bolivian parts of the basin. Since population densities in the Andean parts of the basin are as much as 5 times those of Brazil, the potential for major impact on the whole basin exists as the pressure for development in these areas increases.

Development pressure from the Andean areas of the basin are already evident (as described by Odum elsewhere in Section 2). With plentiful rainfall, rich soils, and storages of oil, development potential in those areas is quite high. In response to development, on the Bolivian, Colombian, and Peruvian borders, Brazil will undoubtably foster increased development to help maintain her borders.

Various indicies and ratios of energy use for Amazon Basin are given in Table 4 with comparison to Brazil, The United States, and Australia. Comparisons with these other areas of the globe gives perspective to energy system of the Amazon. The basin has the greatest renewable energy flow and least imported energy of the four areas. The high ratio of embodied energy per person is typical of newly developing regions, and indicates that if population were spread evenly across the basin, clusters of poverty near urbanized and developing regions might be avoided.

Energy analysis of the inflows of energy to the Amazon Basin indicates that the basin is far from being developed. Comparison with the analysis for the Country of Brazil (Table 4) shows that the basin is less developed on the average and thus is contributing energies to the main economy of Brazil. The ratio of nonrenewable to renewable energy flows for the basin is less than most developed nations of the world, suggesting on the whole that continued development is likely.

Table 2. Energy in long-term storages in the Amazon Basin.

Footnote	Item	Actual Energy, Cal E18	Energy Transformation Ratio,† solar Cal/Cal	Embodied solar§ E22 SE Cal
A	Biomass	0.55	3.2 E4	1.7
B	Soil	0.5	6.2 E4	3.1
C	Iron Ore	1069.2	6.0 E7	6420000
D	Bauxite	655.2	1.32 E7	865000
E	Urban Structure	0.0003	2.72 E7	0.74

†Energy Transformation Ratio: estimate of solar Calories incident on earth required to generate Calories of actual energy (Odum et al. 1983).

§Embodied Energy: energy embodied in the flows of actual energy, calculated by multiplying the actual energy by the energy transformation ratio.

FOOTNOTES TO TABLE 2.

A. The following data were used to determine total dry weight of biomass.

Vegetation Type	Area, E6 Ha	Biomass (dw) MT OM/Ha	Total Biomass E9 MT OM	Source
Terra firma	314	370	116.2	Brown and Lugo 1981;
Secondary forest	314	40	12.6	
Varzea	35.3	150	5.3	Lieth and Whittaker 1975
Igapo	7.1	150	1.1	"
Savanna	28.2	40	1.1	"
Littoral	7.1	40	0.3	"
TOTAL			136.6	

Actual energy in biomass was calculated by multiplying by 4.0 E6 Cal/MT organic matter.

Actual energy = 136.6 E9 MT OM (4.0 E6 Cal/MT OM)

= 5.5 E17 Cal.

B. Soil. To determine the energy stored in soil/area, an average of the total carbon found in Amazon soils was calculated as follows:

tC/Ha	tN/Ha	Source
85		Brown and Lugo 1981
102	11.2	Sanchez 1982
*81	8.9	"
*52	5.7	"

*numbers calculated by multiplying the ratio of tC/tN from Sanchez' first numbers (= 102/11.2 = 9.1).

Average = 80 tC/Ha [(100 g/m^2)/(t/Ha)] = 8000 g C/m^2.

Energy in soil = (8000 g C/m^2)(9.0 Cal/g C)(7.05 E12 m^2)

= 5.0 E17 Cal.

C. Iron ore. 18 Billion Tons Reserve in Carajas (Publication of the Greater Carajas Program). Actual Energy per Ton is equal to 5.94 E10 Cal/Ton.

Total Actual Energy = (18.0 E9 Tons)(5.94 E10 Cal/Ton) = 1.07 E21

D. Bauxite. 2.4 Billion Tons Reserve in Carajas (publication of the Greater Carajas Program). Actual Energy per ton is equal to 2.73 E11 Cal/Ton.

Total Actual Energy = (2.4 E9 Tons)(2.73 E11 Cal/Ton) = 6.55 E20.

E. Urban Structure. The Energy Storage in Urban Structure was calculated by determining the area of structure, multiplying by weight per unit area and then by Chemical Potential Energy per unit weight. The following table lists the data used in this calculation.

Area, Weights, and Chemical Potential Energy of Urban Structure

Material	1. Area	2. Weight lbs/m^2	3. Total Weight	4. Chemical Potential Energy Cal/lb	5. Chemical Potential Energy (E12 Cal)
Structural	2.63 E7 m^2				
Wood	"	699	1.8 E10	1500	270.0
Concrete	"	1829	4.8 E10	20	1.0
Steel	"	18	4.7 E8	700	0.3
Furnishings	5.26 E6 m^2				
Organic	"	30	1.6 E8	1500	0.2
Metal	"	13.5	7.1 E7	700	0.05
Plastic	"	0.2	1.1 E6	3000	0.003
				Total	271.6

1. Area of urban structure was derived using a combination of data. First percent growth of population was determined for the basin for the last 10 consecutive years (4.070/yr). Second, the floor area of new construction in 6 major cities within the Basin were obtained for 1980 (1.05 E6 m^2). Third by dividing new construction by percent change in population (assuming population change is equal to the change in urban structure) an estimate of the total floor area of urban structure was calculated. The area of furnishings was assumed to be 20% of total floor area. (Data from Fundaco Instituto Brasilero de Geograficae Estatistica, 1980.)

2. Weight of Materials from Brown 1980.

3. Product of Area (column 2) and weight (column 3).

4. Chemical Potential Energy from Odum et al. 1983.

5. Product of total weight (column 4) and Chemical Potential Energy (column 5).

Table 3. Distribution of population and embodied energy in the Amazon Basin by country, 1980.

Country	A. Area within Basin E6 km^2	B. 1980 Population		C. Fuel Use E18 SE Cal	D. Goods and Services Used E18 SE Cal	E. Renewable Energy Inflow E18 SE Cal	F. Total Embodied Energy E18 SE Cal
		Total E6	Density hab/km^2				
Brazil	4.60	5.0	1.1	2.1	2.88	223.7	228.7
Bolivia	0.72	2.60	3.6	0.3	0.53	34.6	35.4
Colombia	0.38	0.11	0.3	0.03	0.02	18.3	18.4
Ecuador	0.14	0.22	1.6	0.04	0.08	6.8	6.9
Peru	1.15	6.0	5.2	0.01	1.15	55.6	56.8
TOTAL	7.0	13.93	1.99	2.48	4.66	339.0	346.2

A. Determined by planimeter using map of the basin at a scale of 1:8.5 million. Areas were rounded to equal area of basin, 7.05 E12 m^2 (Sioli 1975).

B. Population for countries other than Brazil was estimated based on geographical distribution of all cities within each country that were within the basin. The percent of total cities that were within the basin was multiplied by total population in each country to determine the population within the basin.

C. Fuel use (see Table 3.1).

D. Good and services used (see Table 3.1).

E. Renewable energy. Based on percent of total basin area within each country and using the inflow of chemical potential energy inherent in rain.

F. Sum of fuel use, goods and services, and renewable energy inflow.

Table 4. Indices using embodied energy for overview of the Amazon Basin.

Description	Amazon Basin	Brazil	United States	Australia
Renewable embodied energy flow (1 E19 SECal)	33.9	24.4	19.7	8.4
Flow of imported embodied energy (1 E19 SECal)	0.25	3.5	36.2	2.2
Use of internal sources within boundary (1E19 SECal)	17.0	2.5	78.8	3.4
Depletion of internal sources (1 E19 SECal)	17.6	3.7	82.6	7.0
Ratio of imported to renewable energy	0.007	0.14	1.84	0.26
Ratio of imported plus internal use of storage to renewable energy	0.51	0.24	5.84	0.67
Ratio of embodied energy per person (x 1 E13/person)	3.67	0.25	0.59	0.96
Ratio of emodied energy per area (x 1 E13/km^2)	7.26	3.57	14.3	1.82

DEVELOPMENTAL PATTERNS IN THE ECUADORIAN AMAZON - A MICROCOSM OF PRINCIPLES AT WORK IN THE WHOLE BASIN

Howard T. Odum

A section of the uppermost Amazon River lies within Ecuador on the equator, dominated by the heavy flows of runoff from the Andes Mountains. See Figure 1. Here, human settlement and economic development is proceeding rapidly as elsewhere in the Amazon, but the pattern is spreading from limited points of access in a still simple landscape where the principles governing the region as a whole may be seen in microcosm.

The Conditions that Produce the Forest Ecosystem

The trade winds flowing westward in the Amazon Basin are geographically elevated against the Andes by the general circulation, by local mountain-valley circulation, and by the convergence of the trades as part of the inter-tropical convergence belt when it is at this latitude. The result is a high rainfall on the slopes and on the flatlands east of the last cataracts, a much more even rainfall than in the eastern Amazon so that true rainforest forms (in the narrower meanings of the word). Compare rainfall records in Figures 2 and 3 with those in Figure 4. Substantial rain occurs in every month in the west.

Even at low water on the days when rain in the Andes is less, the river is turbid yellow-brown unlike the nutrient poor lignin waters of the black Amazon tributaries. These Ecuadorian waters are swift and carrying sediment. The water temperatures of the waters rushing from the highlands are cooler than the forest adjacent to its watercourse. We collected water samples in the Napo River Dec. 29-31 when the river was at medium and low water stage. The particulate matter was analyzed by Robert Tighe using weighted millipore filters (.5 pore size) and weights were 49-80 mg/liter.

Over most of the Ecuadorian plain the soils are predominantly derived from river sediment, some older and some recent. Although there are fluvial sand bars, much of the land is predominantly deposits of river clay left when the high waters o~~f the~~ river overflow their banks. Many of the former river channels are wetlands, lakes, and sloughs. As Figure 5 shows, the inputs of soil materials from the weathering processes of geochemically rich volcanic and plutonic rocks provide a general regional fertility for the upper region.

The upper Andes-fertilized area is clearly different from poor sands supporting tropical forest further east at Manaus where most of the nutrients are in the vegetation with little left to sustain agriculture after initial cultivation. The adaptation of vegetation is entirely different. Whereas at Manaus we found mats of small roots adapted to filter scarce nutrients from rainwaters (B in Figure 6), the pattern of tree roots in the Ecuadorian plain consists of larger roots reaching into the richer clay sediment-soil drawing nutrition with transpiration streams. The mature canopy of the Ecuadorian forest is generally 40 meters with some of the giant kapok trees reaching 67 meters.

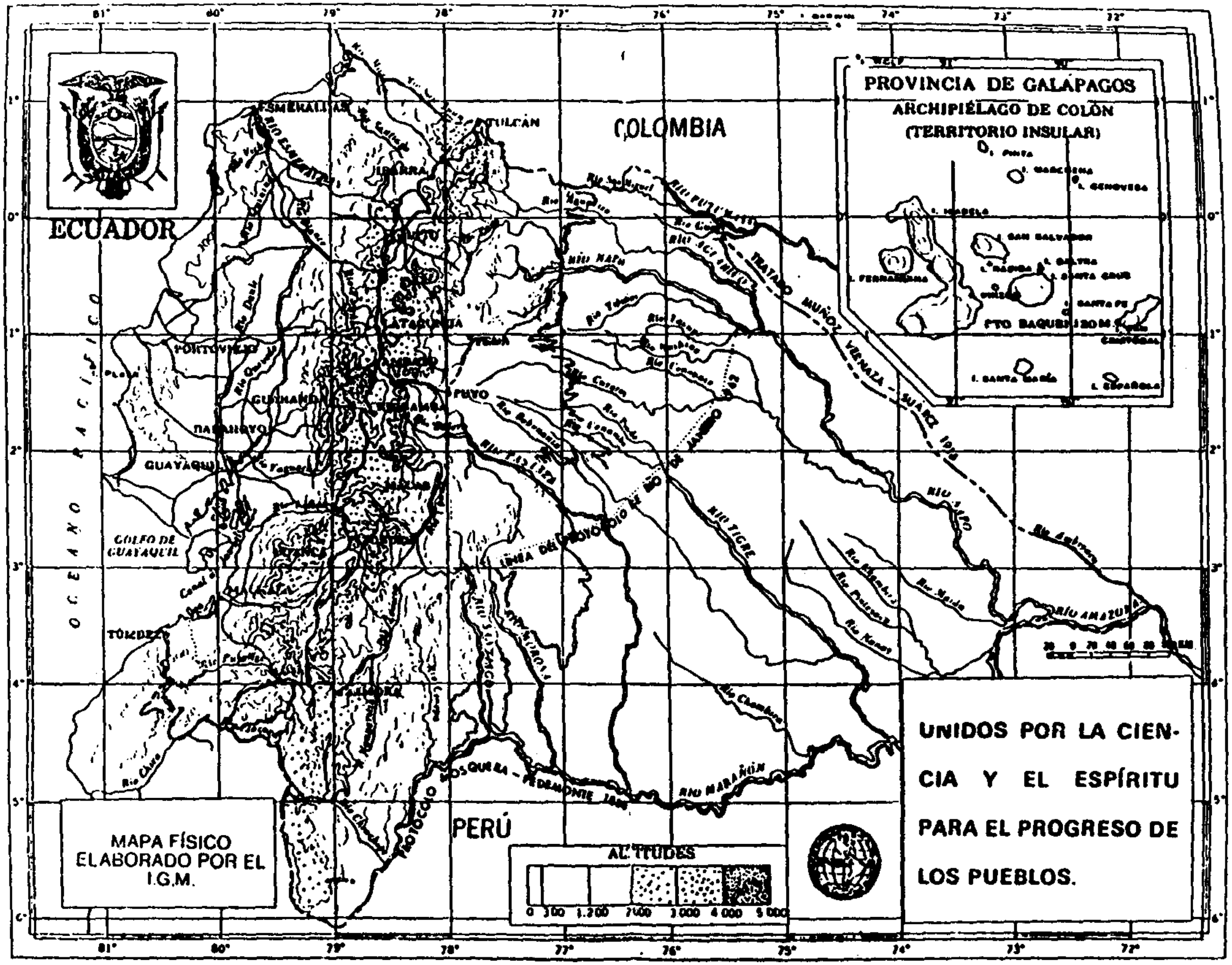


Figure 1. Map of Ecuador with main rivers of the Oriente district (Ecuadorian Amazon). Map from Naranjo (1981).

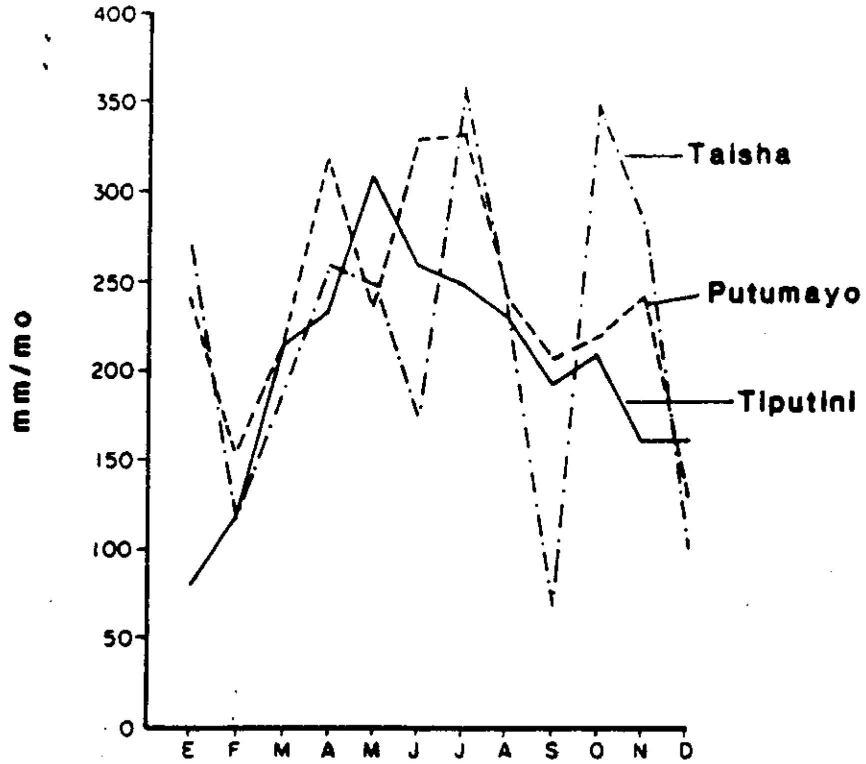


Figure 2. Rainfall records from lower Andes upslope from the main area of lowland rainforest (Naranjo, 1981).

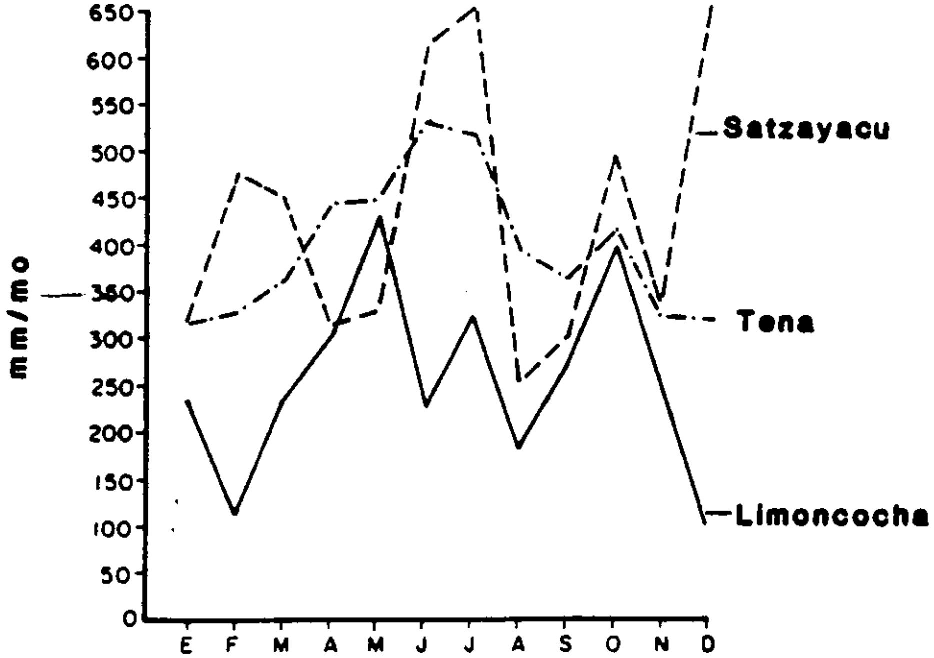


Figure 3. Rainfall record from stations at 210-240 m altitude within the lowland rainforest (Naranjo, 1981).

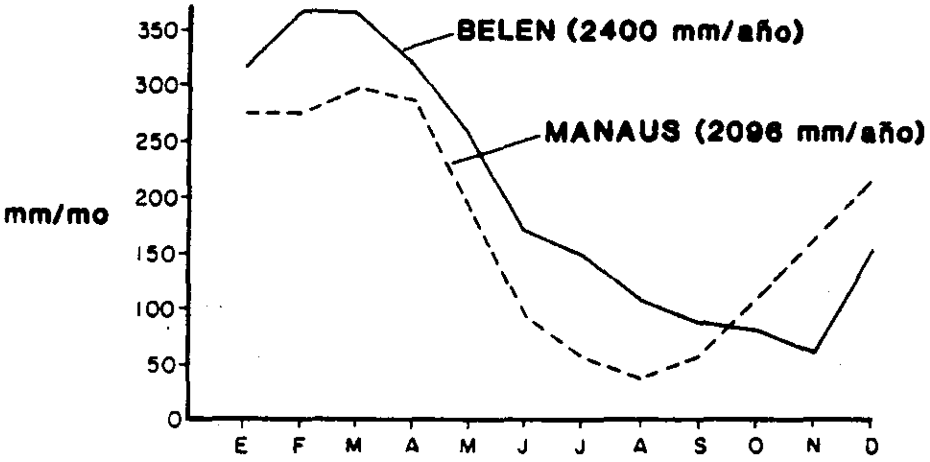
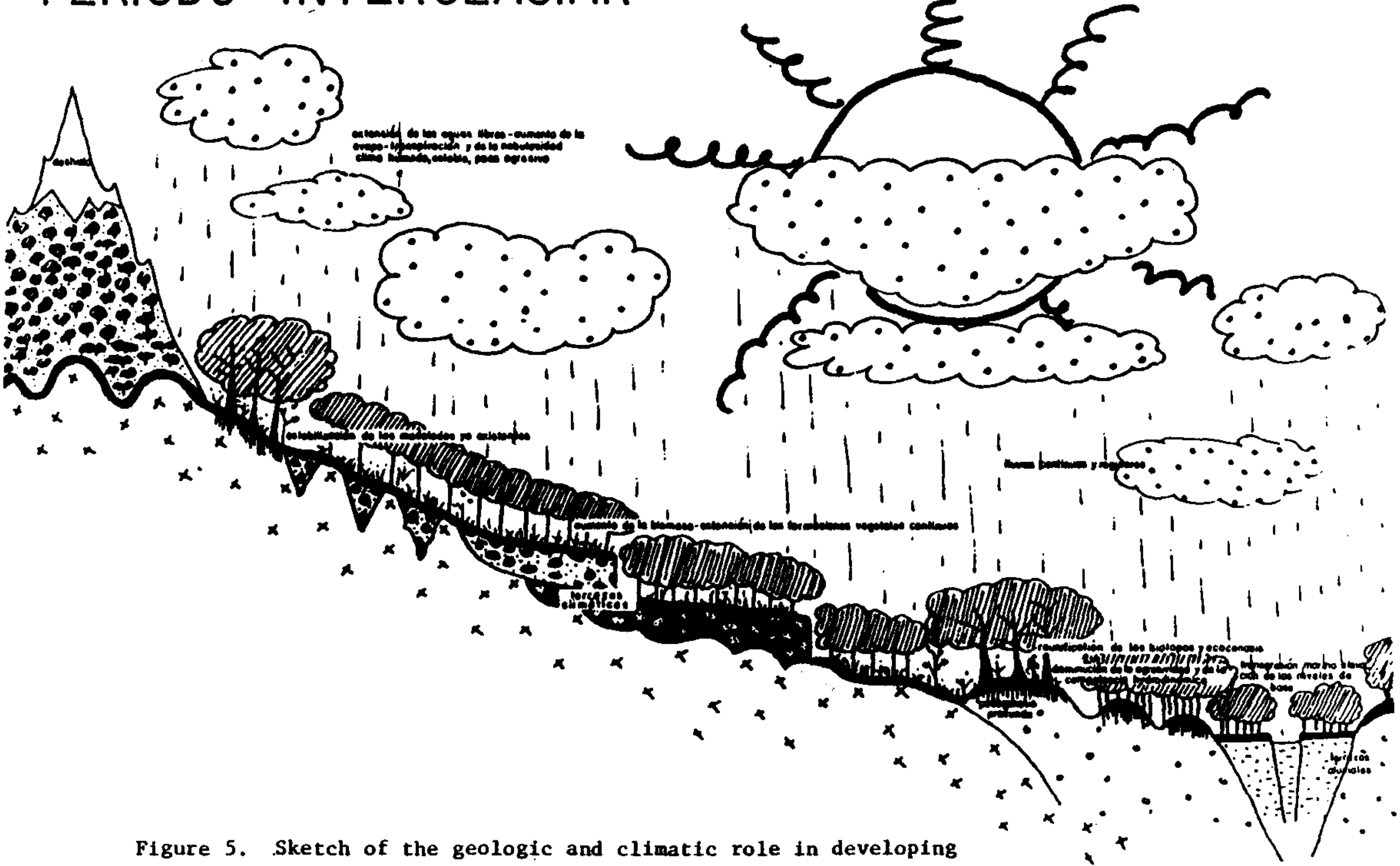
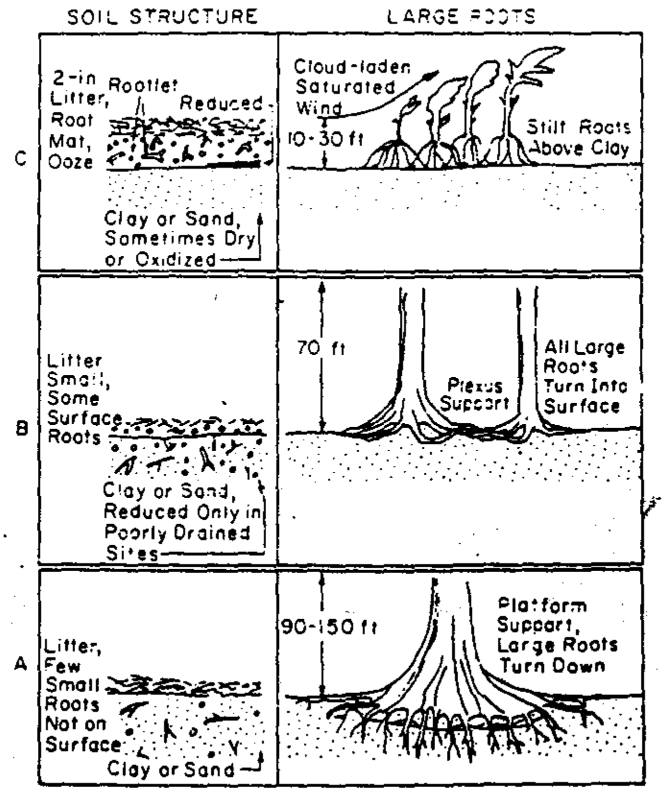


Figure 4. Rainfall record from seasonal rainforests in central and eastern Amazon for comparison (Naranjo, 1981).



PERIODO INTERGLACIAR

Figure 5. Sketch of the geologic and climatic role in developing vegetation zones on the eastern slope of the Andes that supplies water and sediments to the Ecuadorian Amazon (Almeida and Sourdat, 1983).



Odum (1970)

Figure 6. Patterns of roots for different kinds of rainforest substrates and evapotranspiration potentials (Odum, 1970).

Figure 7. Views of Ecuadorian Amazon along Rio Napo, January, 1984. (a) Flotel; (b) forest viewed from 100 m tree tower; (c) riverbank settlements; (d) view of early morning fog shrouding the river, still cold from descent from the Andes.

The flow of tropical air from the east across the Amazon Basin retains its high moisture content because air receives evapotranspired water vapor from the forest that replaces moisture lost from the air as rain. Early morning fog occurs within the forest when winds are less and the sky clear so that plants cool by outgoing radiation. As soon as solar heating develops in the morning, cumulus clouds form at one to two thousand feet. The cloud height is significant since it is proportional to the saturation deficit (gradient of humidity which controls evaporation and transpiration of the plants). There is a moderately large evapotranspiraton so that the forest can readily draw nutrients to the top of giant trees by pulling streams of water from the soil through the roots and the woody part of the tree into the leaves. In other words, the conditions are not those of a cloud forest. Rather the high regular rainfall, good soil, substantial evapotranspiration, and warm temperatures provide the conditions for one of the most magnificent of the tropical rainforests of the world. In the forest classification system of Holderidge (1971) it is Tropical Wet Forest, one with the greatest height, biomass, diversity, etc. in the Americas.

The maturity of the forest may be observed from the air by examination of the size of the tree crowns and the presence of open areas. Much of the forest along the river has been generally cut over for agricultural plantings so that one observes either the typical tropical crops of bananas, manioc, etc. or the typical first natural invaders of wild vegetation that displace crops such as balsa, Heliconia, and Cecropia. There are still sections of the river bank with almost continuous canopy of giant mature trees. In these areas and in much of the area away from the river, mature trees predominate, although even in mature forest the pattern is patchy because the fall of a giant overstory tree with giant crown leaves a large open space into which hundreds of seedlings and saplings burst into rapid growth. Such tangle of vegetation that comes into sunny areas might fit the idea of "jungle" that many people associate with tropical areas. The early invading vegetation that follows cutting or agricultural use is called "successional" because it is the early stage in the succession of plant and animals that repairs and restores the forest to a mature stage. There are always some successional forest species available within the predominantly mature forest to seed the successional process. The seeds of the successional species are numerous, small, and readily transported by wind, birds, mammals, fishes, etc. The river banks and the new sand bars in the river are other sunny places where some successional vegetation is always found.

The ground area under the mature forest is relatively open without a tangle of vegetation because the area is shaded. There is a thin layer of fallen leaf litter that is decomposing within a year of falling because of the efficient utilizaton by insects and mcirobes. Here herbs, seedlings, saplings, and shade adapted plants wait without much biological activity. Here there are dark green leaves of several years of age that have accumulated epiphytic mosses, lichens, and algae. The early subsistence populations also opened limited areas of the forest for their small scale crops with successional vegetation marking the areas for many years. From the air these areas have trees with smaller crown size, larger individual leaves, and often a lighter color. Even before colonization the forest was a mosaic of vegetational areas of different ages with growth and renewal cycles building a giant forest, replacing the older elements one tree at a time in some places and one plot at a time where humans or flood damage was involved. The heterogenity of the plots of different ages is part of the diversity of the tropical rainforest.

More diversity is provided by the long term shifting of position of the river as it deposits its load of sediment from the Andes. Somewhat like a delta, the river builds up one area with its deposits and then changes course to deposit in an area that is now relatively lower. Left behind are the remnants of the river channel forming backwater lakes and wetlands. These are green with eutrophic production and a great diversity of aquatic plants, wetland swamp trees in zones at lake margins and unusual birds. One lake at Limonchoncha has caimans and 460 bird species, although recent hunting may be reducing these. Much of the diversity of the region was generated by the rivers over geologic time.

Human Settlements and Development

The human settlements consist of three cultures each having displaced the previous one from predominance (CICAME, 1981). Now located furthest from roads and main river channels are the subsistence Indian cultures, referred to as Auracas. See also discussion of Jivaro (Meggers, 1973). Because of earlier bad treatment, these tribes still are secretive and some attack intruders, although members enter towns to trade. Dominating the river network and held together by motorized canoe travel are the Quichla-speaking Indians, descendants of Incas that invaded the lowlands at an earlier time. At the present they retain many Indian cultural features, but have become a regular part of the main economy in use of fuel-driven chain saws, outboard motors, and other ways that connect their dooryard garden habitations and agroecosystems with the modern economy.

The most recent wave of human settlement only 15 years ago is part of a development program of the Ecuadorian Government in settlement of Spanish speaking (in part) people on lands between the rivers connected with roads facilitated by the concurrent development of an oil well network, an oil and military town, and a pipeline across the area and up over the Andes to highland intermontane Ecuador. This development includes a jet airport, tourists, hotels, and a floating hotel (flotel) on the Napo River to provide excursions and an Amazon nature experience. The zone of new development shown in Figure 8 includes the new colonization and the river settlements now becoming part of the new regional economy as river activities receive more energy subsidy. Figure 9 is a tourist map of the area.

Wildlife and Tourism

A very remarkable tourist experience has been operating on the Rio Napo where tour groups stay on a riverboat called a flotel (Figure 10) in the

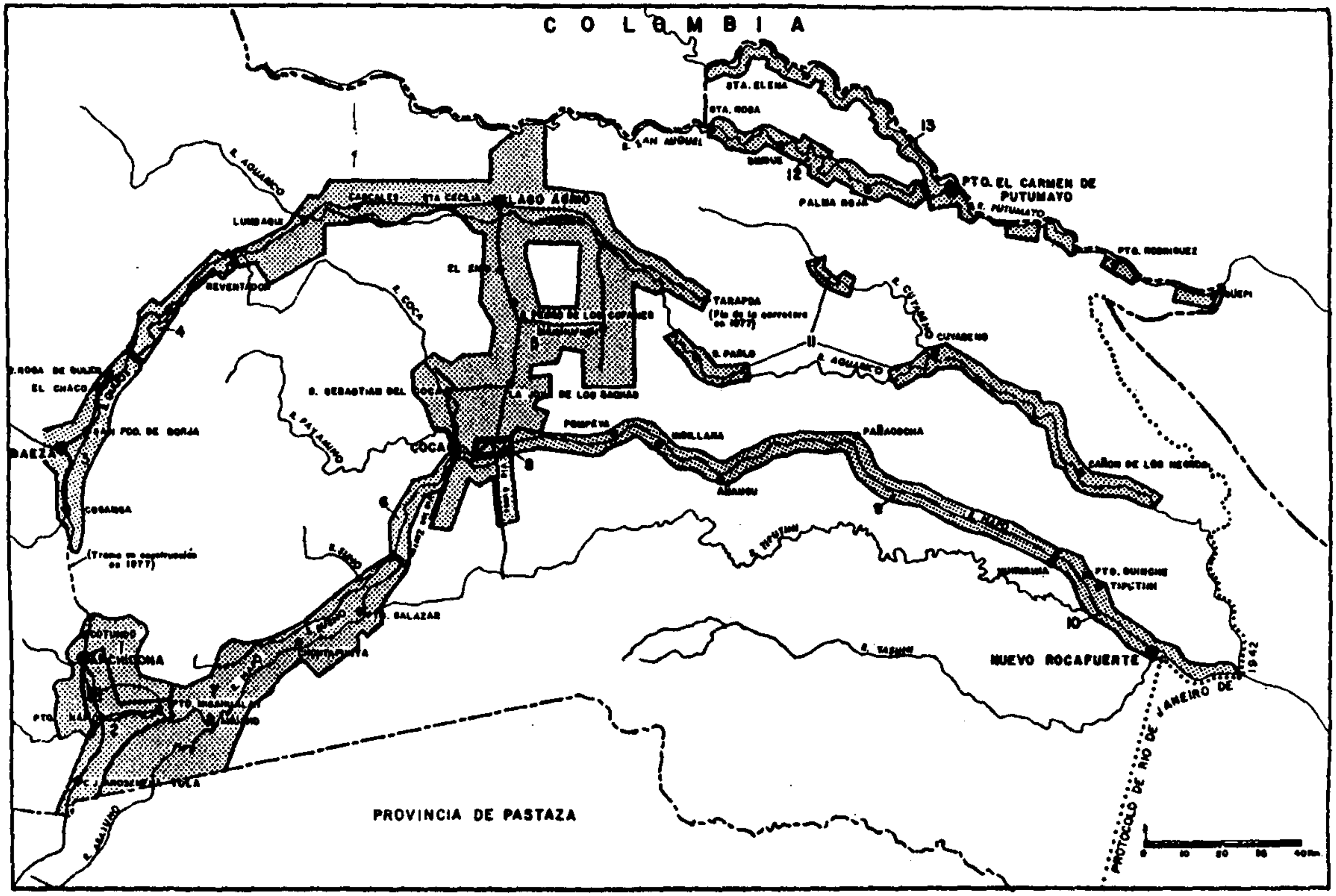
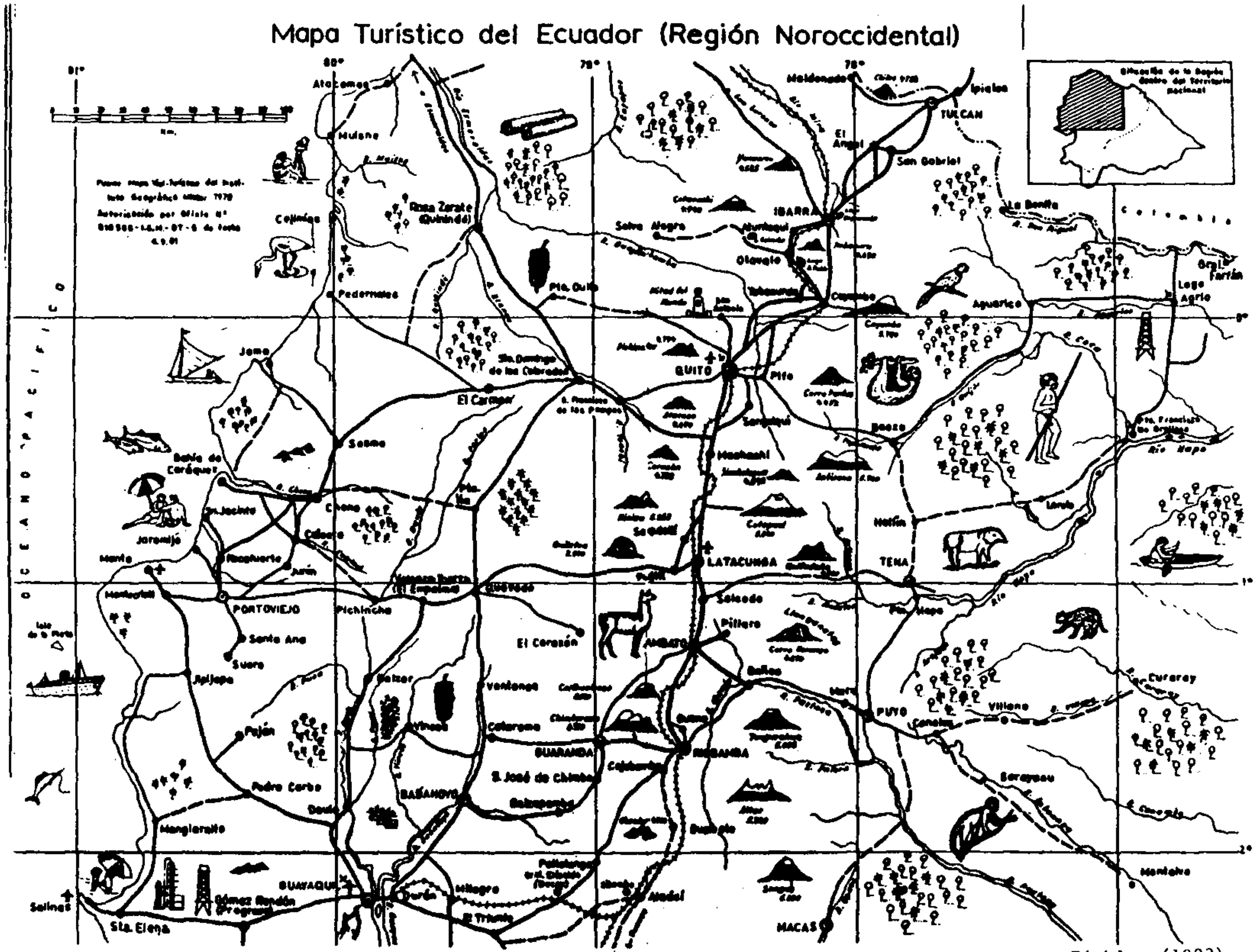


Figure 8. Pattern of recent colonization in the Ecuadorian Amazon (Barral, 1983).



Eichler (1983)

Figure 9. Tourist guide map showing roads and river access (Eichler, 1983).

midst of the still little developed areas of the best Amazon forest observing ecosystems, patterns of human development, tropical crops, and the power of nature at the foot of the Andes. Visitors take a forty minute flight in an Electra to the oil town of Coco (lage agrio) there taking a two hour bus ride through the agricultural developed area with representation of most tropical crops, next taking an hour motorized canoe trip down the Rio Napo to the place where the riverboat is tied up. From there on successive days excursions go to various sites in the diversified region. See Figure 9.

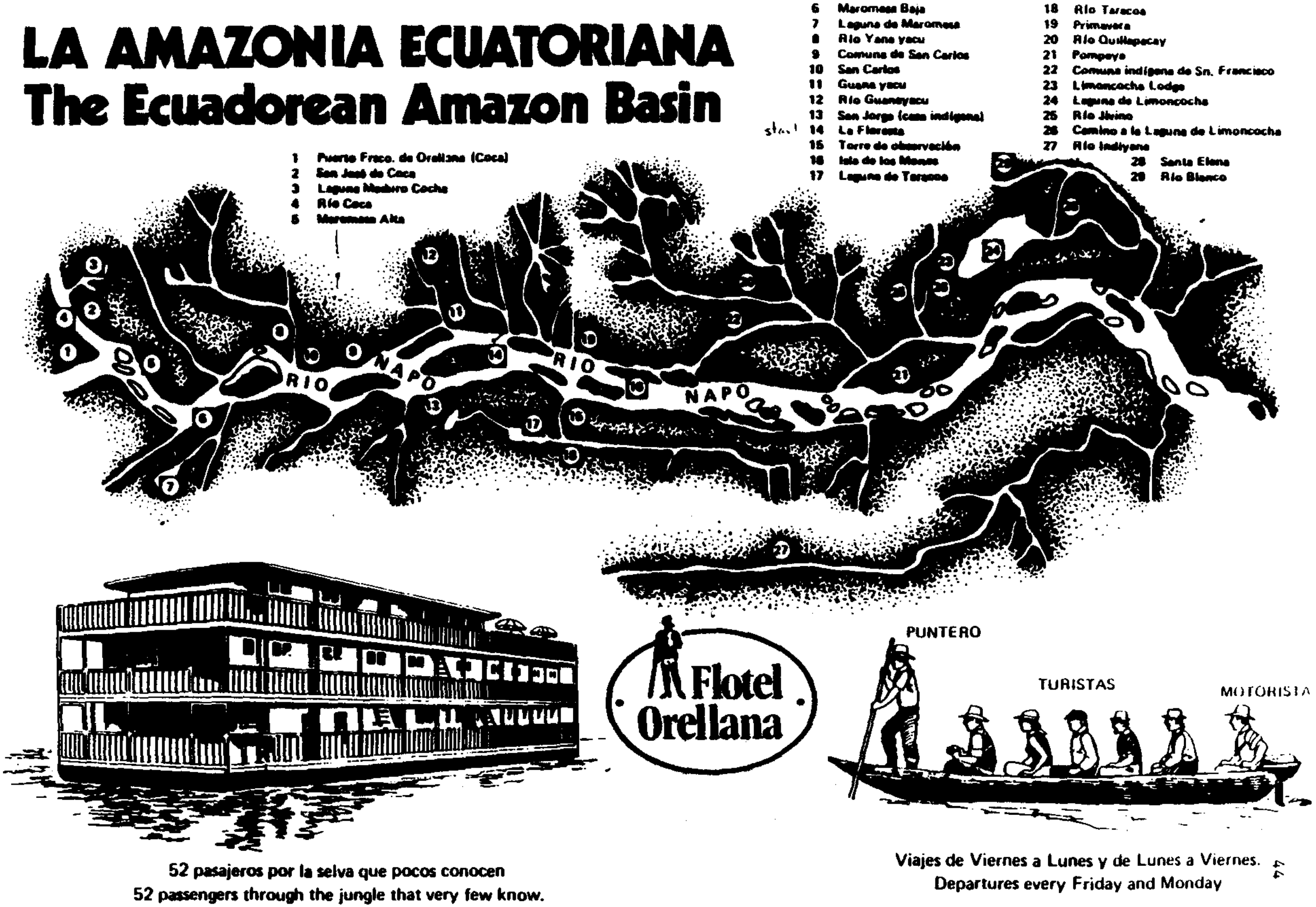
Among the special experiences are meals served by the Indians at river camps with native foods. For example, the manioc is presented in many delicious ways - soups, chips like potato-chips, dumplings, bread, etc. Many fruits, lowland coffee, wild boar, plantains, and rice dishes are included. While hard mineral water bottles are provided at considerable cost for visitors uncertain about water safety, the boiled water in kettles for making tea, coffee, or direct drinking is better tasting and more practical. The local lemongrass tea was popular.

Whereas the flotel rooms were mosquito-tight, the conditions in overnight camps were not and although mosquito presence was barely detectable and malaria incidence small, prudence and worry free excursions in a rainforest with many known and possibly unknown animal vectored disease requires mosquito nets be brought as well as the recommended insect repellants.

Trails in rainforests over which tours have passed become quagmire oozes that are difficult to walk in even with provided boots. An easier time and more area can be seen more cleanly if trails that are used over and over be lined with coarse river gravels. This procedure worked well in rainforest studies in silty soils in Puerto Rico.

The high animal diversity that goes with rainforests corresponds to the high diversity of plants and heterogeneity of the mosaic of plots. The classical wildlife is there, the tapirs, large rodents, wild pigs, ocelots, monkeys, parrots, macaques, army ants, leaf cutting ants, morpheus butterflies, etc. There are difficulties, however, with visiting groups seeing much of this. First, the animals are high in the food chain and the ratio of animals to plants is small and they are dispersed throughout the massive vegetation and are hard to see. An entirely erroneous idea is created by television and picture book presentations of wildlife so that visitors not understanding this are disappointed in having to search so long to see the wildlife and their signs. Simple explanations of ecological principles can help visitors and make them appreciate more the fascinating search for the living forest gems.

To make matters worse the larger wildlife and most conspicuous birds are under devastating hunting pressure now and disappearing or becoming unapproachable from the accessible areas. Earlier when human populations were only one per square mile and life pattern mainly subsistent, the load on the wildlife was small and self correcting. When wildlife became scarcer, the people had to become scarce, leaving the area at least temporarily. The new waves of people deriving their livelihood from crops partly subsidized with fuels, and goods and services derived from fuels, can live in higher density, already three per square mile and can put much greater hunting pressures on the wildlife. Even the formerly subsistence peoples begin selling wildlife products to purchase items from towns so that their load increases beyond the carrying capacity.



LA AMAZONIA ECUATORIANA
The Ecuadorean Amazon Basin

1 Puerto Frsco. de Orellana (Coca)
2 San José de Coca
3 Laguna Mashero Cocha
4 Río Coca
5 Maromasa Alta
6 Maromasa Baja
7 Laguna de Maromasa
8 Río Yana yacu
9 Comuna de San Carlos
10 San Carlos
11 Guana yacu
12 Río Guanayacu
13 San Jorge (casa indígena)
start 14 La Floresta
15 Torre de observación
16 Isla de los Monos
17 Laguna de Taracoa
18 Río Taracoa
19 Primavera
20 Río Quillapacay
21 Pompeya
22 Comuna indígena de Sn. Francisco
23 Limoncocha Lodge
24 Laguna de Limoncocha
25 Río Jivino
26 Camino a la Laguna de Limoncocha
27 Río Indiyana
28 Santa Elena
29 Río Blanco

Flotel Orellana

52 pasajeros por la selva que pocos conocen
52 passengers through the jungle that very few know.

Viajes de Viernes a Lunes y de Lunes a Viernes.
Departures every Friday and Monday

Figure 10. Circular describing floating tourist facility on the river N*po.

Whereas economic gains are developed in the Galapagos Islands by protecting the wildlife and keeping them accessible so as to develop funds from tourism, the Amazon development is rapidly eliminating the attractions that are needed for the tourist monies now starting. A protected park of large enough size to have larger animals is needed that can be justified by tourist dollars along with an educational program. A moratorium is needed on commercial sale of wildlife products, especially the fans of colored bird feathers. The very tourists who came to see the parrots are paying large sums for these birds dead. The target practice by military people in outposts could be avoided. The experience at Barro-Colorado Island in Panama suggests that a large island in a river system could be adequately guarded and managed for wildlife-tourist and/or research purposes.

Differences in cultural perceptions produce counter productive efforts for tourists. At great effort a staircase was built so people can see forest and wildlife at 50 m, from the forest top. To make this of maximum value to those who come to see the forest all the surrounding trees and vegetation should have been left intact. Instead the area underneath was cleared and grassed. Life-long practices in developing jungle-free areas were applied in the wrong place. Local workers did not really understand that people who live in lifeless cities pay a year's savings to see the natural complexity.

Another example of destroying the attraction in arranging access was a trail prepared through a fantastic wetland (swamp) where a great variety of curving network of roots support strange palms and other trees standing in waters where there are interesting fishes, electric eels, wetland birds, and snakes. Those preparing the trail cut the trees to make the walking surfaces and thus turned the area into an uninteresting marshy scrub. Tourist track construction should be supervised by an ecologist.

HIERARCHICAL PATTERNS IN THE ECUADORIAN AMAZON

H.T. Odum

Several principles concerning the nature of energy flow may explain the kinds of development of humanity and nature observed as waves of human culture bring more and more resources into use with larger and larger scales of settlements. Principles are given in paragraphs numbered 1-4 below. Then these principles are used to account for Amazon development patterns.

1. First is the principle of hierarchical organization. Figure 1a is a diagram of the kind of hierarchy we think of in an army or business organization with many participants on the left converging to fewer individuals on the right. The spatial pattern of hierarchy is observed most simply in areas where the main resources are spread out over the landscape evenly as with the sunlight and the rainfall. These driving energies converge in successive steps of the food chain (Figure 1b). Sunlight goes to leaves, to branches, to trunks to animals to human settlements, and these to larger towns, etc. At each step potential energy is used up in the process of transforming some energy to higher quality, more concentrated and more capable of control interactions. The principle of energy transformation in hierarchical organization is illustrated in Figure 1c. Outside inputs are from circles (sources) outside the system frame. Abundant but widely dispersed items are on the left, converge to more concentrated units on the right.

In the Amazon the organization of nature as an energy hierarchy is obvious with vegetation and animals in the forest. On a larger scale the Amazon is also organized into a river hierarchy in which little streams converge to larger ones and these to even larger ones (Figure 1d). Human settlements are also hierarchical with paths and roads converging to villages and towns.

2. Another theory is that economic development responds to the spatial distribution of the energy resources. This is why human settlements often develop at junctions of major rivers, because here the high quality nature of human activity can receive the convergence of the lower quality flows of the region facilitated by the convergence of the water courses. If additional sources of energy are supplied, their spatial distribution must also fit into the hierarchy so as to have maximum utility.

The principle of self organization to maximize power suggests that economy of the ecosystems and that of the humans is maximized together. The economy is spatially to use and transform resources with the most useful results. Good use is one that facilitates further efficiencies and organization.

3. Another principle recognizes different qualities of energy. Energies that have resulted from more transformations, more convergence, and concentration are of higher quality. High quality energy is that in which more previous energy transformations have been used. For example, energy quality increases as energy is successively transformed from energy of sunlight and chemical energy of the rain to leaves, to stored organic matter, to flowers, to seeds, to seed eating animals, etc. In Figure 1c energy quality increases from E to A to B to C.

High quality energy has greatest effect as an amplifier of lower quality energies so that the system as a whole develops maximum possible function. Note the feedbacks from right to left in Figure 1c. High quality energies require more resources in their development and thus are scarcer. If transformed energy required more but was not more useful, that transformed form of energy would not continue to be made. Those patterns of organization retained are those where the transformed energies have greater amplifier control effects.

4. Regional systems like smaller ecosystems may be represented with energy systems diagrams that represent the mathematics of causal relationships and simultaneously the energetic transformations. An energy diagram is given in Figure 2 showing energy hierarchy by arranging low quality, high quantity resources and components on the left side of the paper and high quality, low quantity resources and components on the right. The pattern from left to right represents the successive energy transformations and spatial hierarchy as explained with Figure 1c. Rural items are on the left and the towns and industry on the right.

Amazon Developmental Pattern

The theories just given about energy flow hierarchies and the kinds of spatial patterns help understand and predict the kind of economic-environmental developments which are occurring and are predicted for the future.

When oil was found in the Ecuadorian Amazon a major additional energy was added, one requiring a network of roads, pipelines, and technological activity. Oil is a moderately high quality energy and its maximum use requires it to interact with large areas through a technological economy. Hence, only a small part of the oil is used locally, and most is transported to the nearest main economy, in this case up over the Andes to ship to refineries converging through the upland economy of Ecuador. These pathways are bidirectional with goods and services moving from Andean population centers down the new roads diverging into the Amazon as a second main driving force.

Whereas the previous economy was mainly organized around the river hierarchy as the dominant energy pattern, the addition of the terrestrial oil-road-pipe-town hierarchy is most easily added to the initial river system by fitting like clasped fingers of two hands, the rivers converging eastward and the road-pipeline system converging westward. See the sketch in Figure 3. In this way neither hierarchical pattern interferes with the other, except when river floods wash out bridges.

In Figure 2 an energy diagram is prepared for the Ecuadorian Amazon area showing sunlight, winds and rains driving in large quantity from the left. The rivers converge and their increasing concentration and quality is represented by the river path moving from the left to the right. The convergence of the oil from many scattered wells also goes to the right, whereas the goods and services coming down the mountain by road and airplane feed back while diverging from right to left.

The diagram also represents the waves of peoples, each operating at a higher total energy level, the subsistence Auracs, the river network of Quichla-speaking Indians, and the recent Spanish speaking colonists, part of the new system of oil and roads.

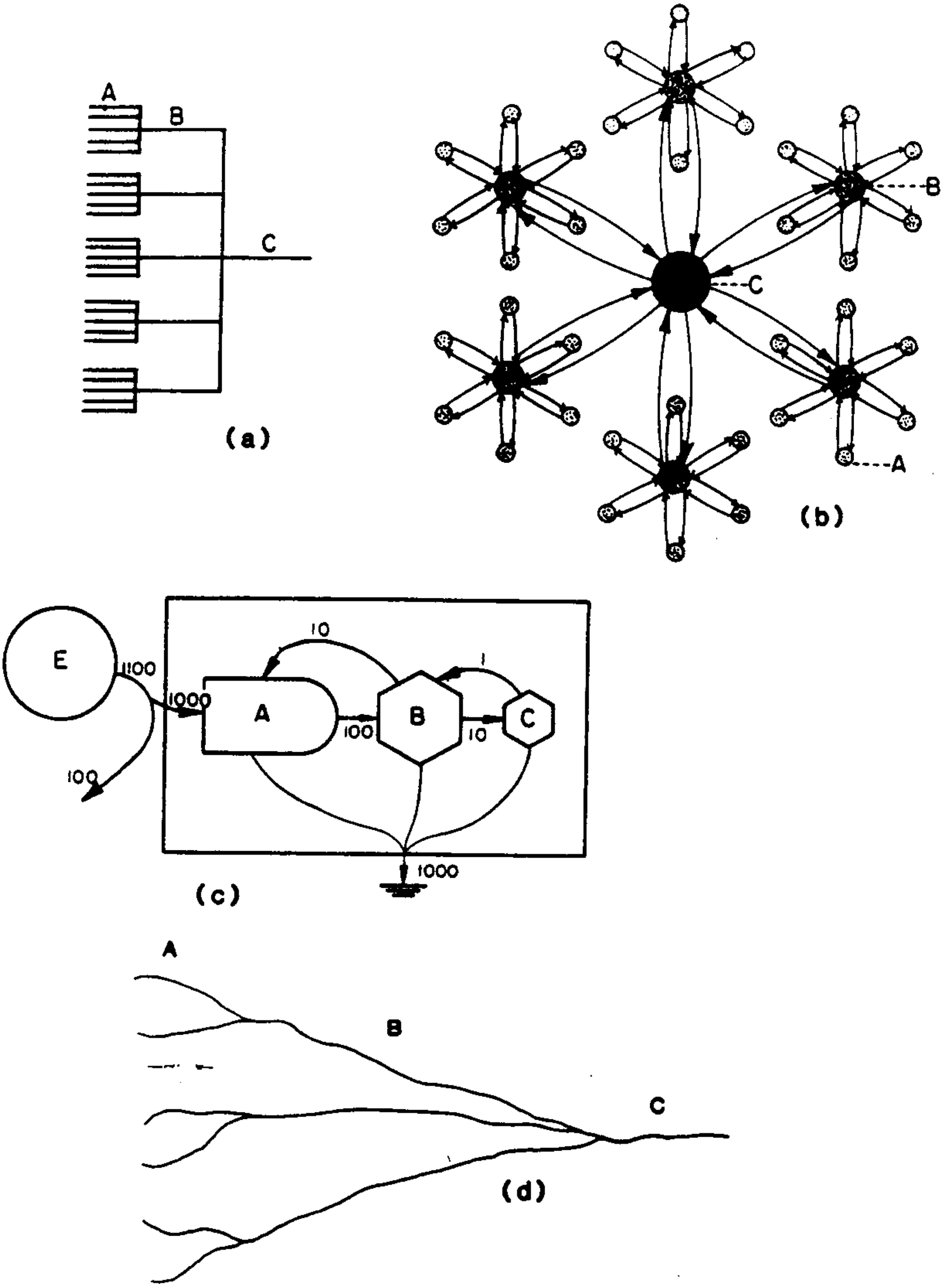


Figure 1. Diagram for representing hierarchy in geographical perspective. (a) Hierarchy in a human organization; (b) spatial distribution of hierarchy that begins with resources evenly distributed over the landscape; (c) energy language diagram of the transformations of energy in a pattern like that in (b); (d) hierarchical patterns in the flow of rain converging in rivers.

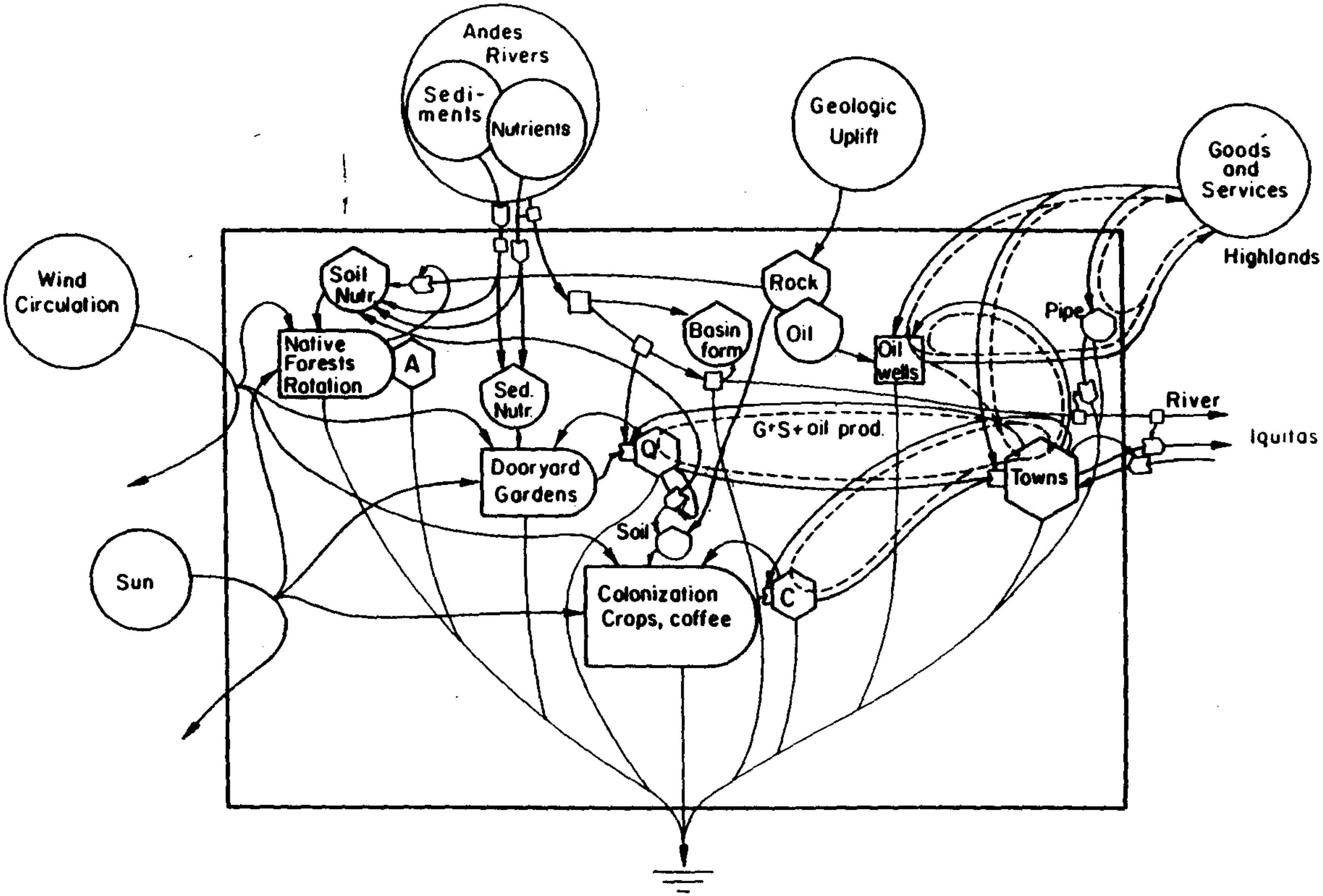


Figure 2. Energy language diagram of the Ecuadorian Amazon region. A, Aurac indians in early subsistence regime; B, Quichla-speaking indians in dooryard garden culture on riverbanks after Inca invasion; C, Spanish-speaking recent colonists along roads between the rivers.

In these patterns the Ecuadorian Amazon developments seem to represent in microcosm the pattern of development over the other Amazon areas where roads are facilitated by various non-renewable resources, interfingering from upstream with the river hierarchy and communications downstream.

As in the world elsewhere, the non-renewable resources such as iron, oil, gold, bauxite, virgin forest wood accumulations and stored soil will become less and less available. However, the Andes Mountains have very high quality energies available. For example, when mountain hydroelectric power is developed, it may substitute for many oil usages. Thus, the emerging hierarchical pattern of human settlements now receiving great stimulus from non-renewable resources (Figure 3) may provide a spatial pattern that can be maintained even after non-renewable resources are gone. The rivers transporting Andean soil material contribute new fertility to soils by their deposits over the area and make agriculture more sustainable there than in many rainforests.

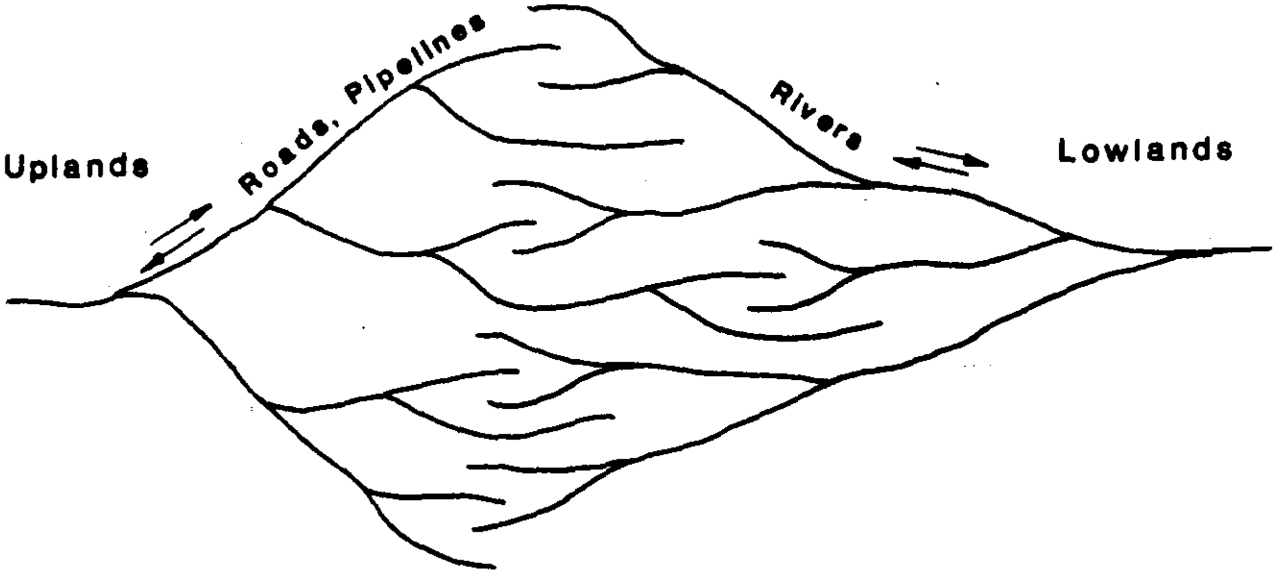


Figure 3. Spatial organization developing in upper Amazon that has two routes of Hierarchical convergence.

SPATIAL SIMULATION OF ECONOMIC DEVELOPMENT IN THE AMAZON BASIN

M.T. Brown

A computer model of economic development in the Amazon Basin that is driven in part by internal storages of energy and resources, and in part by the world economic system is simulated and the changing land use within the Basin is spatially allocated using an hierarchical algorithm. The simulation results indicate the extent to which the basins early development depends on investment from outside sources.

I am very grateful for the technical assistance provided by J. R. Richardson in development of the spatial simulation portion of the model.

Introduction

The Amazon Basin comprises a vast area of environmental resources. The basin is the largest tropical river system in the world, discharging approximately one-fifth of all the fresh water entering the oceans. The forests of the Amazon represent one of the largest stands of tropical-moist and rain forests in the world. The diversity of plant and animal life is so great it is thoughtt that there are many species within the basin yet unknown to modern science. There is much talk concerning the diversity of plant life and the potential benefits to modern medicine that remain to be discovered within the basin.

The resources of the basin are just now being realized. Beside the vast quantities of tropical hardwoods there are recently discovered mineral deposits that represent some of the world's largest finds to date. It is estimated that the potential for hydroelectric generation is about 100,000 MW, or equal to the energy in about 375 million barrels of oil. To date only about 1% of this potential has been tapped.

Brazil's population (approximately 68% of the Amazon Basin is within Brazil) has been growing at a rate of 3.2% per year. In recent years the Brazilian economy has not kept pace with this growth and has been experiencing inflation at over 100% per year for some time. The international debt of Brazil is the largest in the free world, creating great pressure to increase internal productivity and exports to meet interest payments. As Brazil continues to industrialize and segments of its population enjoy greater standards of living, there is increasing demand for forest products, agricultural land, and other resources found within the basin. Land use and land tenure within the basin is undergoing radical change.

Recent government policies are aimed at tapping the resources of the Amazon Basin. Roads are being constructed that open up areas heretofore inaccessible. Enormous hydroelectric projects and mining operations are being undertaken as joint ventures between the government and private industry.

Relocation of the poor from the northeast and urbanized south to the Amazon Basin is current policy.

In all, the pressure to develop the Amazon Basin is great. The resources recently discovered within the Basin suggest it is quite likely that development will continue for the foreseeable future, causing worldwide concern over the loss of the tropical forest and its species, and the global effects of such losses. Much as been written about development of the Amazon, mostly expressing grave concern over the loss of the forests. Brazil defends its policies stating that the environmental resources of the Amazon belong to the Brazilian people. World opinion, on the other hand, asserts that due to the size of the Amazon, it represents concerns of global scale, and hence global jurisdiction. There is also concern over the extinction of species, some of which remain to be discovered. The world environmental community seems to be saying "go slowly", while the Brazilian government and the world development community are moving quickly to develop the Amazon Basin.

There is no question but that the pressure for development of the Amazon Basin and the vast quantities of resourses that it contains are causing very rapid development to occur. In the early 1970's the Trans-Amazon Highway was built, opening up the Southern Basin for homesteading and agricultural development. Large areas of forest are being clear-cut, some land planted in fast growing pulp plantation species, and others planted in pasture. The hydroelectric potential is quickly being developed and the resulting dams have flooded many millions of acres of forest and displaced thousands of indigenous Indians. Because of the remoteness of most development projects, whole cities must be carved out of the forest. With every "planned city", there is always an unplanned, spontaneous city on its outskirts that houses the peasants drawn to the new sources of income and energy.

Simulation Model of Development

Given in Figure 1 is a model of the interplay of the main components of the Amazon Basin. The model is a synthesis model of the main features of the economy of humanity and nature of the basin. Sunlight and rain are the primary renewable driving forces, whole goods and services bought from world markets drive much of the features dominated by humanity.

Shown are the Rain forest, developed lands that are drawn from the forest lands and ~~the~~ storage of urban assets. The river is included as a storage of potential energy in head. Two storages of resources are shown, mineral resources having long turnover time, and fuel resources having a relatively short turnover time. Lands are actively removed from native forest through the interaction of assets, but return as successional lands when abandoned. There river head is tapped and utilized as an energy source in the productive processes of the urbanized areas. Exports include: 1) manufactured goods, 2) minerals and other unrefined materials, and 3) lumber and other forestry products. Monies received from their sale is utilized to purchase goods, fuels and services from world markets. In this way the availability of imported goods, fuels and services is directly related to the sale of exports.

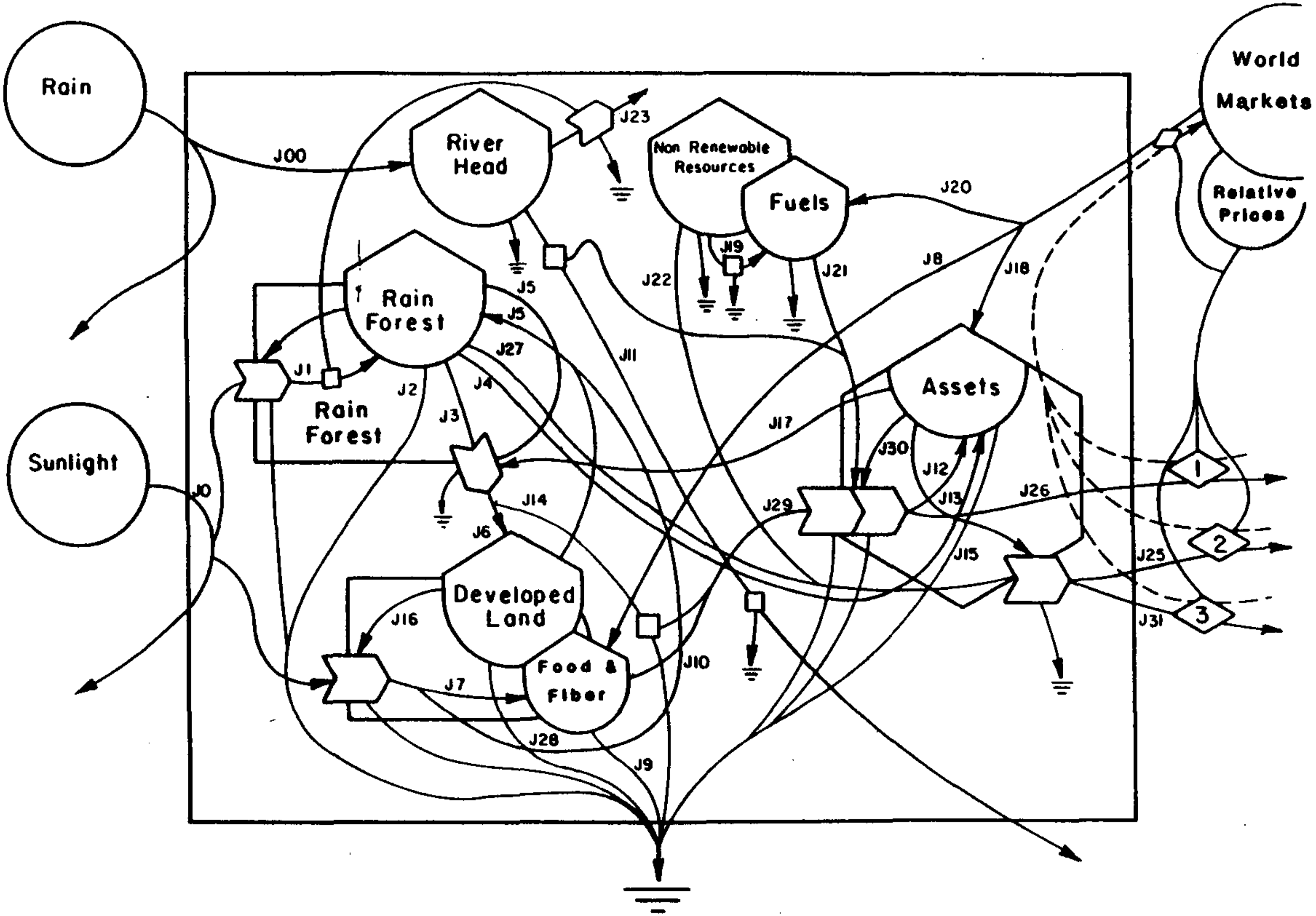


Figure 1. Simulation model of economic development in the Amazon Basin. Numbers refer to evaluated pathways and storages given in Table 1.

Table 1. Values and Explanation of Storages (State Variables) and Flows for the Simulation Model Shown in Figure 1.

Storage or Flow	Value	Explanation
S - Rainforest	2.5 E17g	Total of soil organic matter & biomass 1.37 E17g forest; 1.12 E17g soil
L - Developed Land	26.0 E10m^2	Average of estimates of forest lands converted to other uses - 260,000 km^2
F - Food & Fiber	20.3 E12 Cal	Average of 1 year supply of food & other consumer goods. Based on 4000 Cal/person · y (4000 Cal) x (13.9 E6 people) x (365 day)
N_1 - Non Renewable Resources	1724 E18 Cal	Proven storage of mineral & oil resources. See Table 2. Energy systems overview of Amazon Basin
N_2 - Fuels	47.1 E12 Cal	Short term storage of fuels. See Table 1. Energy systems overview of Amazon Basin
A - Assets	271.6 E12 Cal	Total assets of buildings, machinery etc. See Table 2. Energy Systems Overview of Amazon Basin.
J_{00}	1.82 E16 l/yr	Rainfall
J_0	1.4 E19 Cal/yr	Sunlight
J_1	1.84 E15g/yr	Gross production = 261 g/m^2/yr. Table 1. Energy Analysis of Brazil.
J_2	1.25 E15g/yr	Respiration 1% of Storage
J_3	6.3 E14g/yr	Rate of cutting of forest (1.8 E10m^2/y) x (3.5 E4g/m^2) = 6.3 E14g/yr

Table 1. (cont)

Storage or Flow	Value	Explanation
J_4	3.2 E13g/yr	Assume 5% of forest wood harvested utilized as lumber. See J3.
J_5	2.3 E13g/yr	Return of lands to successional forest (2.6 E9m^2) x (3.5 E4g/m^2) x (25%) = 2.3 E13 g/yr.
J_6	1.8 E10m^2/yr	Conversion of forest to developed land from Hecht (1981)
J_7	27.1 E12 Cal/yr	G.P.P. of agriculture & forestry lands (26 g/m^2/yr) x (4 Cal/g) x (26.0 E10m^2) = 2.71 E12 Cal/yr
J_8	1.38 E12 Cal/yr	Actual energy in imported goods. (Fundacau Inst. Bra. Geo. Est. 1980) (902.1 E6 lbs) x (1530 Cal/lb) = 1.38 E12 Cal/y
J_9	5.4 E12 Cal/yr	Loss due to respiration, insects, disease and waste, assume 20% of G.P.P.
J_{10}	20.3 E12 Cal/yr	Consumption of food and fiber (13.9 E6 people) x (4E3 Cal/day) x (365 days) = 20.3 E12 Cal/yr
J_{11}	4.7 E15 l/yr	River Discharge = 26% Rainfall (Solati and Vose, 1984)
J_{12}	11.1 E 12 Cal/yr	Average growth rate of assets equal to 4.07% from 1958 to 1979 (271.6 E12 Cal) x (4.07%) = 11.1 E12 Cal/yr)

Table 1. (cont)

Storage or Flow	Value	Explanation
J_{13}	1.3 E13 Cal/yr	Wood used for construction of assets. (See J27) (5.3 E14 Cal/yr) x (5%) x (0.5 Cal/Cal) = 1.3 E 13 Cal/yr
J_{14}	1.2 E13 Cal/yr	Fuelwood and charcoal use adjusted for population of basin from Table 1. Energy analysis of Brazil (10.1 E17 J/yr) x (2.4 E-4 Cal/J) x (5%) = 1.2 E13 Cal/yr
J_{15}	2.7 E12 Cal/yr	Depreciation of assets, assume 1%/yr (71.4 E12 Cal) x (1%) = 7.1 E11 Cal/yr
J_{16}	1.3 E10m^2/yr	Utilization of lands and abandonment, assume 20 year rotation time (26.0 E10m^2) x (5%) = 1.3 E10m^2/yr
J_{17}	3.4 E12 Cal/yr	Use of assets for conversion of forest lands to developed lands assume 2%. (271.6 E12) x (2%) = 3.4 E12 Cal/yr
J_{18}	1.4 E12 Cal/yr	Actual energy of good imported as assets (Fundacau Inst. Bra. Geo. Est. 1980) (6.7 E9 lbs) x (210 Cal/lb) = 1.4 E12 Cal/yr
J_{19}	7.0 E12 Cal/yr	Fuels derived from internal storages. See Table 1; Energy Systems Overview of Amazon Basin
J_{20}	40.0 E12 Cal/yr	Fuels Imported. See Table 1; Energy Systems Overview of Amazon Basin
J_{21}	47.0 E12 Cal/yr	Fuels Consumed. See Table 1. Energy Systems Overview of Amazon Basin

Table 1. (cont)

Storage or Flow	Value	Explanation
J_{22}	4.3 E18 Cal/yr	Mineral Extraction. Assume 400 years to exhaust (estimates of greater Carajas Program) See Table 2. Energy Systems Overview of the Amazon Basin (1.71 E18 Cal)/400 = 4.3 E18 Cal/yr
J_{23}	1.3 E 16 l/yr	Evapotranspiration: 74% of rainfall (Solati & Vose, 1984)
J_{24}	3.9 E10 Cal/yr	Hydroelectricity Generated See Table 1. Energy Systems Overview of the Amazon Basin.
J_{25}	3.9 E18 Cal/yr	Export of Minerals. 90% of yearly extractable ore (J22). (Greater Carajas Program.)
J_{26}	1.4 E12 Cal/yr	Actual energy in exported goods. (From Fundaco Inst. Brasilero, de Geograficae Estatistics, 1980) (915 E6 lbs/yr) x (1530 Cal/lb) = 1.4 E12 Cal/yr
J_{27}	1.8 E13 g/yr	Wood Products Cut for Export (See Table 1, Energy Systems Overview of the Amazon Basin (4.5 E6 Tonne) x (1 E6 g/tonne) = 4.5 E14 g/yr.
J_{28}	2.6 E9 m^2/yr	Active loss of lands through utilization assume 1% of developed land.
J_{29}	1.2 E13 Cal/yr	Fuelwood and Charcoal use. See J14
J_{30}	2.7 E12 Cal/.yr	Use of assets for exports of forest products and minerals, assume 1%

Table 1. (cont)

Storage or Flow	Value	Explanation
J_{31}	1.8 E13 Cal/yr	Export of Forest Products. Table 1. Energy Systems Overview of the Amazon Basin. (4.5 E6 Tonne) x (1 E6 g/Tonne) x (4 Cal/g) = 1.8 E13 Cal/yr

Table 1 lists the data used in the determination of coefficients and calibration of the model. Storages are given first, then yearly flows corresponding to each pathway in the model. Using these data the model is calibrated, then initial conditions of assets and developed lands are set to zero and forest set to 100% to mimic the undeveloped condition. Simulation runs begin in the year 1800. It was assumed that there was no development in 1800, although it is quite well known that there was some minimal settlement in these early years.

The results of 3 differing simulation runs are given in Figure 2. Curves shown are for forest land, developed land, assets, and food/fiber. This latter state variable is the storage of consumable goods having relatively quick turnover, and not considered assets. In the first simulation (Figure 2a) development achieves a level that is sustainable with incident renewable energies and internal resources. Development is constrained by not allowing trade with world markets. With no exports, there are no imports of goods, fuels and services from outside. Thus the level of development atained reflects a level that is sustainable in a steady state pattern with no subsidy from nonrenewable resources. Developed land represents approximately 1% of the Basin (note that the scales of the verticle axis are different.).

The graphs in Figure 2b result from allowing foreign trade and the export of large quantities of mineral resources. Since imports are tied to exports through national balance of payments, imports increase rapidly after mineral resources are "discovered" in the late 1900's. The resulting graphs show an economy that is almost wholly dependent on outside markets and external trade. Level of development peaks, declines somewhat, and levels by the year 2200. The main assumption in this simulation is that there is a "healthy" world economy with which to trade. The next simulation run shows what might happen to the Basin economy and level of development should the world economy falter.

As the economy begins to level in the third simulation (Figure 2c), trade is cut off mimicing what might happen should the world economy falter, or what might happen if economic sanctions were imposed as a result of loan defaults. It is of particular interest, how quickly the assets of the Basin decline, and that the area of forest returns almost to levels characteristic of the basin prior to the mid 1900's.

Spatial Simulations

Driven by the simulation model described above, development of lands within the Amazon Basin is spatially simulated. Known and planned highways are generated by the computer, and where roads cross river networks, cities are located. The development potential of each city is determined using an algorithm based on the embodied energy of its "hinterland". Those with larger Hinterlands, have greater potential for development. A second algorithm is overlayed on the first. This algorithm is based on the concept of aglomeration. Older and larger cities have greater potential to "attract" development than do newer ones, thus older cities have greater drawing power for new development.

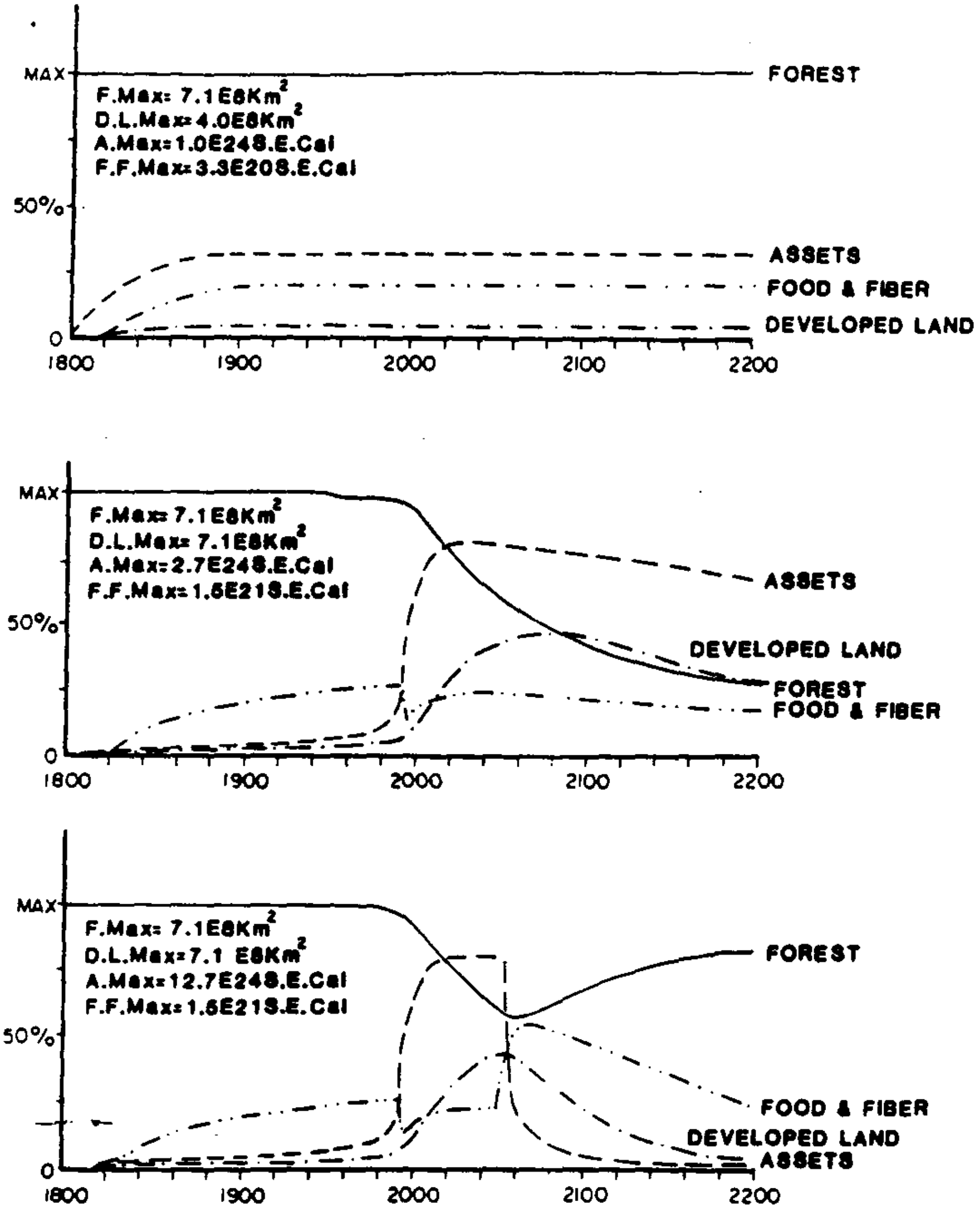


Figure 2. Simulation results of the model in Figure 1, showing levels of development, assets, and forest attained by a solar based economy (a), unconstrained growth (b), and levels achieved with a halt in external trade at about year 2050 (c).

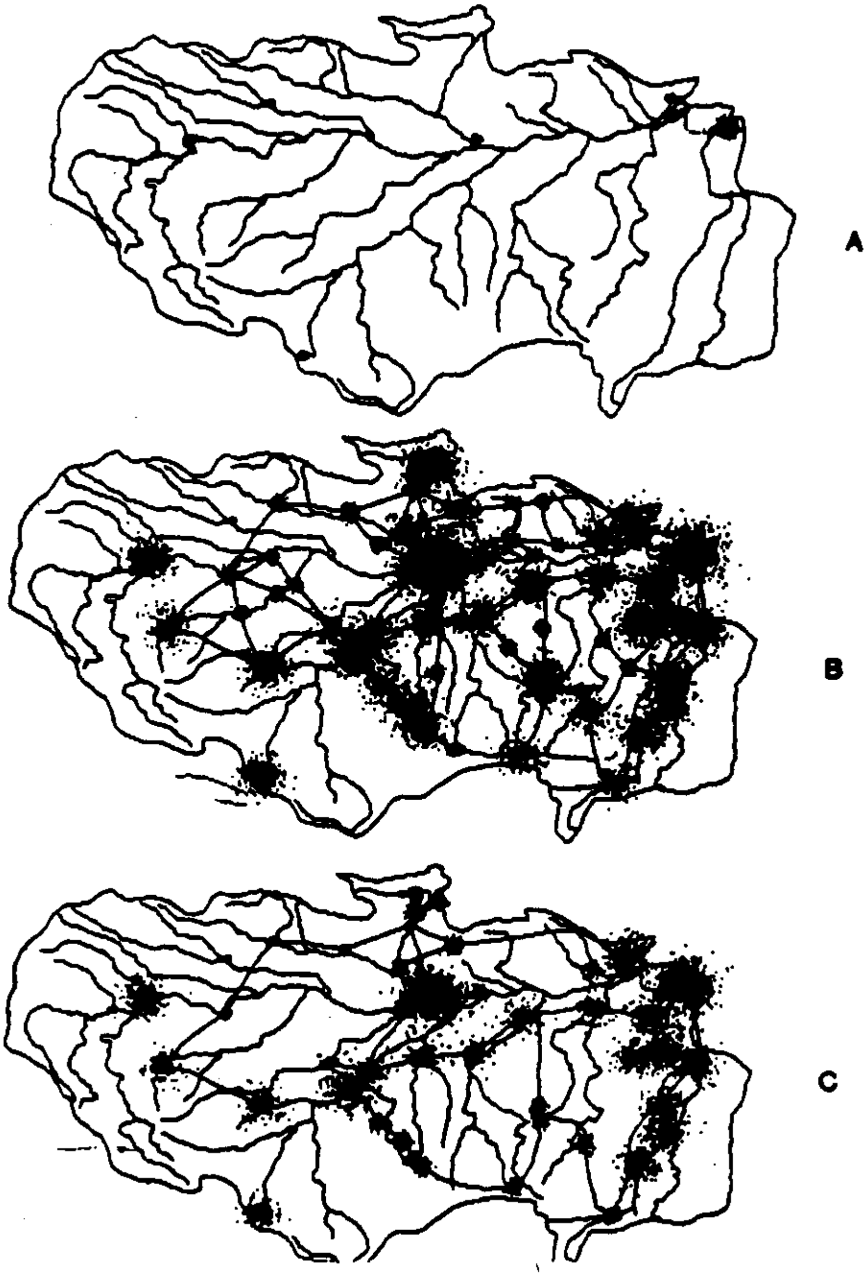


Figure 3. Computer generated maps of development in the Amazon Basin, showing a solar based economy (a), unconstrained growth (b), and level of development achieved after a halt in external trade (c).

Using these spatial allocation methods, computer routines were developed that spatially allocate developed lands within the Basin that correspond to the levels of development attained during the simulation of the model in Figure 1. The maps of development shown in Figure 3 are the results of spatially allocating developed lands for each of the simulation runs graphed in Figure 2. Figure 3a corresponds to the level of developed attained at the end of the simulation run shown in Figure 2a, Figure 3b corresponds with 2b and 3c with 2c. During the simulation runs, the maps are plotted, so that not only is developed land spatially allocated within the basin, but it is done so on a yearly basis.

A major limitation of the spatial allocation technique is that it relies on an imput of known or planned road location to determine city location. As conditions change, roads may be planned and built that were not perceived in the early years of development of a region. Such may be the case in the western portions of the basin at the base of the Andeas. It is strongly suggested that major development in these areas will occur by the turn of the century, since valuable resources, and good agricultural lands are plentiful. However, the simulation does not show such development occurring. As the model is refined, a different technique for determining location of roads, and cities is being developed. Environmental attributes of the landscape, such as storages of natural resources, soils, and terrain are being utilized on an equalivent basis to determine location.

III. FUELS, ELECTRICITY, AND ECONOMIC POLICY

To understand the Amazon Basin and consider its future, the national economies affecting the basin may be considered, especially that of Brazil. Economic development is driven partly by the availability of resources, particularly fuels and electric power, and partly by outside investments and benefits from foreign trade. In the chapters of Part III that follow, an examination of the Brazilian economy is made to see how it is causing change in the Amazon Basin. Next, energy analysis methods are used to evaluate the potentialities of a new hydro-electric dam, the supply of fuels from tree crops, and outside trade.

ENERGY ANALYSIS OVERVIEW OF BRAZIL*

Howard T. Odum

Starting with geographic inventory as to what is important suggested by an emphasis map in Figure 1, perspectives on Brazil were developed with overview systems diagram given in Figure 2. On the left is shown the forest sector, largely of the Amazon. Note the pathways of development of thse lands into croplands and pastures partly under rotation and shifting cultivation. Note the importance of the Andes in supplying headwaters to maintain the net water balance of the river and net sediment balance, ultimately contributing to long range land fertility in many areas. The diagram shows the rural people based on and controlling the rural sectors. Included are important marine ecosystems of the continental shelf at the Amazon mouth (Figure 1).

The large urban populations to the right of the diagram are shown with their resource base from the rural sectors increasingly based on food, fiber, fuels, mining, and electricity generated from the Amazon region. Also shown as feedback loops from the right to left in Figure 2 are the liquid fuels, fertilizers, technological inputs, labor and rural land uses. A more integrated coupling of rural and urban sectors facilitated by new transportation infrastructures maximizes the power of the region with consumption of resources exceeding the environmental production of these resources. On the far right are shown the trade balances and other fiscal exchanges such as international loans. The diagram helps show the way the Amazon destiny is part of the accelerating national organization, ultimately based on the excess consumption crescendo of the western world at this time.

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* This overview was prepared as part of work in summer 1983 at the International Institute of Applied Systems Analysis, Laxenburg, Austria. I am grateful for comments on the earlier study from Celso Testa, Deputy Director, Estado do Grande do Sul, Assembleia Legislativo, Commissao de Obras Publicas, Porto Alegre; P.T. Alvim, Visiting Professor at the University of Florida; and scientific and management staffs at Jari, Brazil. Main data sources were yearbook statistics of Brazil (Fundacao Instituto Brazileiro de Geografia e Estatistica, 1981); a useful summary by Goldemberg (1982) and OLADE energy summary by Banados (1981). Corrections were made for double counting in use of dollar flows to estimate embodied energy of services.

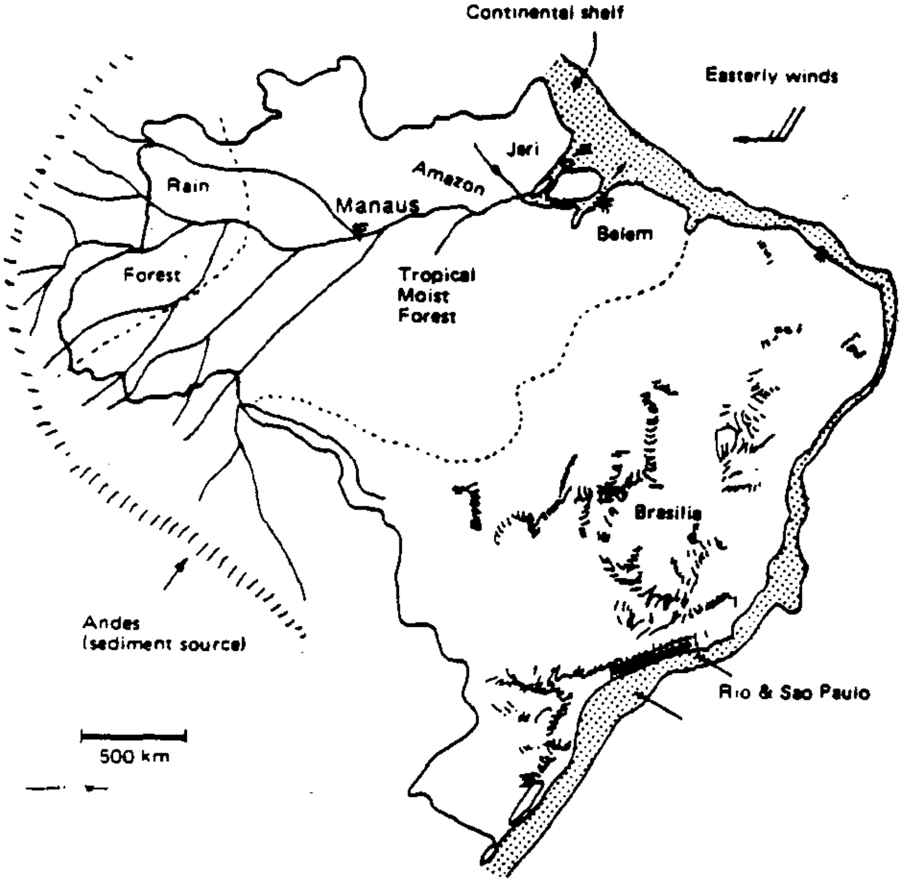


Figure 1. Overview map of Brazil.

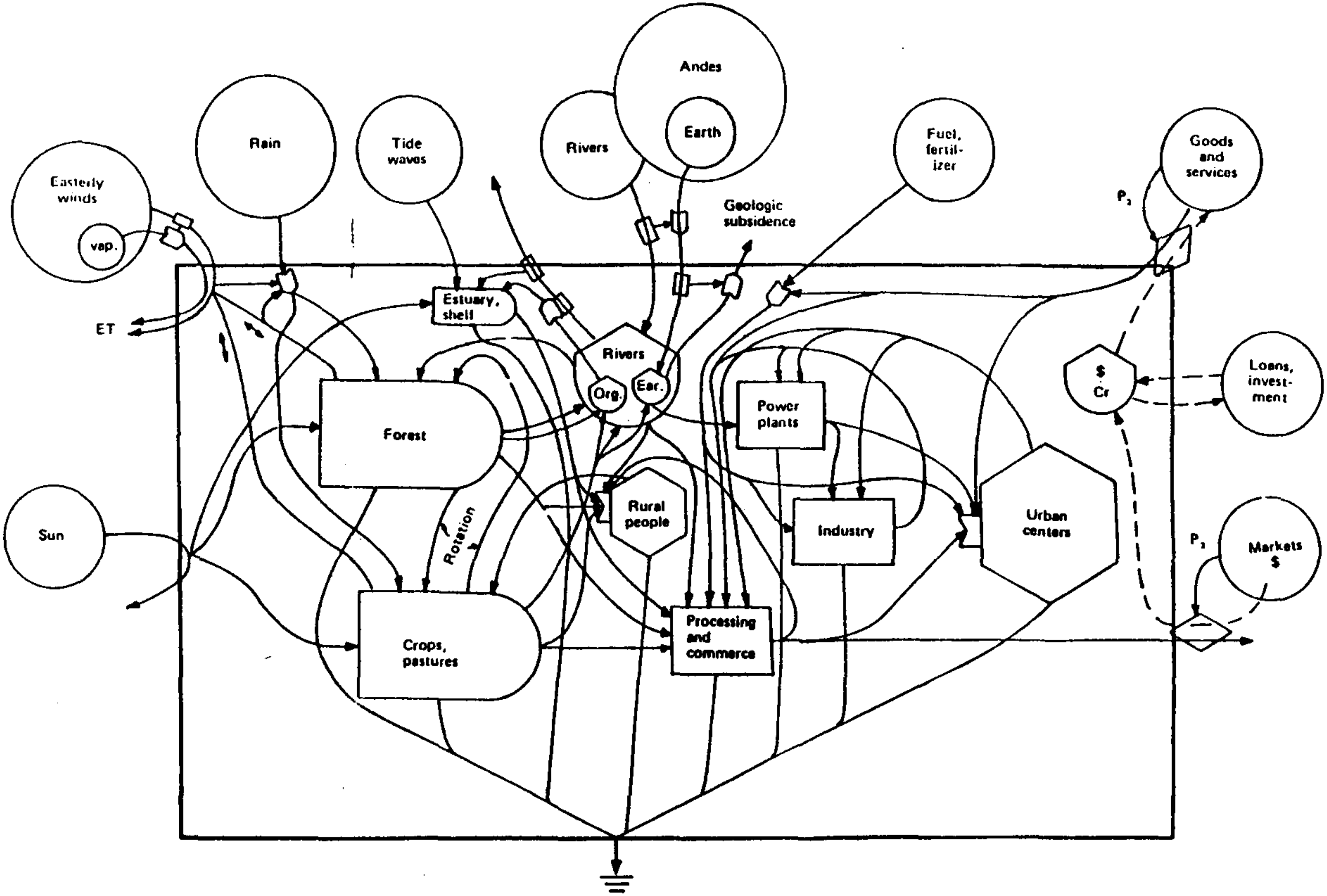


Figure 2. Energy diagram of Brazil (Odum and Odum, 1983).

In Table 1 the main pathways of the system as given in aggregated overview are listed and evaluated, first with raw data estimates (in grams, joules or international dollars in column 1). Then the importance of the flows to the economy was evaluated by calculating the embodied energy units (solar equivalent joules in column 3 or solar equivalent kilocalories in column 4). These were obtained by multiplying the raw data by energy transformation ratios in column #2. Some items evaluated in the table are part of others. For example, the wood contribution is based on the transpired rain.

The results in Table 1 show that the most important contributors to the combined economy of environment and humanity of the national economy are the rain and inflowing river from the Andes including the sediments transported from the Andes. These drive many of the other flows evaluated separately such as wood production, hydroelectric power, and coffee. Much of the valuable water-related embodied energy passes out to sea, some contributing to estuarine fisheries. Possibly, there would be net energy in routing some of these waters to dry parts of the country. These environmental resources are many times the imported fuels or purchased goods and services from outside.

Table 2 evaluates some of the reserves (storages) of resources in embodied energy units. Notice the large values in the soil and wood, mostly from the Amazon. At the present rate of primary forest cutting and conversion to agricultural soil, the use is 5.5 E23 SEJ/J. Depletion time for the reserves is 100 years. When the fuel uses (16 E22 SEJ/y) in Table 1 are compared to storages of fossil fuels in Table 2 (2412 E22 SEJ) the depletion time is 153 years, much longer than that available to most nations. Growth of native forest (73 E22 SEJ/y) is 1.32% of the 5550 E22 SEJ stored in forest biomass (Table 2).

The calculation of sediment balance indicates the role of Andes generating earth exported to Brazil in excess of that going to the ocean, contributing to the long-term subsidence cycle. These inflows are a valuable input to Varzea forest floodplains, carrying nutrients and soil-making earth.

Calculations of topsoil loss and formation is dependent on estimates of area of forest in successional regrowth which is large because of the shifting agriculture and other rotations. Until data being accumulated in carbon-dioxide related studies provide more detail, the sketchy calculations suggest considerable formation of new soil.

The importance of these resources is shown in embodied energy analysis but is less recognized with microeconomic money evaluations because the contributions are indirect. The analysis shows the importance of preserving the water, sediment, forest regenerative system, finding ways to couple it to agricultural, forestry, and other economic yield systems without losing the environmental service. The damming, channelization, and diking of rivers in other parts of the world shows how development without attention to the renewable services can lose much of the ultimate economic base. Waters are diverted from their land interaction. Sediments are wasted in filling up reservoirs or shunted to the sea. The annual floods of the Amazon and their role in rejuvenating the Varzea floodplains and the upper Amazon lands needs to be used. Innovative ways are needed to couple economic production without losing the sources of high embodied energy.

Table 1. Energy flows in Brazil.

Foot-note	Type of energy	Actual energy J/y	ETR SEJ/J	Embodied solar energy E22 SEJ/y	Embodied solar energy E19 SECal/y
1	Direct sun	4.6 E22	1.	4.6	1.1
2	Chemical potential				
	Rain	6.76 E19	1.5 E4	101.4	24.2
	Inflowing river	1.34 E19	4.1 E4	55.0	13.1
3	Geopotential of rain	4.66 E19	8.9 E3	41.5	9.9
4	Geopotential of runoff				
	Within Brazil	1.35 E19	2.35 E4	31.8	7.6
	Flowing into Brazil	1.07 E19	2.35 E4	25.1	6.0
5	Hydroelectricity	3.1 E17	1.59 E5	5.0	1.2
6	Total electricity, 1980	3.3 E17	1.59 E5	5.2	1.3
7	Waves	8.55 E17	2.59 E4	2.2	0.5
8	Tide	2.37 E17	2.35 E4	0.56	0.13
9	Net earth inflow				
	0.55 E15 g/y	--	1.71 E9/g	94.0	22.4
10	Net topsoil formation	1.67 E18	6.25 E4	10.4	2.5
11	Wood growth	2.22 E19	3.3 E4	73.3	17.5
12	Lumber-use	1.65 E18	3.5 E4	5.7	1.4
Fuel uses:					
13	Fuelwood use (in oil J)	0.88 E18	3.5 E4	3.1	0.74
14	Charcoal use (in oil J)	1.31 E17	7.0 E4	0.92	0.22
15	Oil consumption:				
	Indigenous	3.78 E17	5.3 E4	2.0	0.48
	Imported	2.24 E18	5.3 E4	11.9	2.8
16	Coal consumption (in oil J)	1.47 E17	5.3 E4	0.78	0.19

Table 1. (continued). Energy flows in Brazil.

Foot-note	Type of energy	Actual energy J/y	ETR SEJ/J	Embodied solar energy E22 SEJ/y	Embodied solar energy E19 SECal/yr
17	Uranium use	4.9 E16	1.79 E3	0.008	0.002
18	Natural gas	3.0 E16	4.8 E4	0.144	0.034
19	Alcohol use	1.09 E17	6.0 E4	0.65	0.16
20	Sugar cane Bagasse	2.71 E17	6.11 E4	1.65	0.39
Exports:					
21	Amazon organic discharge	1.26 E18	6.25 E4	7.9	1.9
22	Bauxite	5.9 E13	1.32 E7	0.08	0.02
23	Iron ore	8.48 E14	6.0 E7	5.09	1.2
24	Wood and paper	2.64 E16	3.0 E5	0.79	0.19
25	Sugar	2.14 E16	8.4 E4	0.18	0.04
26	Coffee, 6.22 E5 T/y				
Imports:					
27	Potash	1.23 E15	2.61 E6	0.32	0.08
28	Phosphate	1.06 E14	4.14 E7	0.44	0.10
29	Nitrogen	2.99 E15	1.69 E6	0.51	0.12
30	~~Fuels~~	2.24 E18	5.3 E4	11.9	2.84

Footnotes for Table 1.

1. Direct sun

Insolation 140 kcal/cm^2/y (Sellars 1965)
Area, 8.51 E12 m^2 land + 0.67 E12 shelf = 9.18 E12
Land: albedo 15%

(0.85)(8.51 E12 m^2)(140 kcal/cm^2/y)(4186 J/kcal)(1 E4 cm^2/m^2)
= 4.2 E22 J/y

Shelf:

(0.67 E12 m^2)(140 kcal/cm^{2}y)(4186 J/kcal)(1 E4 cm^2/m^2)

0.392 E22 J/y

Total: 4.633 E22 J/y

2. Chemical potential

Rain: Mean of annual rainfall of 27 capital cities, 1589 mm/g (Fundacao Instituto Brasileiro de Geografia e Estatistica 1980).

(8.51 E12 m^2)(1.589 m/y)(5 J/g)(1 E6 g/m^3)

= 6.76 E19 J/y

Inflowing river: dissolved solids, 67 g/m^3; water inflow, 2.73 E12 m^3/y (Marlier 1973)

(2.73 E12 m^3/y)(G)(1. E6 g/m^3) = 1.34 E19 J/y

where G = 138 log$_e$ = 4.9 J/g

3. Geopotential of rain

Data from Footnote 3

(1.589 m/y)(1 E3 kg/m^3)(8.51 E12 m^2)(9.8 m/sec^2)(352 m)

= 4.66 E19

4. Geopotential of runoff from within Brazil

Runoff estimated as rain minus pan evaporation (1.589 m/y - 1.128 m/y); 27 rain storms, 26 evaporation stations and mean elevation from hypsometric data (Fundacao Instituto Brasileiro de Geografia e Estatistica 1980)

(0.461 m/y)(8.51 E12 m^2)(1 E3 kg/m^3)(9.8 m/sec^2)(352 m)

= 1.35 E19 J/y

Flowing into Brazil:

2.72 E12 m^3/y or more (Marlier 1973)

(2.73 E12 m^3/y)(400 m)(1 E3 kg/m^3)(9.8 m/sec^2)

= 1.07 E19 J/y

5. Hydroelectricity

Fundacao Instituto (1980)

(34.1 E6 T oil equiv.)(44 E9 J/T)

= 1.50 E18 J/y oil equivalents

3.14 E17 J elect

6. Total electricity (1980)

7% thermal power added to hydroelectric power.

7. Waves

6100 km facing coastline
Wave height, 0.6 m in 10 m water assumed similar to other trade wind region, South Florida

(3.35 E7 kcal/m/y)(4185 J/kcal)(6.1 E6 m)

= 8.55 E17 J/y

8. Tide

(0.5)(0.67 E12 m^2 shelf)$(1\ m)^2$(706/y)(1.023 E3 kg/m^3)(9.8 m/sec^2) (.1)

= 2.4 E17 J/y

9. Net earth inflow

Earth ~~from~~ Andes + earth formation in Brazil-Amazon discharge area of Andes drainage outside Brazil contributing earth estimated from map as 6.22 E11 m^2; earth cycle of Amazon Basin, 50 E-6 m/y; for Andes source of sediment value for Himalayas used, 848 E-6 m/y (Ollier 1981); sediment discharge of Amazon, 1 E15 g/y (Snead 1980).

(Andes input) + (Brazil formation) - (Amazon discharge)

(0.33)(6.22 E11 m^2)(848 E-6 m/y)(2.6 E6 g/m^3) + (8.51 E12 m^2)
(50 E-6 m/y)(2.6 E6 g/m^3) - (1 E15 g/y)

= 0.55 E15 g/y deposited*

* may be equal to geological subsidies.

10. Topsoil formation

On agricultural areas, 8.1 E11 m^2, loss rate assumed for southeastern U.S., 850 $g/m^2/y$ (Larson et al. 1983); new soil formation assumed on half of forest area, 2.5 E12 m^2

(soil formed) - (soil eroded)

= (2.5 E12 m^2)(1260 $g/m^2/y$) - (8.1 E11 m^2)(850 $g/m^2/y$)

=3.21 E15 g/y

(3.21 E15 g/y)(0.03 organic)(5.4 kcal/g)(4186 J/kcal)

= 1.67 E18 J/y

11. Wood growth

Estimated 261 E6 g/ha in 100 y at Jari;

(261 $g/m^2/y$)(4 kcal/g)(4186 J/kcal) = 4.37 E6 $J/m^2/y$

(4.37 E6 $J/m^2/y$)(5.08 E12 m^2 forest) = 2.22 E19 J/y

12. Lumber

(Fundacao Instituto 1980) 1977.

(1.22 E8 m^3/y)(0.8 E6 g/m^3)(4 kcal/g)(4186 J/kcal)

= 1.65 E18 J/y

13. Fuelwood use

Banados (1981), for 1980

(2.0 E7 T oil equiv.)(44 E9 J/T) = 0.88 E18 oil J/y

14. Charcoal use

Goldemberg (1982) for 1979

(2.98 E6 T oil equiv./y)(44 E9 J/T) = 1.31 E17 oil J/y

15. Oil consumption

Banados (1981) 1980

indigenous--

(8.593 E6 T oil equiv.)(44 E9 J/T) = 3.78 E17 J/y imported--

(51.0 E6 T oil equiv.)(44 E9 J/T) = 2.24 E18 J/y

16. Coal consumption

1980 domestic production, Banados (1981)

(3.34 E6 T oil equiv.)(44 E9 J/T) = 1.47 E17 oil J/y

17. Uranium use

Fundacao Instituto (1980)

(1.114 E6 T oil equiv.)(44 E9 J/T) = 4.9 E16 J/y

18. Natural gas

Fundacao Instituto (1980)

(0.68 E6 T oil equiv.)(44 E9 J/T) = 3.0 E16 J/y

19. Alcohol use

(2.47 E6 T oil equiv.)(44 E9 J/T) = 1.09 E17 J/y

20. Sugarcane Baggasse

Fundacao Institute (1980)

(6.168 E6 T oil equiv.)(44 E9 J/T) = 2.71 E17 J/y

21. Amazon organic discharge

Richey et al. (1980)

22. Bauxite

Fundacao Instituto (1980) 9.91 E6 T/y @ $3.55 E8 U.S.

(0.91 E6 T/y)(65.3 E6 J/T) = 5.9 E13 J/y

23. Iron ore

Fundacao Instituto (1980) 5.97 E7 T/y @ 8.91 E8 U.S.

(5.97 E7 T/y)(14.2 E6 J/T) = 8.48 E14 J/y

24. Wood and paper

Fundacao Instituto (1980) 1.58 E6 T/y @ $2.47 E8 U.S.

(1.58 E6 T/y)(4 E6 kcal/T)(4186 J/kcal) = 2.64 E16 J/y

25. Sugar

1.28 E6 T/y)(4 E6 kcal/T)(4186 J/kcal) = 2.14 E16 J/y

26. Coffee

Fundacao Instituto (1980)

6.22 E5 T/y @ $1.99 E9 U.S.

Imports (Fundacao Institute 1980)

27. Potash

(1.758 E6 T/y)(702 E6 J/T) @ $1.77 E8

28. Phosphate

(1.40 E6 T/y)(76.4 E6 J/T) @ $2.78 E8

29. Nitrogen

(1.38 E6 T/y)(2170. E6 J/T) @ $1.63 E8

30. Fuels

See footnotes 13 - 18.

Table 2. Energy storages in Brazil.

Foot-note	Type of energy	Actual energy E18 J	ETR SEJ/J	Embodied solar energy E23 SEJ	E20 SECal
1	Petroleum	8.11	5.3 E4	4.3	1.0
2	Natural gas	1.83	4.8 E4	0.88	0.21
3	Coal	592.0	4.0 E4	236.8	56.6
4	Uranium oxide	70.0	1.8 E3	1.3	0.3
5	Wood biomass	1720.0	3.2 E4	550.4	131.5
6	Topsoil, litter	3142.0	6.2 E4	1948.0	465.4

* Shale oil reserves are given by Goldemberg (1982) and pilot plants are operating, but there is no evidence that the net energy is sufficient to contribute to the economy.

Footnotes for Table 2.

1-4 fuel reserves from Goldemberg (1982)*

1. Petroleum

   $(198\ \text{E}6\ \text{m}^3)(41\ \text{E}9\ \text{J/m}^3) = 8.11\ \text{E}18\ \text{J}$

2. Natural gas

   $(47\ \text{E}9\ \text{m}^3)(3.89\ \text{E}7\ \text{J/m}^3) = 1.83\ \text{E}18\ \text{J}$

3. Coal

   $(2.2\ \text{E}10\ \text{T})(26.9\ \text{E}9\ \text{J/T}) = 5.92\ \text{E}20$

4. Nuclear

   Reserve at less than $95 (1979, U.S.) per kg.:

   $(0.007)(1.26\ \text{E}5\ \text{T}\ U_3O_8)(1.\ \text{E}6\ \text{g/T})(7.95\ \text{E}10\ \text{J/g}\ U_{235})$

   $= 7.0\ \text{E}19\ \text{J}$

5. Wood biomass

Biomass assumed half mature; half 15 years of succession (Uhl, 1983):

Mature = (2.54 E12 m^2)(3.7 E4 g/m^2)(4 kcal/g)(4186 J/kcal) = 1.57 E21 J

Successional = (2.54 E12 m^2)(4.0 E3 g/m^2)(3.6 kcal/g)(4186 J/kcal) = 1.53 E20 J

Sum = 1.72 E21 J

ETR used, wood unharvested, 3.23 E4 SEJ/J.

6. Topsoil including litter

Land areas (Goldemberg 1982) forest, 5.1 E12 m^2; Cropland, 4.1 E11 m^2; pasture, 4.1 E11 m^2; other 1.29 E12 m^2; half of forest assumed mature with 3.5 E4 g/m^2 organic matter; half of forest assumed successional with 1.7 E4 g/m^2

(2.54 E12 m^2)(3.5 E4 g/m^2)(5.4 kcal/g)(4186 J/kcal) = 20 E20 J

(2.54 E12 m^2)(1.7 E4 g/m^2)(5.4 kcal/g)(4186 J/kcal) = 9.7 E20 J

(4.1 E11 m^2)(0.5 m)(1.5 E6 g/m^3)(0.02 kcal/g)(4186 J/kcal)

= 0.26 E20 J

(4.1 E11 m^2)(0.5 m)(1.5 E6 g/m^3)(0.03 kcal/g)(4186 J/kcal)

= 0.38 E20 J

(1.29 E12 m^2)(0.5 m)(2.0 E6 g/m^3)(0.02 kcal/g)(4186 J/kcal)

= 1.08 E20 J

Total: 3142 E18 J

In Table 3 and Figure 3 the separated flows are aggregated further to show the high fraction of renewable sources. This suggests that the economic developments could be much more permanent than those in much of the world's present economic centers that are fossil fuel based. The figure and table is used to estimate the ratio of embodied energy to dollars circulating in the gross national product. (See item P1 - 6.6 E12 SEJ/$). This value is 2.5 times that of the U.S. That means the real standard of living in Brazil is averaging 2.5 times higher than a comparison of incomes would indicate.

In Table 4, the flows in Table 3 are combined in various indices. The energy per person is large when environmental resources are included. In other words, a family with a dooryard garden living along an Amazon tributary has a substantial and varied existence although the part of their living passing through the monied economy is small. To the extent that the shifting agriculture is renenable, these resources are renewable, although the press of population reproduction and immigration is increasing the density of people relative to the forest, making the pattern more and more one of mining the forest life support role.

Either on a money or an embodied energy basis, the exports and imports are a small proportion of the total system. On an embodied energy basis imports are only 9% (Table 4, item 7), and on a dollar basis imports are also 9% - ratio of I to X in Table 3). Brazil has a high degree of self-sufficiency.

The ratio of exports to imports was 1.025, indicating little imbalance in embodied energy. The imbalance of payments in money terms often concerns economic planners, but the imbalance in emergy in many undeveloped countries is often many times greater with much of the value of raw resources going unrecognized to stimulate other economies. In this 1980 analysis this was not true for Brazil.

However, the large foreign loans used to accelerate development projects created a large need to generate foreign exchange to pay 10% interest and the principal to be paid back is equivalent to 250% return. This impossible situation is recognized in embodied energy analysis, not recognized in dollar evaluations because the high embodied energy contributing to the economy directly and through rural support of labor is not accompanied by money circulation.

The rapid economic growth of Brazil's economy was almost unaffected by the OPEC oil price jump of 1972 because the economic basis of Brazil's growth was internal. Only when the large foreign loans were added did the economy develop the severe problems. The solution is to recognize the embodied energy basis for foreign exchange rather than the international dollar and restructure payments of principal and interest to be 0.4. If this analysis is correct, it would restore Brazil to economic viability, which would readily generate the means to repay the loans. The alternative of defaulting is much more severe. A sensible development of the Amazon requires a healthy Brazilian economy. This could follow a better understanding of the real internal basis of their economic growth.

Some of the loan monies went into projects to generate excess electricity and excess alcohol, neither of which are exportable in a way to generate net embodied energy to Brazil's economy. Analysis of these systems follows in sections below. Discussion of the special disadvantages of exporting fuels or buying fuels is given.

Table 3. Summary flows for Brazil in Figure 3.

Letter in Figure	Item	
R	Renewable sources used, SEJ/yr	102.0 E22
R'	Rivers from Andes	55.0 E22
N	Nonrenewable sources flow within the country (SEJ/yr):	
	N_0 dispersed rural source (SEJ/yr)	4.0 E22
	N_1 concentrated use (SEJ/yr)	6.3 E22
	N_2 exported without use (iron)	5.17 E22
	$N'_2 = N_2$ minus service	12.7 E22
F'	Imported minerals and fuels (SEJ/yr)	11.2 E22
F	F' minus service	
G	Imported goods (SEJ/yr)	
P_2I	Imported service (SEJ/yr)	3.62 E22
I	Dollars paid for imports ($/yr) (1979, U.S.)	$19.9 E9
E	Dollars paid for exports ($/yr) (1979, U.S.)	15.2 E9
P_1E	Exported services (SEJ/yr)	10.0 E22
B	Exported products, transformed within the country (SEJ/yr) (rubber, wood)	--
X	Gross National Product ($/yr) (1979, U.S.)	$2.135 E11
P_2	Ratio embodied energy to dollar of imports (SEJ/$) (1979, U.S.)	1.82 E12
P_1	Ratio of embodied energy to dollar of country and for its exports (SEJ/$)	6.66 E12

Debt in 1983 was 83.0 E9 $.

Footnotes for Table 3.

R Chemical potential of rain plus tide; this assumes salt-fresh interaction mainly at Amazon mouth.

N_o (Native forest fuelwood, 3.1; charcoal, 0.92) E22

N_1 (Lumber, 5.7; coal 0.59) E22

N_2 (Iron ore, 5.09; bauxite, 0.08) E22

F' Imported minerals with services subtracted $US (1979):
(fuel, 7.33; phosphate, 0.278; potash, 0.177; nitrogen, 0.16) E9/g

Service = ($US per year)(Energy-dollar ratio for US in 1979)

($8.0 E9)(1.85 E12 SEJ/$) = 1.48 E22

F' = (12.71 - 1.48) E22 = 11.23 E22

F (fuel, 11.9; phosphate, 0.44; potash, 0.32; nitrogen, 0.05 E22) = 12.71 E22

G Not separated from total service

P_2I (US Energy-dollar ratio for 1979)(Brazilian imports in $)

(1.85 E12 SEJ/$)(19.9 E9 ES$ 1979)

= 3.68 E22

I&E (Fundacao Institute 1981)

P_1E (6.6 E12 SEJ/$)($15.2 E9) = 10.0 E22 SEJ/y

B Export goods not isolated from services in overview calculation. Energy sources to wood, coffee, sugar, etc. already included in R

X Cruzeiro to US$ 1979 = 25.8 Cr/$
(Fundacao Instituto 1980)
GNP, $2.31 E11 US 1979.

P_2 (3.62 E22 SEJ/gr)/($19.9 E9) = 1.82 E12 SEJ/$

P_1 U/GNP; U from Table 4

(190.2 E22 SEJ/y)($2.135 E11) = 8.9 E11 SEJ/$

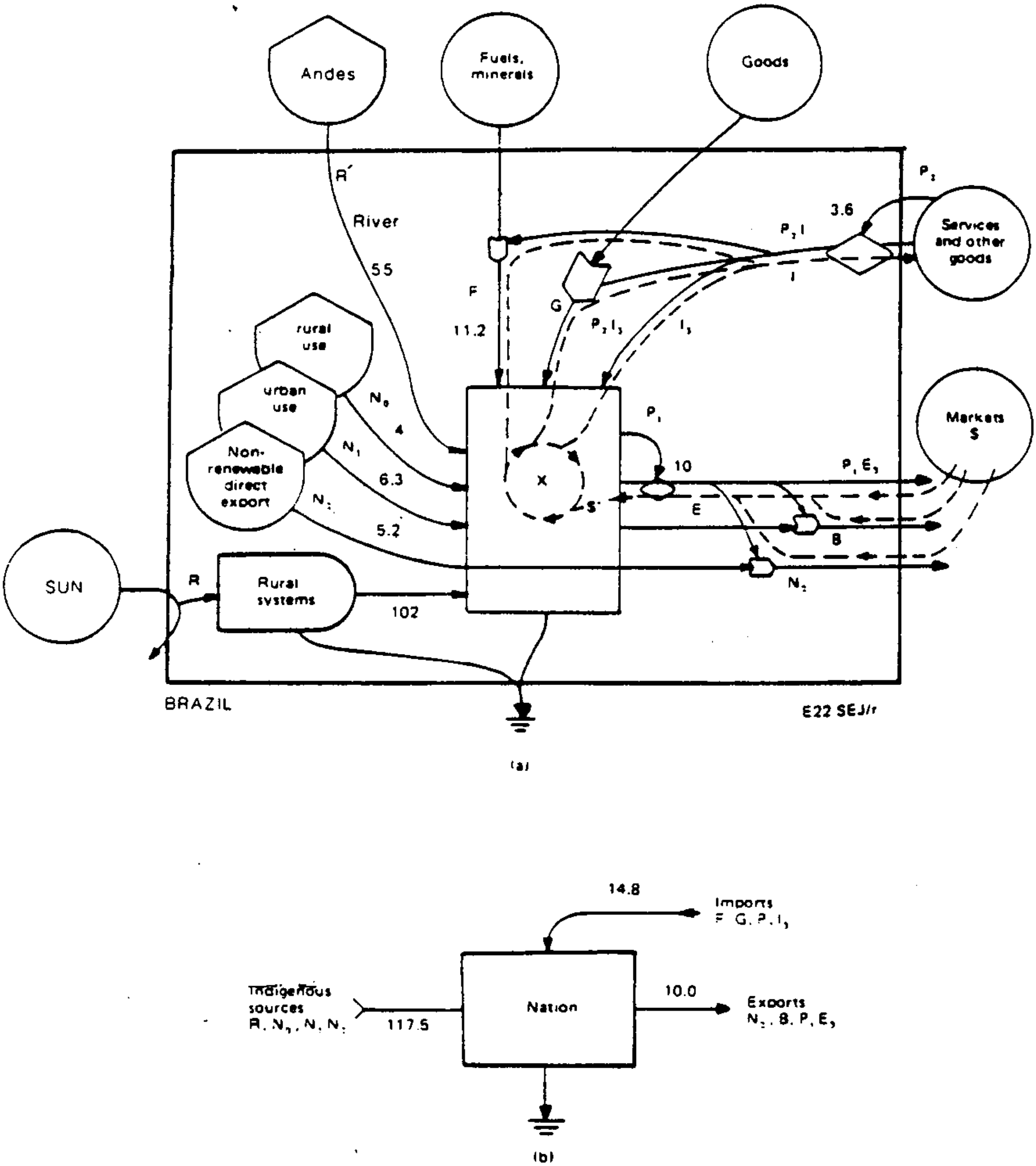


Figure 3. Summary of embodied energy flows of Brazil. See Tables 1 and 3.

Table 4. Indices using embodied energy for overview of Brazil.

Item	Name of index and expression. See Figure 3.		
1	Renewable embodied energy flow energy flow	R + R'	157.0 E22
2	Flow from indigenous nonrenewable reserves	N	15.5 E22
3	Flow of imported embodied energy	$F+G+P_2I$	14.8 E22
4	Total embodied energy inflows	$R+N+F+G+P_2I$	190.9 E22
5	Total embodied energy used, U	$U=N_o+N_1+R+F+G+P_2I$	178.2 E22
6	Total exported embodied energy	B+P1+E+N2	10.0 E22
7	Fraction of embodied energy used derived from home sources	$(N_o+N_1+R)/U$	0.91
8	Exports minus imports	$(N_2+B+P_1E)-(F+G+P_2I)$	0.37 E22
9	Ratio of exports to imports	$(N_2+B+P_1E)/(F+G+P_2I)$	1.025
10	Fraction used, locally renewable	R/U	0.83
11	Fraction of use purchased	$(F+G+P_2I)/U$	1.8
12	Fraction used that is imported service	P_2I/U	0.03
13	Fraction of use that is free	$(R+N_o)/U$	0.86
14	Ratio of concentrated to rural	$(F+G+P_2I+N_1)(R+N_o)$	0.19
15	Use per unit area (9.18 E12)	U/(area)	2.08 E22 SEJ/m^2
16	Use per capita (121 E6 population)	U/(population)	1.57 E16 SEJ/per.
17	Renewable carrying capacity at present living standard	(R/U)(population)	100.0 E6 people
18	Developed carrying capacity at same living standard	8(R/U)(population)	800.0 E6 people
19	Fuel per person	(fuel use)/(pop.)	1.55 E15 SEJ/pers.
20	Fraction electric	(total elect.)/U	0.07

ENERGY ANALYSIS OF A HYDROELECTRIC DAM NEAR TUCURUI

Mark T. Brown

To better understand the overall contributions and characteristics of hydroelectric dams in the low relief tropics and help with policy, an energy evaluation of the dam at Tucurui on the the Tucantine river is presented next. Embodied energy in the fuels, goods, and services utilized to construct the dam as well as the embodied energy in yearly operation and maintenance are evaluated. Also evaluated are the embodied energy in forest wood, gross production, soils, and sediments, and these are related to the energy yield of the project. Renewable energies of sunlight and rain over the entire "powershed" of the project are evaluated and compared to the electricity generated.

Introduction

Upon completion, the Tucurui hydroelectric plant will be the fourth largest dam (in generating capacity) in the world. It is the largest of nine hydroelectric plants now in various stages of planning and construction within the Amazon Basin. Projected generating capacity in its first phase will be 4000 MW and 8000 MW after the completion of the second phase, now only planned. With little landscape relief in the Tucantine Basin, the reservoir will cover an area of approximately 243,000 hectares. Maximum normal head for the dam will be 60.8 meters and average yearly flow of the river is 11,000 m^3/s.

There is much controversy surrounding the dam and its effects on the environment. The large area inundated, indigenous Indians that must be moved, and the potential water quality problems are the impacts discussed most often. This analysis addresses some of these issues and looks at long-term effects, both positive and negative, to determine the net effect of the dam. Embodied energy is used as a common denominator to evaluate impacts and benefits of the project. In this way, all aspects of the dam can be evaluated and an overall net benefit or net energy can be calculated for the project.

System boundaries include the "powershed" of the dam since the overall effects of the dam are felt throughout that entire area. Publications of the company that is building the dam, Eletronorte, (Usina Hidreletrica Tucurui, and Eletronorte: 100,000,000 KW, both publications of Cantrais Eletricas do Norte do Brasil SA) give the powershed as a triangular area with Belem, Maraba, and Sao Luis at each corner. The area is approximately 2.3 E5 km^2 and includes the delta of the Tucantines River. Where it meets the Amazon River.

Energy Evaluation of the Dam

An energy evaluation of the flows and storages in the Tucurui Dam Powershed is given in Table 1. First, Flows and Storages are evaluated in actual energy; second, the energy transformation ratios (ETR) are given; and third, in the final column, the flows and storages are given in embodied energy (Solar Equivalent Calories). Each flow or storage given in Table 1 is shown in the summary diagram (Figure 1.)

Sunlight, rainfall and river inflow are the main driving energies for the region, driving native forests and some rural agricultural settlements. Mineral resources have recently been discovered, leading to mining activity. Loans have made possible the purchase of outside goods and services for the construction of the dam.

As the dam is completed, the reservoir fills, and forest lands are converted to aquatic systems. Electricity is provided to three sectors; industry (mining), urban, and rural settlements. Growth in all sectors in response to the plentiful and inexpensive energy is likely. With increased growth of rural settlements, more forest lands are converted, and sediments in the river are likely to increase. Food and fiber are harvested form the forest and the rural settlements, and sold to the urban centers where some goods are purchased.

Repayment of principal and interest from the construction loans adds a long term embodied energy cost to the project over and above the energy embodied in the dam itself. As these monies are repaid, they are returned for the purchase of goods from the Brazilian economy. Whenever money is exchanged, what is actually being exchanged is its purchasing power. The embodied energy to dollar ratio is another way of expressing purchasing power. The ratio in Brazil is 15.9 E 8 S.E.Cal/\$, while it is about 9.1 E 8 S.E.Cal/\$ for other industrialized nations. In other words one gets 1.7 times as much for his dollar if he buys from Brazil rather than other countries. This coupled with the fact that 4 times the principal is repaid on such loans, places an additional energy cost most often hidden. Often not considered a loss to a region, exports represent energy that is diverted from internal productive processes in favor of driving productive processes in the importing region.

The cost of the dam is estimated as \$4.6 billion current U.S. dollars by Eletronorte (Centrais Eletricas do Norte do Brasil SA). Since the project is scheduled to come on line by the end of 1983 and is close to being on schedule, it is felt that the estimated costs are fairly accurate. Dollar costs are converted to energy costs using the current dollar/energy ratio of imported goods. Life of the dam is estimated as 50 years by Eletronorte. The operation and maintenance costs of the dam are estimated as \$0.001 per KWH generated.

Fuel and other materials have two energies associated with their utilization. The first is the services that are behind their manufacture and transportation, and the second is the embodied energy. The energy in services are accounted for in their dollar costs converted to energy, using an energy to dollar ratio, but their embodied energy must be calculated separately. Fuel energy, embodied energy in concrete, and embodied energy in steel are calculated separately and given in Table 1.

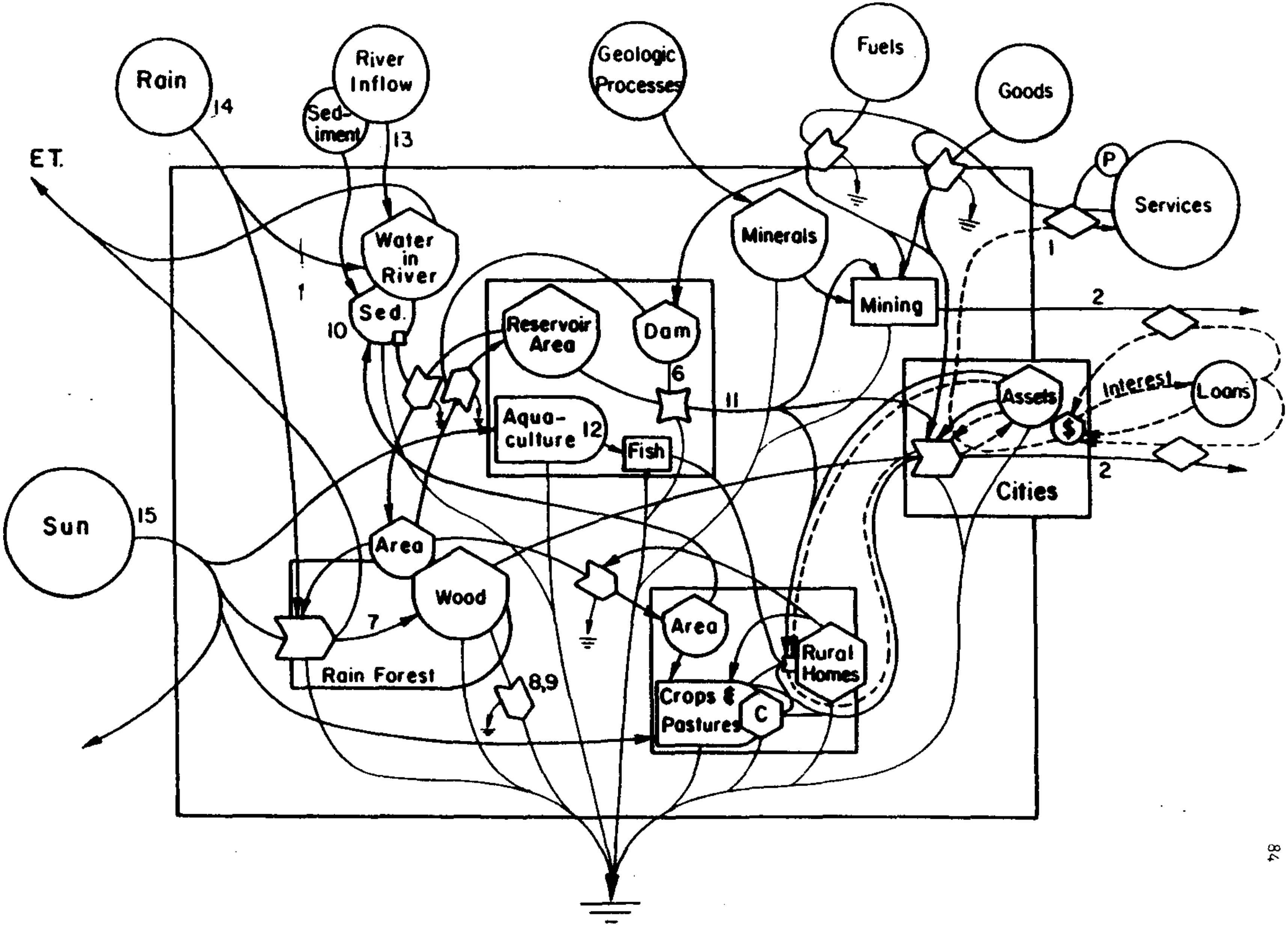


Figure 1. Energy analysis diagram of hydroelectric dam at Tucurui. Numbers are keyed to Table 1.

Table 1. Embodied energy flows in the region of the hydroelectric dam on Tucantine River at Tucurui

Footnote	Flow or Storage (from Figure I)	Items of Change	Actual Energy, Cal/yr	ETR Solar Equivalent, Cal/Cal	Change in Embodied Energy, X1 E16 SE CAL/yr
1	Dam	Embodied Energy in imported services	$4.6 E9/50 yr	9.1 E8*	8.4
2	Services	Embodied Energy in Debt Service	$18.6 E9/50 yr	15.9 E8@	59.1
3	Fuels	Fuels consumed	69.9 E10	5.3 E4	3.7
4	Concrete	Concrete consumed	1.5 E9	1 E7	1.5
5	Steel	Reinforcing Steel consumed	3.2 E9	1.97 E7	6.4
6	Operation and maintenance	Annual operation and maintenance costs	$1.4 E8	15.9 E8@	22.3
7	Terrestrial gross primary production	Loss of terrestrial gross primary production	4.86 E13	7.58 E2	3.7
8	Rain forest	Loss of wood due to inundation	3.0 E12	3.2 E4	9.6
9	Topsoil	Loss of topsoil due to inundation	3.5 E12	6.2 E4	21.8
10	Sedimentation	Loss of potential energy in buried sediments = 1.05 E13 g/yr	—	4.1 E5 +	430.5
11	Production of electricity	Annual electricity produced	2.4 E13	15.9 E4	381.6
12	Aquatic gross primary production	Gross primary production in reservoir	1.2 E13	4.4 E2	0.5
13	River flow	Geopotential energy in elevated river flow	4.93 E13	2.36 E4	116.4
14	Rainfall	Chemical potential energy in rainfall in the Tucurui Powershed	4.3 E14	1.5 E4	638.8
15	Sunlight	Sunlight on the Region	44.9 E16	1	44.9

*Global Energy to Dollar Ratio Expressed as S.E. Cal/$.
@Brazilian Energy to Dollar Ratio Expressed as S.E. Cal/$.
+Expressed as Cal/g

FOOTNOTES TO TABLE 1.

1. Dam and support facilities are expected to cost $4.6 E9 (1980, U.S.). The embodied energy in imported goods & services bought with this money is calculated using the global energy to dollar ratio of 9.1 E8 S.E. Cal/$. Embodied energy in imported goods & services:

   $$\$4.6\ \text{E9} \times 9.1\ \text{E8 S.E. Cal/\$} = \frac{418.6\ \text{E 16 S.E. Cal}}{50\ \text{yrs}} = 8.4\ \text{E16 S.E. Cal/yr.}$$

2. Embodied Energy in dept service. Monies are diverted from the local economy to repay principal and interest on loans. These monies in turn flow back into the Brazilian economy to purchase exported goods, when so doing, the lending countries benefit not only from the interest, but also from the very favorable embodied energy to dollar ratio of Brazil. Total dept is calculated as compounded interest of 15% for 10 years on $4.6 E9 loan. The total dept is equal to $18.6 E9.

   Embodied energy of debt service is calculated using the Brazilian dollar to energy ratio:

   $$\$189.6\ \text{E9} \times 6.66\ \text{E 12 S.E. J/\$} \times 2.389\text{E-4 J/Cal} = \frac{2959.4\ \text{E16 Cal}}{50\ \text{yrs}} = 59.2\ \text{E16 Cal/yr.}$$

3. Fuel use in heavy equipment. Total of 7.5 E6m^3 of earth and rock to be excavated (Eletronorte, 1981). Average excavation fuel costs estimated as .38 liters/m^3 x 9.1 E3 Cal/liter = 2.6 E10 Cal.

   Total embankments and dikes equal to 7.6 E6m^3 of earth and rock (Eletronorte 1981). Average fuel consumed in for hauling and placing material estimated as 3.4 liters fuel/m^3: 7.6 E6m^3 x 3.4 liters/m^3 x 9.1 E3 Cal/liter = 2.4 E11 Cal.

   Total fuels consumed for earth work = 26.6 E10 Cal.

   Total concrete hauled and placed equal to 1.36 E6 m^3 (Eletronorte 1981). Fuels consumed for hauling and placing concrete estimated as 3.4 liters fuel/m^3. Fuel consumed for hauling and placing concrete: 1.36 E6m^3 x 3.4 liters/m^3 x 9.1 E3 Cal/liter = 4.2 E10 Cal.

   Fuels consumed for Miscellaneous transport and equipment estimated from number of vehicles, average consumption per hour and percent of time in operation 318 vehicles x 37.9 liters/hr x 12 hrs x 300 days/yr. x 10 yrs. x 10% utilization = 4.3 E7 liters

   Fuel consumed: 4.3 E7 liters x 9.1 E3 Cal/liter = 39.1 E10 Cal

   Total fuels consumed: 26.6 E10 + 4.2 E10 + 39.1 E10 = 69.9 E10 Cal

4. Concrete. Total concrete equal to 1.36 E6m^3 (Eletronorte 1981). Actual energy of concrete equal to 1.1 E3 Cal/m^3.

   Actual energy in concrete: 1.365m^3 x 1.1 E3 Cal/m^3 = 1.5 E9 Cal.

5. Steel. Total reinforcing steel equal to 150,000 Tonnes (Eletronorte 1981). Actual energy equal to 2.2 E4 Cal/T.

   Actual energy in steel: 1.5 E5 Tonne x 2.2 E4 Cal/T = 3.2 E9 Cal.

FOOTNOTES TO TABLE 1.

6. Operation and maintenance. Estimated as 5.0 E-3 \$/KWH produced yr^{-1} (Healy 1974). Operation and maintenance = 5.0 E-3 \$/KWH x 2.8 E10 KWH/yr = 1.4 E8 \$/yr.

7. Loss of terrestrial gross primary production due to inundation. Energy value of GPP = 2 E8 Cal/ha·yr x 2.43 E5 ha = 4.86 E13 Cal/yr.

8. Loss of rain forest wood. Area of reservoir is 243,000 ha. Only a minor amount of the wood was cut before inundation. The resulting loss of storage of potential energy in wood is calculated as follows: Energy in standing rain forest wood = (2.615 E2 m^3/ha x 2.43 E5 ha x 9.86 E9 J/m^3 x 2.389 E-4 Cal/J)/50 years = 3.0 E12 Cal/yr.

9. Loss of soil due to inundation. Soil that is inundated represents a loss of a valuable storage. The potential energy in soil is different than the potential energy in earth materials (See #10 below). Basically the potential energy in soil is the organic matter while the potential energy in earth material is related to the structural aspects of soil that is made from the weathering of the parent rock. Using carbon content of soil (8 E7 g C/Ha) the energy value of soil is calculated as follows:

   Energy value of soil loss = (8 E7 g C/Ha 2.43 E5 Ha 9.0 Cal/g C)/50 yrs = 3.5 E12 Cal/yr.

10. Sedimentation is a loss to the river basin. Under normal circumstances valuable earth materials are carried by the river, some deposited along the way, and most deposited at the river delta. Since the study area includes the area of the delta, there is a net loss within the basin after completion of the dam, for most sediments will be deposited behind the dam. When sediments are deposited and buried in the reservoir instead of at the river delta, the energy value is lost to the region. Sediment load taken as 30 g/m^3.

    Energy value of sediments = (30 g/m^3)(3.5 E11 m^3/yr) = 1.05 E13 g/yr.

11. Annual production of electricity. Plant rated at 4000 MW, assume 80% loading factor. Electrical energy = 4 E6 KW x 0.8 x 8.76 E3 hr/yr x 860 Cal/KWH = 2.4 E13 Cal/yr.

12. Aquatic gross primary production. Gross production of eutrophic lake is 4.93 E3 Cal/m^2·yr (Wetzel, 1975). Energy value of aquatic GPP = 4.93 E3 Cal/m^2·yr x 1 E4 m^2/ha x 2.43 E5 ha = 1.2 E13 Cal/yr.

13. Geopotential energy in river flow with average head of 60.8 m and average flow of 11,000 m^3/s is as follows: Geopotential energy in river = 11,000 m^3/s x 3.15 E7 s/yr x 1 E3 kg/m^3 x 60.8 m x 9.8 m/s^2 x 2.389 E-4 Cal/J = 4.93 E13 Cal/yr.

14. Chemical potential of rainfall in the Tucurui Dam Powershed. Average rainfall equals 1550 mm/yr, size of powershed 2.3 E5 km^2. Chemical potential energy in rainfall = 2.3 E11 m^2 x 1.55 m/yr x 5 J/gm x 1 E6 g/m^3 x 2.389 E-4 Cal/J = 4.3 E14 Cal/yr.

15. Direct sunlight. Solar insulation = 195 Cal/cm^2 · yr.
    2.3 E5 Km^2 x 1 E10 cm^2 x 195 Cal/m^2 · yr = 44.9 E10 S.E. Cal/yr.

Gross primary production of the forest is lost as the reservoir for the dam is established. This daily contribution of upgraded sunlight is no longer possible once the forest has been eliminated. As long as the dam and its associated reservoir remain, the annual contribution of gross primary production by the forest will continue to be interrupted.

Most of the rain forest wood from the reservoir area will not be harvested prior to inundation by the dam. This represents a loss, but at the same time productivity will increase in the reservoir. The loss is determined separately from the increase in productivity and is calculated based on 261.5 m^3/ha of wood over the 243,000 hectares of the reservoir.

Other losses associated with the dam and its reservoir are the loss of soil and sediments. There are two components to soil: earth materials such as clay (sediments) and the organic materials usually given as carbon content. The making of a good soil matrix requires both components, but each comes from an entirely different source and thus have different embodied energies. The earth materials result from the erosion of parent rock, taking many thousands of years to accomplish. The carbon content of soils is built up through the years from the accumulation of organic matter. Soil structure depends on both components, and when eroded, both are lost. In the case of inundation, the loss is associated with the burying of the sediments and the organic component of the soil. Sedimentation will continue to bury the organic matter over the years and make recovery more or less out of the question for future terrestrial ecological systems. The organic component will have to be rebuilt when the reservoir is again exposed for terrestrial vegetation colonization. Sediments are trapped behind the dam, and will no longer be carried to the River Delta where they supported much work. Once deposited and buried behind the dam, valuable processes at the River Delta are lost.

Electricity produced by the dam is very significant. The dam, upon completion, will be the fourth largest (in generating capacity) in the world. Rated at 4000 MW, the generators are assumed to operate at 80% load factor.

Aquatic gross primary production is anticipated to increase significantly over the production that is characteristic of the river. The wood and organic matter that is left in the reservoir area will decompose and add fertility that will support more production and probably a larger fishery. The increase in production is calculated as the gross primary production characteristic of eutrophic waters.

The remaining energies in Table 1 are included for the purposes of comparison. They are the flow of energy in the river, and the energy in the rainfall over the powershed of the Tucurui Dam, and direct sunlight over the powershed.

By far the largest energy flow in the powershed of the dam is the chemical potential of rainfall over the region. Second largest is the energy in sediments. These sediments carried by the river to the Amazon, and on into the delta, are a vital part of an estuarine system. If sediments are decreased, much of the inputs of organic matter, nutrients, and delta building materials are lost, and estuarine processes are affected. The large energy associated with the flow of sediments in Table 1 indicates their value to downsteam processes. In the short time frame (the 50 year life of the dam) sediment accumulation and subsequent burial behind the data is a net loss to the system. However, over the long time frame, sedimentation whether behind the dam, or at the rivers mouth is balanced and is neither a loss or gain. Also relevant to the question of sediment loss or gain, is the effect of the boundary around the region. If the boundary does not include the delta and estuarine systems, then the accumulation of sediments can be considered a positive benefit of the dam, since valuable sediments are held and not lost to the sea. On the other hand, if the boundary includes the estuary and delta, then once again accumulation behind the dam can be considered a diversion of a valuable energy to a non-productive use.

If the embodied energy in sediments is included in the net energy yield ratio, the ratio is less than 1 (see the 2nd ratio in Table 2). The loss of production in downstream varzea forests, and estuarine systems is porportional to the large embodied energy associated with the sediments. Declines in estuarine processes and fisheries as well as decreases in nutrient deposition along river floodplains have caused dislocation of populations and interruption of economies, elsewhere, where dams trap sediments. The exact extent of dislocation and economic disruption is little known at this time, but is predicted using the embodied energy value of sediments trapped behind the dam.

Whether an energy source stimulates an economy for additional growth, or just adds energy without a stimulatory effect is related to its net energy ratio. Rich energy sources (those with high net energy ratios) have large stimulatory effect. While energy sources with low ratios, are not primary energies and do not stimulate additional growth of economies. Hydroelectric energy has long been considered as having large net energy yields; and where geologic features are well suited for deep reservoirs yields are high for little investment. But where the geology does not favor deep reservoirs, yield ratios are lower. The Net Yield ratio (See Table 2) of the dam at Tucurui is about 2.8/1. Primary energies such as oil and natural gas have net yield ratios of greater than 6/1; thus the hydroelectric dam will probably not stimulate the economy as much as the same amount of oil or natural gas bought on the world market. Sediments were not considered in the yield ratio, since it is still not well understood to what extend their accumulation behind the dam will effect the regional economy.

Given in Table 2 are a series of ratios for the hydroelectric dam at Tucurui. The yield ratio is comparable with electricity generated from wood (2.6/1) using data from Jari, and is greater than that calculated for oil palm and ethanol. However, with such a low ratio, and considering that the generating capacity will be the 4th largest in the world, it is likely that other hydroelectric dams with lower capacities will not have the favorable ratio. A useful ratio in low relief landscapes that is derived from the analysis of the Tucurui dam is the ratio of area of reservoir to generating capacity to obtain a net positive yield. This ratio assumes that all other costs are equal, and that the only variables are reservoir size and generating capacity. The ratio of 2.1 hectares per KW of generating capacity indicates that other dams where reservoirs are as big as that of Tucurui, but which have generating capacities smaller than that of Tucurui, may not be economic in the long run, and instead of providing a stimulas to the economy, may actually drag the economy. A case in point is the Balbina dam north of Manans, where the reservoir is almost equal in size to that at Tucurui, but generating capacity is only 4% of Tucurui's.

Table 2. Characteristics and Energy Ratios of Hydroelectric Dam at Tucurui.

Number in Table 1 and Figure 1	Item	Value
$\frac{1+2+3+....+9}{11+12}$	Net Yield Ratio	2.8/1
$\frac{1+2+....+9+10}{11+12}$	Net Yield Ratio With Sedimentation Included as a Loss to Region	0.67/1
11/3	Ratio of Electricity Produced to Fuel Consumed	103/1
11/13	Upgrade Ratio	3.3/1
$\frac{1+2+....+9}{13}$	Economic - Environment Ratio	1.2/1
11/14	Energy Matching	0.6/1
$\frac{1+2+....+9+14}{11\text{ (actual)}}$	Energy Transform Ratio	10.5E4
-	Ratio of Area of Reservoir To Generating Capacity for Net Positive Yield	2.1 Ha/KW

A ratio of electricity produced to fuels consumed is quite high and if mistakenly viewed as the efficiency of the dam, reveals the dam as having a high efficiency. However, this ratio does not include all energy inputs to the process, as the net energy ratio does. The upgrade ratio, is the ratio of the embodied energy in the electricity produced to the embodied energy in the river flow at the dam site. Again a ratio that is sometimes mistakenly used to describe the efficiency of the dam.

The economic-environment ratio in Table 2 is the ratio of total invested energy (sometimes called feedback energy) to the environmental energy of the site (river flow). Indicating the relative energy intensiveness of processes, the economic-environment ratio of the hydroelectric dam is 1.2/1; a ratio that is relatively low, especially in light of the magnitude of the project. Another ratio that provides a relative measure of the energy utilization and its effectiveness in the regional economy, is the energy matching ratio. Energy matching is the ratio of energy produced (and therefore consumed) to the regional renewable energy base (rainfall over the powershed), it is a measure of the energy intensity of the region. A ratio of 0.6/1 is low and characteristic of developing regions.

Summary

The hydroelectric potential of the Amazon Basin has been estimated to be over 100,000,000 KW. The evaluation of the dam a Tucurui lends insight into the potential impacts of future projects. In low relief areas where little geologic work has been done, the costs associated with hydroelectric dams are higher, since area of reservoirs are greater, and the dam structure does not benefit from steep geologic formations. If proposed dams inundate large areas of forest and generate relatively small amounts of electricity, net yields are small and in some cases may be negative. A useful ratio, assuming that all other things are equal, is the ratio of area of reservoir to generating capacity. At the Tucurui dam the ratio is 2.4 ha of reservior area per KW of generating capacity. Higher ratios will have yield ratios less than 1 and should be avoided.

Net yields are on the order of other alternatives for generating electricity. The ratio for the hydroelectric dam at Tucurui is 2.61, comparing favorably with alternative energy sources like palm oil, and sugarcane ethanol (see Table 3, Energy Analysis of Fuel Crops and Their Foreign Trade). However, comparison to the net yields from harvests of native forests on a sustaining basis (103/1), and the yields for conversion of native forests to electricity at, Jari (3.6/1), and even the yields from tropical forest plantations (4.6/1) , suggests that inundation of large areas of forest may not be the best use, and will not compete in the long run.

ENERGY PERSPECTIVES ON PLANTATION AND PULPMILL AT JARI

R.A. Christianson

An energy analysis of the combined plantation and pulpmill operations along the Jari River was undertaken to determine economic viability, to help with comparisons of other production systems, to identify unrecognized subsidies, and to measure environmental impact. The dominant inputs, outputs, storages, and internal flows are shown in Figure 1. Virgin forests are currently being cleared to provide land for plantations of exotic, successional species of fast-growing trees. Harvested virgin rainforest wood is primarily burned in the boilers of the electrical generating facility which provides power to the pulpmill. Principle external inputs include fossil fuels, sulfur, carbonate, equipment, and goods and services to support the isolated, local population of workers. The complex diagram in Figure 1 is simplified further in Figure 2 to show the main components and flows of energy across the boundary.

Energy Analysis

The underlying foundation of the energy analysis techniques used herein is that energy, as a property of all other flows, is the common denominator for evaluating systems.

After an energy systems diagram is drawn for a given system to be evaluated, the sources and other flows across the system boundary provide an "energy signature" of that system. The kind of system developing depends on the magnitude of the energy sources, the spatial and temporal distribution of those energies, and their combining effects. Each flow is evaluated as to the rate of energy flow across the boundary of the system. The resulting energy balance diagram illustrates the principles of hierarchy, conservation of energy, and quantities of energy flow.

Given a complete set of energy transformation ratios and the energy balance diagram, flows of actual energy across system boundaries are transformed into units of embodied energy. Several ratios can be calculated which indicate the relative standing of the system, such as: embodied energy delivered to embodied energy spent, contribution from the environment versus expenditure of human effort, depletion of internal storage (e.g., mineral reserves, biological storages), embodied energy of product to dollars received, etc. A system is predicted to be economic if the embodied energy from the local sources is high relative to the embodied energy of purchased imports. Where flows have a common source, such as sun and wind, only the largest is used to compensate for double counting. Other flows are byproducts of the same process and hence not independent.

Results & Discussion

The energy systems diagram for Jari is given in Figure 1. Whereas the plantations supply the fibers for pulping, the fuel for steam and electric power comes from clear-cutting of the native forest as more plantations are started. The depletion of soils also represents an input of embodied energy from within the system. Inputs that are not local include liquid fuels for transport and supplementation of the wood fuel in the boilers; chemicals used in the Kraft pulping process; some equipment replacements; and goods and services for the plant's operation. Included are operation of roads, health facilities, housing, and other necessities for people working within the system. The complex diagram in Figure 1 was aggregated to provide a simpler overview (Figure 2). The estimates of embodied energy of inputs that were calculated from tables are written on the pathways and storages. Energy flows, energy transformation ratios, and embodied solar equivalents for input and output flows are given in Table 1. Table 2 includes critical indices which typify the Jari plantation and pulpmill project. Comparable values are included for other systems.

Intensity of Economic Activity

One measure of the environmental contribution to a system is the ratio of investment of high quality goods and services to the use of environmental energies. This ratio for Jari is 0.46, which is greater than that for Brazil on the whole, 0.14 (See Table 2). It is lower than those of the U.S.A. (2.14) steel production (2.15) or pulp production (3.4). This suggests that the economic activity has a high enough ratio of local resources to compete economically on a worldwide scale. When storage depletion is included with outside investments to mimic the situation of obtaining fuels for electrical generation and fertilizers to replace depleted soil nutrients from outside the region, the above ratio is 1.25; still less than most of those mentioned above. Because the ratio is much higher than the rest of Brazil, such economic intensity may not be competitive with alternative investment opportunuties there.

Yield Ratio - Net Energy

The ratio of yield to investment in embodied energy units, the yield ratio, ~~provides~~ a relative measure of the yield per unit outside investment. The ratio decreases as one moves towards more finished goods. For Jari pulpwood, the ratio is 4.6 without fertilizers. For Jari pulp production, it is 2.43 (Table 2) which means there is net energy. The Jari ratios are greater than the average for Brazil (0.68) and the U.S.A. (0.45). The yield ratio for pulp production (2.43) is less than that when tropical forest wood is used to generate electricity (3.63, see the next section on fuel crops), reflecting the use of additional energies in producing more finished products.

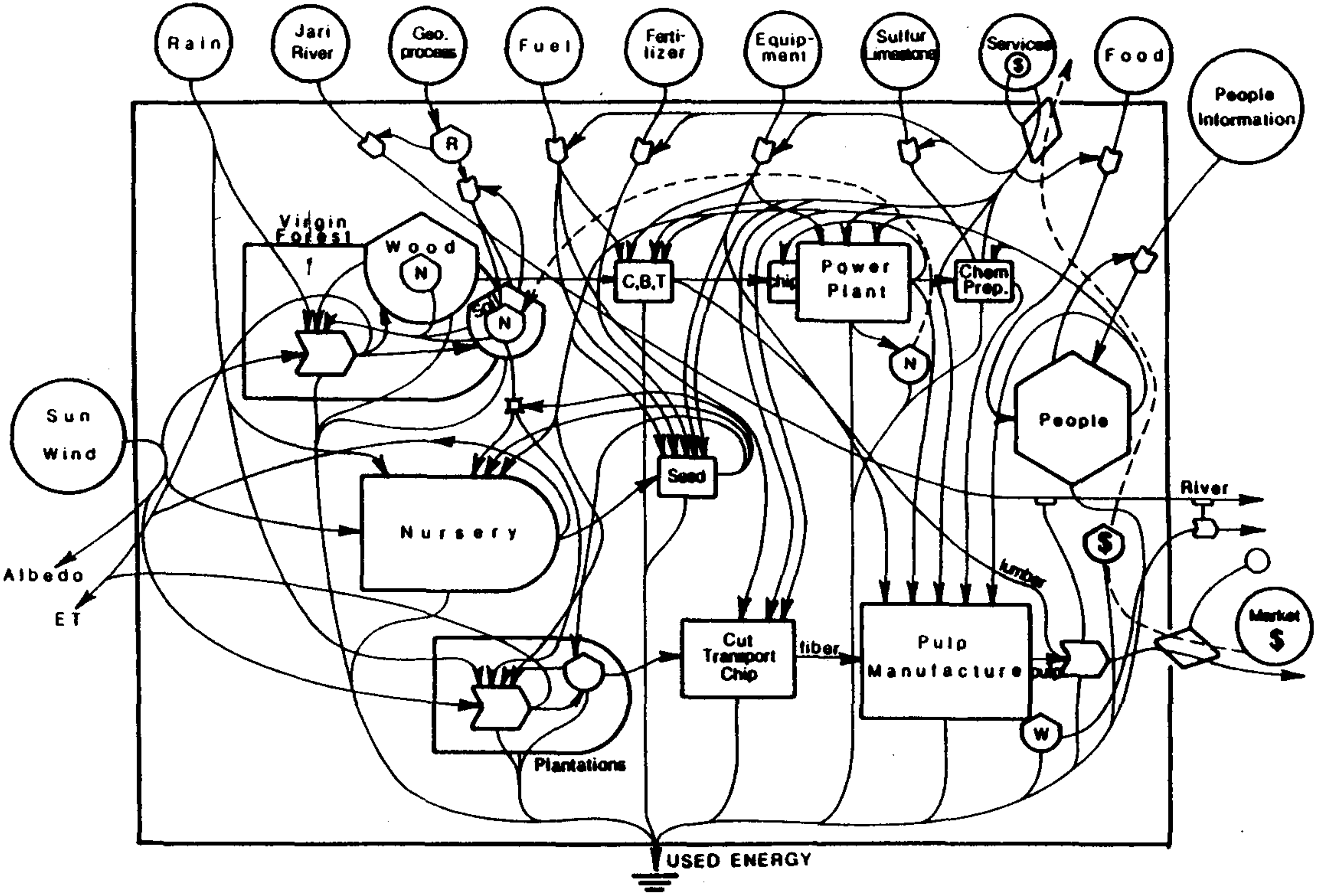


Figure 1. Overview of Jari plantation and pulpmill. N = Nutrients, R = Rocks, C, B, T = Cut, Burn, and Transport, W = Waste, ET = Evapotranspiration.

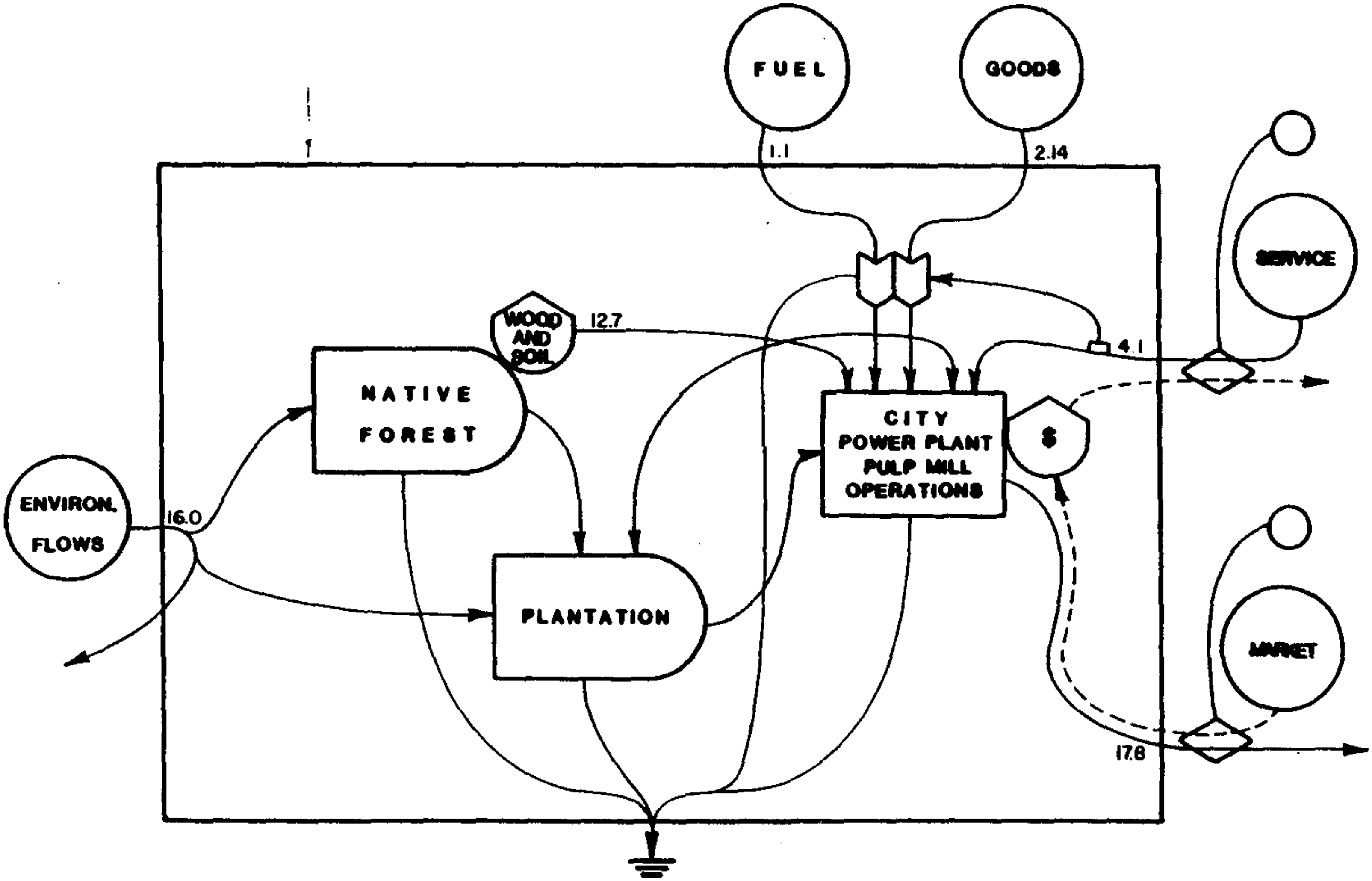


Figure 2. Aggregated overview of Jari plantation and pulpmill - major flows across boundaries and storage depletion. Flows in SE Cal/yr x 1 E16.

Table 1. Energy flows in the Jari system in Figures 1 and 2.

Footnote	Item	Actual Energy Cal/yr	ETR† SE Cal/ Unit	Embodied Energy SE Cal/yr x 1 E16
A	Sun	1.6 E16	1	1.6
B	Wind (Kinetic)	1.7 E11	663	0.01
C	Vapor (Vert. Exchange)	3.5 E14	62	2.2
D	Rain (Kinetic)	9.3 E10	5.3 E5	4.9
E	Rain (Phys. Potential)	1.3 E12	8888	1.2
F	Rain (Chem. Potential)	1.04 E13	15423	16.0
G	Tide	1.2 E11	23564	0.28
H	Stream (Physical)	6.5 E11	2.36 E4	1.5
I	Stream (Potential)	9.4 E8	5.2 E7	4.8
J	Flood	3.5 E9	8.9 E5	0.3
K	Fuels	2.0 E11	5.3 E4	1.1
	Goods (Salt)	2.5 E7 Kg	2.27 E8	0.57
	Goods (Sulfur)	3.7 E6 Kg	2.0 E8	0.07
	Soil Loss (Fert. required)	---	---	4.3
	Goods (Carbonate)	2.2 E7 Kg	7.0 E8	1.5
	Goods (Native Fuel Wood)	6.0 E5 tonnes	1.4 E11	8.4
	Lumber Export	1.1 E4 tonnes	1.2 E10	0.01
	Pulp Product	2.15 E5 tonnes	8.3 E11	17.8
L	$ (In) Exports	$81.6 E6	1.6 E9/$	13.0
	$ (Out) Imports	$46 E6	9.0 E8/$	4.1

†ETR's from Odum et al. (1983b).

FOOTNOTES TO TABLE 1.

A. Average absorbed solar energy (incident minus albedo) was determined for the location (adapted from Vonderhaar and Suomi, 1969 and Sellers, 1965). Solar insolation was calculated by multiplying the average absorbed solar energy by the area of Jari (Fearnside and Rankin, 1982).

$$ES = \text{Solar influx} = IA \cdot A \tag{1}$$

where $IA = 197\ \text{Cal/cm}^2 \cdot \text{yr}$, and
$A = 1.6\ \text{E6 Ha}\ (1\ \text{E8 cm}^2/\text{ha})(0.5)$ (multiplied by 0.5 to represent legal requirement to withhold 50% of land from use).

$$= 1.6\ \text{E16 Cal/yr.}$$

B. Wind was calculated by assuming parameters of average value to determine relative importance of its flow. The kinetic energy in wind is calculated from equation 2.

$$Pm = \text{kinetic energy of wind} = Zb\ Km(du/dZ)^2(7534) \tag{2}$$

where Zb = planetary boundary layer height = 1000 m,
= $1.23\ \text{kg/m}^3$,
Km = Eddy diffusion coefficient = $1.0\ \text{m}^2/\text{s}$ (Odum and Pigeon, 1970),
du/dZ = velocity gradient = 1.5 E-3 1/s (Odum et al., 1983a).

$$Pm = 1000(1.23)(1.0)(1.5\ \text{E-3})^2 7534$$

$$= 20.9\ \text{Cal/m}^2 \cdot \text{yr} \times 0.8\ \text{E10 m}^2 \text{ (area of project)}$$

$$= 1.7\ \text{E11 Cal/yr.}$$

C. Vertical vapor exchange was calculated by estimating the evapotranspiration rate and using equation 3.

$$Fg = \text{Flow of Gibbs Free Energy} = (ET)(\ )(\ F) \tag{3}$$

where ET = Evapotranspiration Rate = 1.15 m/yr = 1/2 Rainfall = 1/2(2.3 m/yr) (Sioli, 1980; Fearnside and Rankin, 1982),
= $1\ \text{g/cm}^3\ (1\ \text{E6 cm}^3/\text{cm}^3)$, and
F = Free energy/g = 0.038 Cal/g (Table 1, Odum et al., 1983a).

$$Fg = (1.15)(1\ \text{E6})(0.038)$$

$$= 4.37\ \text{E4 Cal/m}^2 \cdot \text{yr} \times 0.8\ \text{E10 m}^2$$

$$= 3.5\ \text{E14 Cal/yr.}$$

D. Kinetic energy in rain was determined using an average rainfall velocity using equation 4.

$$Ke = \text{Kinetic energy in rainfall} = P(1/2mv^2)2.38\ \text{E-7} \tag{4}$$

where P = rainfall = 230 cm/yr,

$m = 1\ g/cm^3$,
$v = 700\ cm/s$ (Average value from Table E12, Odum et al., 1983a), and
$2.38\ E\text{-}7$ = ratio of Cal/erg x cm^2/m^2.

$$Ke = 200(1/2)(1)(700)^2(2.38\ E\text{-}7)$$

$$= 11.7\ Cal/m^2 \cdot yr \times 0.8\ E10\ m^2$$

$$= 9.3\ E10\ Cal/yr.$$

E. Gravitational potential of rainfall was based on the potential energy of the water falling from the average elevation of land to the exit elevation. The average elevation was calculated from areal averages of a topographic map of the region. Calculation was based on equation 5.

$$GE = \text{gravitational potential} = P(\ gh)\ 2.38\ E\text{-}7 \qquad (5)$$

where P = average rainfall = 230 cm/yr,
= $1\ g/cm^3$,
$g = 980\ cm/s^2$,
h = average drop = 3.05 E3 cm (adapted from U.S. Dept. of Defense, 1971), and
$2.38\ E\text{-}7$ = ratio of Cal/erg x cm^2/m^2.

$$GE = (230)(1)(980)(3.05\ E3)(2.38\ E\text{-}7)$$
$$= 163\ Cal/m^2 \cdot yr \times 0.8\ E10\ m^2$$

$$= 1.3\ E12\ Cal/yr.$$

F. Chemical potential of solids dissolved in rainwater was calculated based on equation 6.

$$Fr = \text{chemical potential of rain} = KP(nRT)(C_2)\ln(C_2/C_1)$$

$$+ (1 - K)PnRT(C_3)\ln(C_3/C_1) \qquad (6)$$

where K = % rainfall as evapotranspiration,
P = rainfall = 2.3 m/yr,
n = 1/18 mole/g,
R = 1.99 E-3 Cal/°K·mole,
T = 300°K,
C_2 = seawater concentration = 1,000,000 - 35,000 = 965,000,
C_1 = rainwater concentration (assumed 10 ppm; Odum et al., 1983a) = 1,000,000 - 10 = 999,990 ppm, and
C_3 = river concentration (50 ppm, Richey et al., 1980) = 1,000,000 - 50 = 999,950 ppm.

$$Fr = (2.3)(1/18)(1.99\ E\text{-}3)(300)(965{,}000)\ln(999{,}990/965{,}000)$$

$$= 2.8\ E3\ Cal/m^2 \cdot yr \times 0.8\ E10\ m^2$$

$$= 2.2\ E13\ Cal/yr.$$

G. The physical energy in tidal absorption was calculated after estimating the areal extent of river bodies and using equation 7.

$$\text{Et} = \text{Tidal energy} = N \cdot A \cdot 1/2 \cdot (\ g h^2) 2.38\ \text{E-11} \tag{7}$$

where N = number of tides per year = 706 (Odum et al., 1983a),
A = 2.4 E12 cm^2 (Adapted from U.S. Dept. of Defense, 1971),
= 1 g/cm^3,
g = 980 cm/s^2,
h = 80 cm (Fearnside and Rankin, 1982), and
2.38 E-11 = ratio of Cal/erg.

$$\text{Et} = (706)(2.4\ \text{E12})(1/2)(1)(980)(80)^2 2.38\ \text{E-11}$$

$$= 1.2\ \text{E11 Cal/yr.}$$

H. The physical energy in streamflow is based on the assumption that runoff is equal to rainfall - evapotranspiration, 115 cm/yr and using equation 8.

$$\text{Gt} = \text{physical energy in streamflow} = q \cdot \ \cdot g \cdot h (2.38\ \text{E-7}) \tag{8}$$

where q = runoff = 115 cm/yr (see above),
= 1 g/cm^3,
g = 980 cm/s^2,
h = average drop in elevation = 3.05 E3 cm, and
2.38 E-7 = ratio of Cal/erg x cm^2/m^2.

$$\text{Gt} = (115)(1)(980)(3.05\ \text{E3})(2.38\ \text{E-7})$$

$$= 81.8\ \text{Cal}/m^2 \cdot \text{yr} \times 0.8\ \text{E10}\ m^2$$

$$= 6.5\ \text{E11 Cal/yr.}$$

I. The physical potential energy in streamflow is calculated from flow rate of the rivers and density of materials based on equation 9.

$$\text{Gm} = \text{physical potential energy in streamflow} = J \cdot \ g h (2.38\ \text{E-11}) \tag{9}$$

where J = average annual streamflow = (1.5)(2 E9 cm^3/s)(3.15 E7 s/yr) (assuming Rio Paru flow = 0.5 flow of Jari River; U.S. Dept. of Defense, 1971),
= 1.4 E-4 g/cm^3 (Richey et al., 1980),
g = 980 cm/s^2,
h = 3.05 E3 cm, and
2.38 E-11 = ratio of Cal/erg.

$$\text{Gm} = (1.5)(2000)(3.15\ \text{E7})(1.4\ \text{E-4})(980)(3.05\ \text{E3})(2.38\ \text{E-11})$$

$$= 9.4\ \text{E8 Cal/yr.}$$

J. The gravitational potential in floods is based on an estimate of areal extent of flooding of 75,000 ha (Jari Florestal Officials, personal communication) and an assumed height of flooding of 2 m. The potential energy was then calculated using equation 10.

$$Ef = \text{energy of floods} = A \cdot 1/2 \cdot \ \cdot g \cdot h^2 (2.38\ E\text{-}7) \qquad (10)$$

where A = area of flooding = 75,000 ha,
 = $1\ g/cm^3$,
$g = 980\ cm/s^2$,
h = average height of flood = 200 cm, and
2.38 E-7 = ratio of Cal/erg x cm^2/m^2.

$$Ef = 1/2(1)(980)(200)^2(2.38\ E\text{-}7)$$

$$= 4.66\ Cal/m^2 \cdot yr \times 7.5\ E8\ m^2$$

$$= 3.5\ E9\ Cal/yr.$$

K. Flows of materials are based on information supplied by the management of Jari Florestal.

Fuel oil = 2.1 E7 kg x 9525 Cal/kg = 2.0 E11 Cal/yr.
*Salt = 2.5 E7 kg/yr.
*Sulfur = 3.7 E6 kg/yr.
*Carbonate = 2.15 E7 kg/yr.
Pulpwood = 1.2 E6 tonnes/yr (doesn't actually cross boundary of system).
Fertilizer = (3.9 E11 SE Cal/ha·yr)(1.1 E5 ha) = 4.3 E16 SE Cal/yr (see Table 9).
Native fuel wood = 6.0 E5 tonnes/yr.
Pulp product = 2.15 E5 tonnes/yr.
Lumber = 1.1 E4 tonnes/yr.

*ETR for salt based on potassium chloride; sulfur as percent global crust (Odum et al., 1983b); and carbonate adapted from Gilliland et al., 1981).

L. Money across boundary is

In = \$81.6 E6/yr (Jari Florestal Fact Sheet, 1983).

Out = Fixed costs

For pulp mill \$2.6 E8 (Kinkead, 1981) every 20 years = \$13 E6/yr
For Infrastructure \$3.2 E8 every 40 years = \$ 8 E6/yr
\$21 E6/yr.

Plus variable costs

= \$/MT 21 chemicals
25 Maintenance, materials, administration
70 Frt, Ins, etc.
\$116/MT x 215000 MT/yr

= \$25 E6/yr (Jari Florestal Fact Sheet, 1983).

TOTAL money out = \$46 E6/yr.

Table 2. Energy analysis ratios for industries at Jari with comparisons from other systems.

Description (See Figures 4 and 5)	Jari Plantation and Pulp Mill*	Pulpwood Production, Jari*	Electrical Production from Tropical Forest Wood†	Steel Production†	Brazil†	USA†
Outside investment:Natural energy	0.46	2.7	0.38	2.15	0.14	2.14
Outside investment:(Natural energy + Storage depletion)	0.26				0.13	0.36
Outside investment:Storage depletion	0.58				1.44	0.41
(Outside investment + Storage depletion):Natural energy	1.25				0.25	7.35
Yield:Outside investment	2.2	4.6	3.63	1.48	0.68	0.45
Yield:(Outside investment + Storage depletion)	0.89	1.4			0.40	0.13
Embodied energy:$ (Product, x E9)	2.2				1.6	0.62

*This study.
†Odum et al. 1983b.

When the storage depletion (wood and soil nutrients currently used) is added to the outside investment the yield ratio for pulpwood is 1.4. This yield ratio is less than the ratio calculated using only outside investment (4.6).

When yield ratios are greater than 1 there is a net yield of a process, and the process contributes "extra" energy or the net to sustaining the larger economy of which it is a part. The higher the net yield, the greater the contribution. Generally, an entire economy has no net yield (as indicated in the last 2 columns of Table 2). Individual processes within the economy may have net yield.

The production of pulpwood at Jari has a net yield ratio of 4.6 when the depletion of valuable storages of native wood and soil are not considered, and a lower yield ratio (1.4) when these storages are considered. However, when the yield ratio is calculated for the entire Jari plantation and pulpmill (column 2), the ratio when storage depletion is not considered is 2.2, and only 0.89 when loss of storage is considered. The latter ratio indicates that Jari cannot contribute net energy to the larger economy of Brazil, of which it is a part.

The net energy of the pulpwood contributes to the local economy (although not much, since the ratio is only 1.4/1) and may develop a small sustainable local economy. However, national plans to develop other similar projects as a means of "mobilizing" the national economy may not contribute growth, and may in fact become "drags" on the economy where more energy is invested than is yielded.

ENERGY ANALYSIS OF FUEL CROPS AND THEIR FOREIGN TRADE

Howard T. Odum and Elisabeth C. Odum

Since the 1973 jump in world fuel prices, underdeveloped areas like the Amazon and to some extent Brazil as a whole have had their economic growth and vitality limited by high cost of liquid fuels, which have to be purchased abroad. Especially in Brazil, which already has major use of wood as fuel, there has been a movement to develop fuels from biomass yields of plantations. Are these economically competitive, and if not, when do they beome compeititve as world fuels become more and more expensive in the long run? Energy analysis provides a way to determine the contributions of an agroecosystem to an economy so as to answer some of these questions.

The energy analyses of Amazon wood given here were included in an earlier working paper (Odum and Odum,1983); the energy analyses of Brazilian ethanol and oil palm production were done at CEPEC (Centro de Pequisas do Cacao) research center at Itabuna, Bahia, Brazil arranged through the initiative and collaboration of Dr. Paulo T. Alvim. E.S. Freire, H.I.L. Ferreira, and J. Iturbe helped in gathering and interpreting data.

Special Disadvantages in Foreign Fuel Purchase

Brazil and the Amazon are using biomass products as fuels more than most of the countries in the world. This includes a large use of wood and more recently sugarcane and alcohol. Energy analysis helps to explain why these uses are competitive economically in Brazil. The environment provides large inputs of food, fiber, and fuel directly to rural people without much cost in human service payments.

Therefore labor is paid less monetarily. Money represents more real value. The embodied energy to dollar ratio is higher than in more developed countries (see P1 on page 76. The ratio, 6.6 E12 sej/$ is 2.5 times higher than that of the United States). Consequently, any purchases abroad send out more real puying power than similar purchases by developed countries. This effect makes fuel import less economic.

The following calculation indicates why the high embodied energy in the Brazilian currency makes the purchase of foreign oils a lower net energy than for developed countries that obtain net energy yield ratio of 6 to 1 with purchase of foreign oil.

Embodied energy obtained in a barrel of oil:
(6.3 E9 joules/barrel of oil)(5.33 E4 sej/j)
= 3.34 E14 sej received

Embodied solar energy paid out in buying power of Brazil's national dollar:
(\$28/barrel)(6.6 E12 sej/1980 \$)
= 1.85 E14 sej paid

The net energy yield ratio for this purchase abroad
= (3.34/1.85) = 1.81

Because of the high solar embodied energy in its more rural economy, its fuel purchases on the international market yield only a third of that available to the United States.

These analyses may help explain why Brazil and the Amazon are using products of solar biomass for fuels more than other countries. In the paragraphs that follow, emergy analyses are reported for four main sources being considered for further development in the Amazon: Wood from wild forest, wood from plantation forest, alcohol from sugarcane plantations, and palm oil, which has food and fuel uses. By evaluating net energy, investment, and exchange ratios, we determine if there are real potentials for these products as fuels or for other uses.

Wood Yielded from Complex Natural Forest

When tropical forests grow for a century or more, adequately supplied with seeding of plants and animals from similar high diversity forests nearby, a very valuable diverse mixture of woods develops. There is a large biomass per area, part in wood of high density and part in the deep organic matter of the soil. Such older, mature forests with little sign remaining of their earlier history we sometimes call "virgin forest". Sometimes wood is used from such forests a few trees at a time; sometimes the forest is clear cut and left to its own regeneration.

Where human utilization takes the form of selective removal of a few trees at a time, the forest remains heterogenous with some open spots, some young trees, and some old trees. Forests of this type may have a "stable age distribution," which means that trees are being replaced at about the same rate as they are removed. The floodplain forest of the Amazon (Varzea forest) is an example.

Where the old complex forests are utilized by clear cutting and left alone for another century, the large valuable "virgin" biomass and soils are again developed from the natural environmental inputs. In the well-known shifting agriculture, the forests are cut more frequently, farmed briefly and left for the natural restoration process. The biomass, diversity, and soil quality maintained in the shorter cycle is less. In the Amazon the landscape is a heterogeneous mixture of areas with histories of different cutting cycles ranging from the "virgin" cycle to those where cutting has been so frequent that only a tropical scrub condition is prevalent.

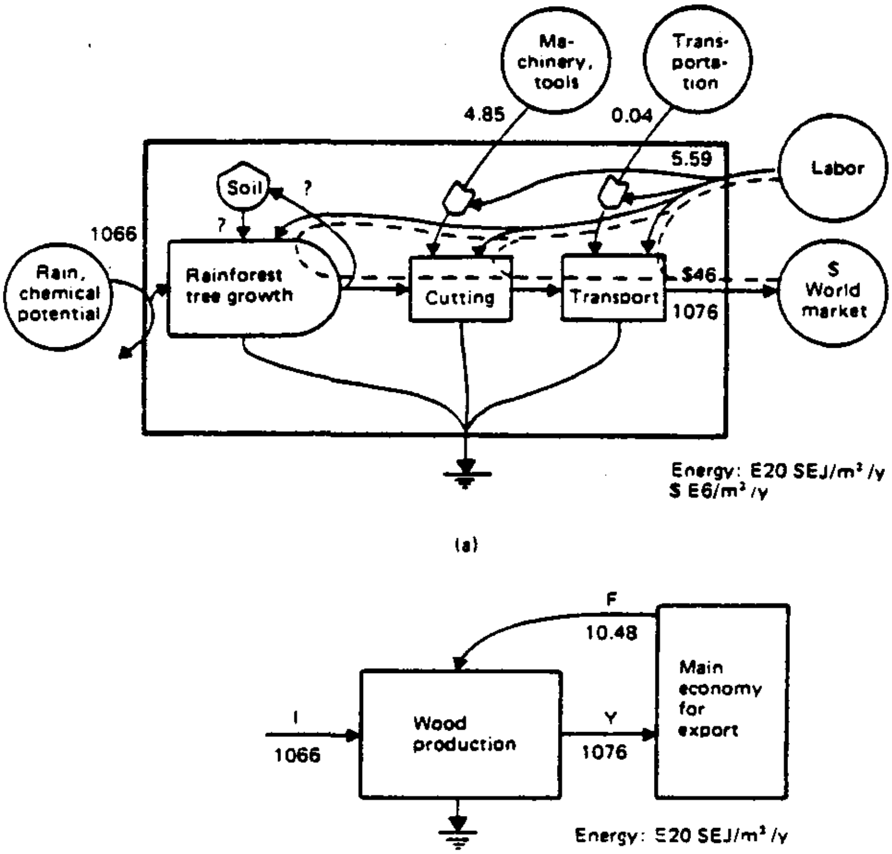
In all these regimes the restoration is left to the complex of natural organisms and environmental processes to restore the forest. Since the forest takes care of itself, the only input from the economy required to develop wood yield is the cutting and transporting. Consequently, the human efforts and monetary costs are small. There is a large available net energy yield. Especially with the longer cycles, woods are high quality, representing longer periods of environmental work so that the embodied energy of the stored wood is large. Whether trees are cut a few at a time or clear-cut, the use of woods of high embodied energy gives the economy a big stimulus.

For example, given in Figure 1 and Table 1 is an energy analysis of the yields obtained by cutting tropical forest on a long rotation cycle. There is a very high net energy yield ratio (102.7 in Figure 16)), but the total yield is small. The energy transformation ratios of the woods are high (ETR = 3.08 E5 sej/j in footnote 6 of Table 1), representing the longer contributions of environmental resources utilized. Some of these woods may be too valuable to be used for low quality fuel. However used, they stimulate the rest of the economy because of the large net energy yield ratio.

Another example given in Figure 2 and Table 2 is an energy analysis of the use of old complex forest trees at Jari, Brazil for generation of electric power. The net energy yield ratio for the delivery of the wood is 12. After processing the wood and transforming the energy into electrical power the net energy yield ratio is still positive, 3.6. This means that the wood plantation can sustain an economy, but since the ratio is less than that in fossil fuel plants that operate in much of the world economies (ratio = 6), the level of economic activity possible on plantation wood alond is less.

Where forests are cut and used faster than they are being regenerated in rotation, the use constitutes a non-renewable use, and the stimulus to the economy is temporary, disappearing when the initial large stocks of trees are gone. At present the rate of usage of the Amazon tropical forest woods is apparently faster than its rate of regrowth. The present stimulus to the economy due to the current surge of economic use of prior growth is greater than is sustainable by the environmental processes.

The determination of which utilization systems will prevail can be examined with the embodied energy investment ratio (ratio of embodied energy from the economic inputs to the embodied energy free from the environment). The systems of complex forest use have a smaller ratio of embodied energy from the economy to that from the environment than more intensive uses of the land such as agriculture and plantation forestry. See the example in Figure 1. This means that adding additional economic investments that bring in more inputs from outside will be economic because the ratio of purchased items to free items from the environment is still less than for the average economic land use. The intensification process should proceed only until the intensity of outside economic investment reaches that of alternative outlets for this economic investment. The ultimate level of economic involvment reached should be predicted by the average embodied energy investment ratio of the nation. Ultimately this ratio should decline as the availability of world resources for import decreases.



(a)

(b)

Y/F = 102.7
F/I = 0.0098
ETR = 30.8 E4 SEJ/J

Figure 1. Energy analysis diagram of the system of energy yield from mature complex tropical forest. Data were supplied from Table 1.

Table 1. Liberian rain forest wood production subsystem (for Figure 1) (Odum and Odum, 1983).

Footnote	Kind of energy	Actual energy J/m^2/y	Energy transformation ratio (ETR) SEJ/J	Embodied solar energy E10 SEJ/m^2/y
1	Rain, I	6.9 E8	15,444	1066.0
2	Wood yield, Y	3.5 E7	30.7 E4	1076.0
3	Export, services	---	---	5.9
4	Feedback, transport, fuel	2.4 E3	1.7 E5 (fuel ETR)	.04
5	Feedback, cutting	2.85 E5	1.7 E5 (fuel ETR)	4.85
6	Selected rainforest timbers shipped:		30.8 E4	

Footnotes to Table 1.

1. Renewable inflow, rain embodied in the wood

   Rain: 4.4 m/y; runoff: 3 m/y (Min.Info 1979); 100 years to grow rainforest trees.

   4.4 m - 3 m = 1.4 m/y used.

   $(1.4 \text{ m}^3)(4.94 \text{ J/g})(1 \text{ E6 g/m}^3)(100 \text{ y}) = 6.9 \text{ E8 J/m}^2\text{/y}$

2. Yield of rainforest wood production

   Total rainforest: 12 E6 acres; 4% cut/y (Min.Info. 1979). Yield: sawnwood 233 E3 m^3; roundwood 4.6 E6 m^3, 1977 (U.N. 1981). Density of rainforest wood: 0.8 g/cm^3.

   Area cut: $(12 \text{ E6 acres})(4047 \text{ m}^2\text{/acre})(.04) = 1.9 \text{ E9 m}^2\text{/y}$

   Yield: $(4.8 \text{ E6 m}^3\text{/y})(0.8 \text{ g/cm}^3)(1 \text{ E6 cm}^3\text{/m}^3) = 3.84 \text{ E12 g/y}$

   $(4.2 \text{ kcal/g})(4186 \text{ J/kcal}) = 17.58 \text{ E3 J/g}$

   $(3.84 \text{ E12 g})(17.58 \text{ E3 J/g}) = 6.79 \text{ E16 J/y}$

   $(6.79 \text{ E16 J/y})/(1.95 \text{ E9 m}^2) = 3.48 \text{ E7 J/m}^2\text{/y}$

Footnotes to Table 1 (continued)

3. Export services

US energy/dollar ratio: 2.31 E12 SEJ/$US (Table A4).
Export $: 46 E6 $US (Min.Info. 1979)

(46 E6 $US)(2.31 E12 SEJ/$US)/(1.9 E9 m^2) = 5.59 E10 SEJ/m^2/y

4. Transportation fuel

46% exported (Min.Info. 1979a). Transport energy costs: 1.78 E6 J/T/km (Fluck and Baird 1980). Estimated distances to Monrovia: 1/3 - 100 km, 1/3 - 150 km, 1/3 - 184 km.

(3.86 E10 g)(1 E-6 T/g)(.46) = 1.78 E4 tons exported.

(1/3)(1.78 E4 T)(1.78 E6 J/T/km)(100 km + 150 km + 184 km)

= 4.61 E12 J

(4.61 E12 J)/(1.9 E9 m^2) = 2.4 E3 J/m^2

5. Cutting energies

Forest cutting, logging: 52 E6 J/m^3; debarking: 28 E6 J/m^3; loading: 33 E6 J/m^3 (Min. Forestry 1979)

(113 E6 J/m^3)(4.8 E6 m^3 wood/y)/(1.9 E9 m^2) = 2.85 E5 J/m^2/y

6. Energy transformation ratio

(I + F)/actual J of wood; F = feedback service and transport and cutting in SEJ/m^2/y

(1066 + 5.59 + 0.04 + 4.85) E10 SEJ/3.5 E7 J = 3.08 E5 SEJ/J

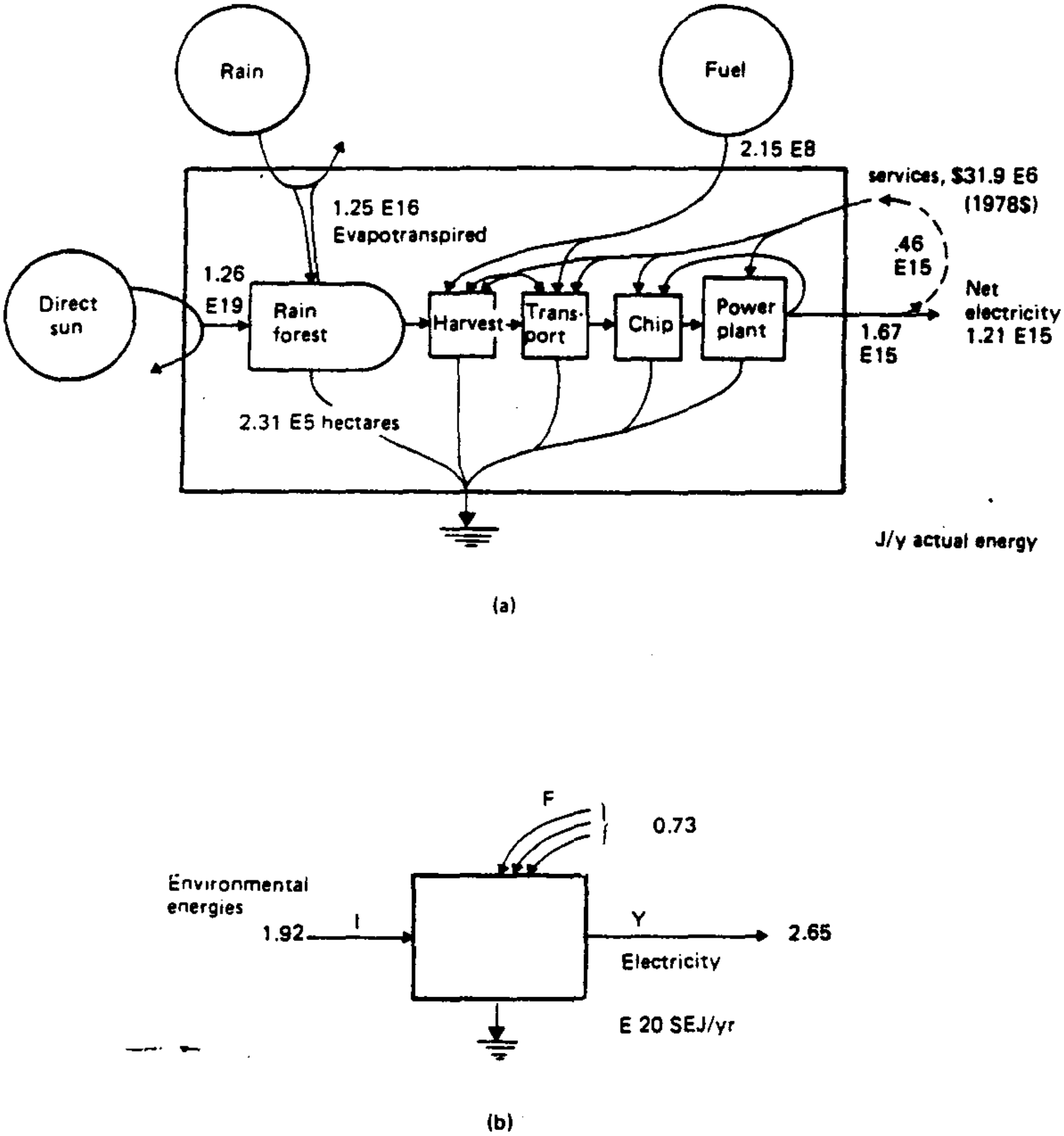


Figure 2. Energy analysis diagram of the production of electricity from mature forest wood at Jari, Brazil (Odum and Odum, 1983).

Table 2. Energy power plant at Jari, Brazil, see Figure 2, calculated as steady state requiring 2.31 E5 Ha.

Footnote	Item	Actual Energy J/y	ETR SEJ/J	Embodied Solar Energy E20 SEJ/y
1	Direct sun	1.26 E19	1	0.126
2	Rainforest evapotranspiration	1.25 E16	1.54 E4	1.925
3	Rainforest wood burned	5.92 E15	3.49 E4	2.06
4	Fuel used in harvest	1.8 E14	5.17 E4	0.093
5	Services used in harvest	1.58 E14	5.17 E4	0.082
6	Electricity, debarking chipping	5.93 E13	5.17 E4	0.032
7	Electricity generated	1.67 E15	1.59 E5	2.66
8	Feedbacks to power plant	0.46 E15	1.59 E5	0.67
9	Net electrical output	1.21 E15	1.59 E5	1.92

Footnotes to Table 2.

1. Direct sunlight assumed

   (1.29 E6 kcal/m^2/yr)(4186 J/kcal)(2.31 E9 m^2) = 1.257 E19 J/yr

2. Rainforest water used as evapotranspiration and Gibbs free energy relative to leaf salt (Footnote 6, Table 3.1, 4.94 J/g)

   (3 mm/d)(365 d/y)(1 E-3 m/mm)(1 m^2)(1 E6 g/m^2)(4.94 J/g)(2.3 E9 m^2) = 1.25 E16 J water/y

3. Rainforest wood burned in power plant

   6.05 E5 T/y wood used from 2314 Ha; 9.86 E9 J/T; to supply in steady state, 100 times this area is required, 2.314 E9 m^2

   (6.05 E5 T/y)(9.86 E9 J/T) = 5.92 E15 J/y

Footnotes to Table 2 (continued)

4. Fuel used in harvest

Data from similar machine harvests of podocarp virgin forest in New Zealand: liquid fuel, logging 52 E6 J/m^3 wood; loading: 33 E6 J/m^3 wood; transport: 130 E6 J/m^3 wood.

(215 E6 J/m^3 wood)(261.5 m^3 wood/Ha)(2,314 Ha/y)

= 1.8 E14 J/y

5. Services used in harvest

$300/Ha in similar harvest in New Zealand, 1978.

($300/Ha)(2.28 E8 fuel J/$)(2314 Ha/y) = 1/58 E14 fuel J/y

6. Electricity used in debarking and chipping

Equivalent data used from New Zealand, 98 E6 fuel J/m^3 wood

(98 E6 fuel J/m^3)(261.5 m^3/Ha)(2314 Ha/y) = 5.93 E13 fuel J/y

7. Electricity generated

53 megawatts

(53 E6 watts)(1 J/sec/watt)(3.154 E7 sec/y)

= 1.67 E15 electric J/y

8. Feedbacks of fuels and embodied energy of service from economy to power plant maintenance and operation assume 1/4 of electric output, Footnote 7.

(1.67 E15 Elec. J/y)(.25) = 0.42 E15 electric J/y

9. Net electrical output

Electricity minus feedbacks in Footnotes 4-7

(1.67 - .46) E15 J/y = 1.21 E15 Elec. J/y

The immediate future can also be predicted with another line of reasoniong. According to the maximum power principle, the more intensive systems tend to displace the complex forest systems because they have greater total embodied energy use (environmental sources plus imported sources). Thus the trend towards conversion of the complex forests to the intensive uses is expected to continue as long as there are reasonably cheap external sources of embodied energy to import. However, to be competitive in attracting the outside inputs, there must be a coupling of the imported inputs to the maximum possible contribution of environmental work. The necessary role of diversity and environmental restoration processes in a landscape dominated by intensive agriculture and forestry is considered with models in the rotation section in Part III. Consider next the energy analysis of Amazonian tropical forest plantations.

Because of the high energy embodied in woods from complex mature forest, and the relatively small cost of cutting and transport, this sale of mature woods in international trade at market prices sends much more economic stimulus to the outside buyer than is received by the Amazon seller. More economic stimulus and jobs are provided by using the woods locally, processing the raw wood product into final products that incorporate additional embodied energy inputs from the economy. In this stategy the environmental embodied energy is matched by additional embodied energy.

Wood Yielded from Tropical Forest Plantations

The massive development of forest plantations along the Jari River in the northeastern Amazon provided information on the performance and environmental interactions of plantation systems supplying wood for electrtic power and for paper mill manufacature of newsprint. An energy analysis of the wood production and its use in the paper mill was given in the previous chapter by Christianson; many details, models, and simulations on Jari follow in a later chapter. Because of the huge areal extent, more was involved than just the wood production and its industrial processing. Organization of human settlements, schools, and health services, were also involved so that any evaluation of the Jari project as a whole requires a regional energy analysis.

Here we are concerned with the energy analysis of these plantations as a source of fuel. Figure 3 is an aggregated summary diagram of the main environmental and economic inputs to the production, harvest and transport of plantation wood. The net energy yield ratio (2.2) can support only a simple economy. The ratio is much less than the 6 or 7 available to many countries through their sources of fossil fuels. An entirely wood based economy would support less economic development and be less competitive now. Much later however, as the net energy yield ratio of available fossil fuels falls below 2.2, an Amazon solar-based wood economy becomes more competitive.

Although the net energy yield ratio of the plantation (2.2) was less than that of the complex forest (103), the total yield of embodied energy (including environmental and economic inputs) was greater from the plantation. Sales of plantation wood like those of mature wood contributed

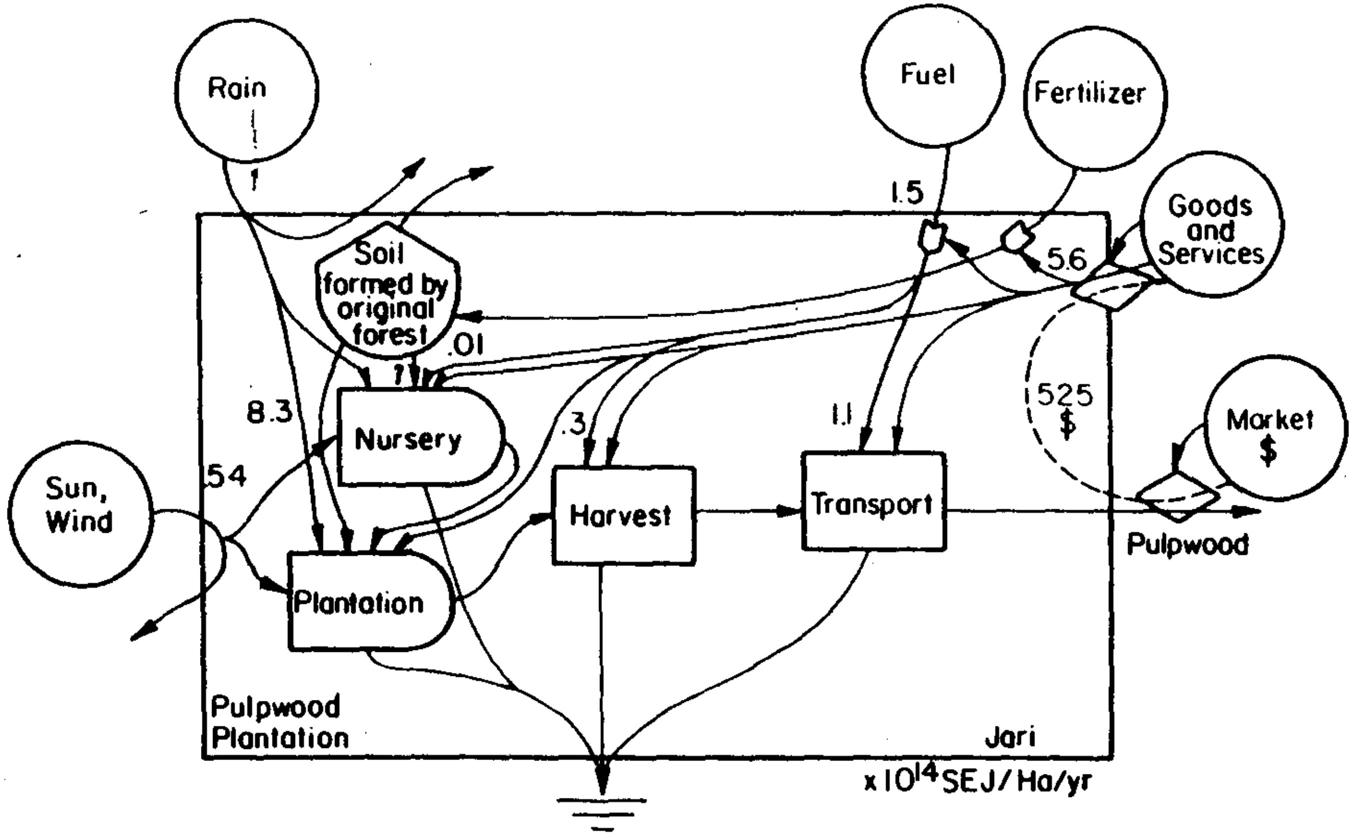


Figure 3. Energy analysis diagram of production of 8 yr old pulpwood from tropical forest plantations at Jari, Brazil; price in 1980 $; transpirational use, e mm/day.

more embodied energy to the outside buyer than was represented by the money received from sales at international prices. See comparisons of embodied energy trade advantage ratios (gains from foreign sales) in Table 3.

Home use of raw products such as wood provides more economic stimulus than export sales. Further economic developments that utilize the plantation wood to draw in more outside embodied energies in increased processing into more valuable products will tend to maximize power and prevail. The pulp mill at Jari is an example which was analyzed in the previous chapter.

Ethanol Production from Sugar Cane in Brazil

Since the 1973 oil embargo, public policy in Brazil has accelerated investment, development, and yield of ethanol from sugar-cane for operation of automobiles. By 1984 ethanol production was being sold abroad. During this time the economy of Brazil was depressed. Energy analysis that follows suggests the effect of ethanol program on the economy.

Following a tour of the new sugarcane-ethanol plant at Embauba, Bahia, Brazil an energy analysis diagram of the system was made as given in Figure 4. The system included continuous growth of sugar cane on suitable soil, some uses of fertilizer and pesticides, harvest and pressing of cane, fermentation and distillation of juices to form ethanol, a use of the fibrous by-product bagasse as source of heat for distillation and to generate electricity, a return of liquid wastes to the cane fields as fertilizer, purachase of outside goods and services, sale of ethanol, regrowth of cane from residual roots and/or replanting. A wetland with considerable wildlife was receiving those wastes not absorbed by the recycle to the fields, an arrangement much superior to the discharge of organic wastes to rivers reported in some older plants previously.

An important characteristic of sugar cane production in an underdeveloped region as observed at Embauba is the use of a large labor supply that is partly supported directly by subsistence living on the surrounding tropical forest landscape. Therefore monetary payments for labor are less. The embodied energy contributed to the production by the environment without monetary payment through available low cost labor is large and unevaluated in normal economic analysis. In the energy analysis this hidden input of embodied energy is evaluated by using the high embodied energy to dollar ratio determined for Brazil in the preceding chapter on the energy analysis of Brazil.

Table 4 contains the energy analysis of the sugar cane ethanol system. Each line evaluates a different input or output first in energy units. Then by multiplying by the energy transformation ratio from sunlight, flows of embodied solar energy were determined in the last column. This analysis was done on a microcomputer spread sheet which makes corrections and substitutions easy. In a computer spread sheet any correction or change is immediately processed through successive steps automatically recalculating items throughout the table wherever the change affects other values.

Table 3. Characteristics of systems for deriving fuels from tropical biomass.

Item	Plantation pulp wood	Mature forest wood	Sugarcane ethanol	Palm oil
Source	Fig. 3	Fig. 2	Table 4	Fig. 6
Energy transform ratio	1.8 E4	3.5 E4	8.8 E4	9.3 E4
Net energy yield ratio	2.2	12.	1.14	1.06
Fuel prod. per fuel use	10.1	22.	7.6	3.5
Economic-environ. ratio	0.85	0.14	7.0	17.
Gain from local sale	2.35	0.36	0.83	0.66
Gain from foreign sale	0.89	0.14	0.31	0.25
Gasoline from foreign sale*	2.6	0.40	0.92	1.09

* Gain from selling abroad, using funds received to purchase gasoline on world markets.

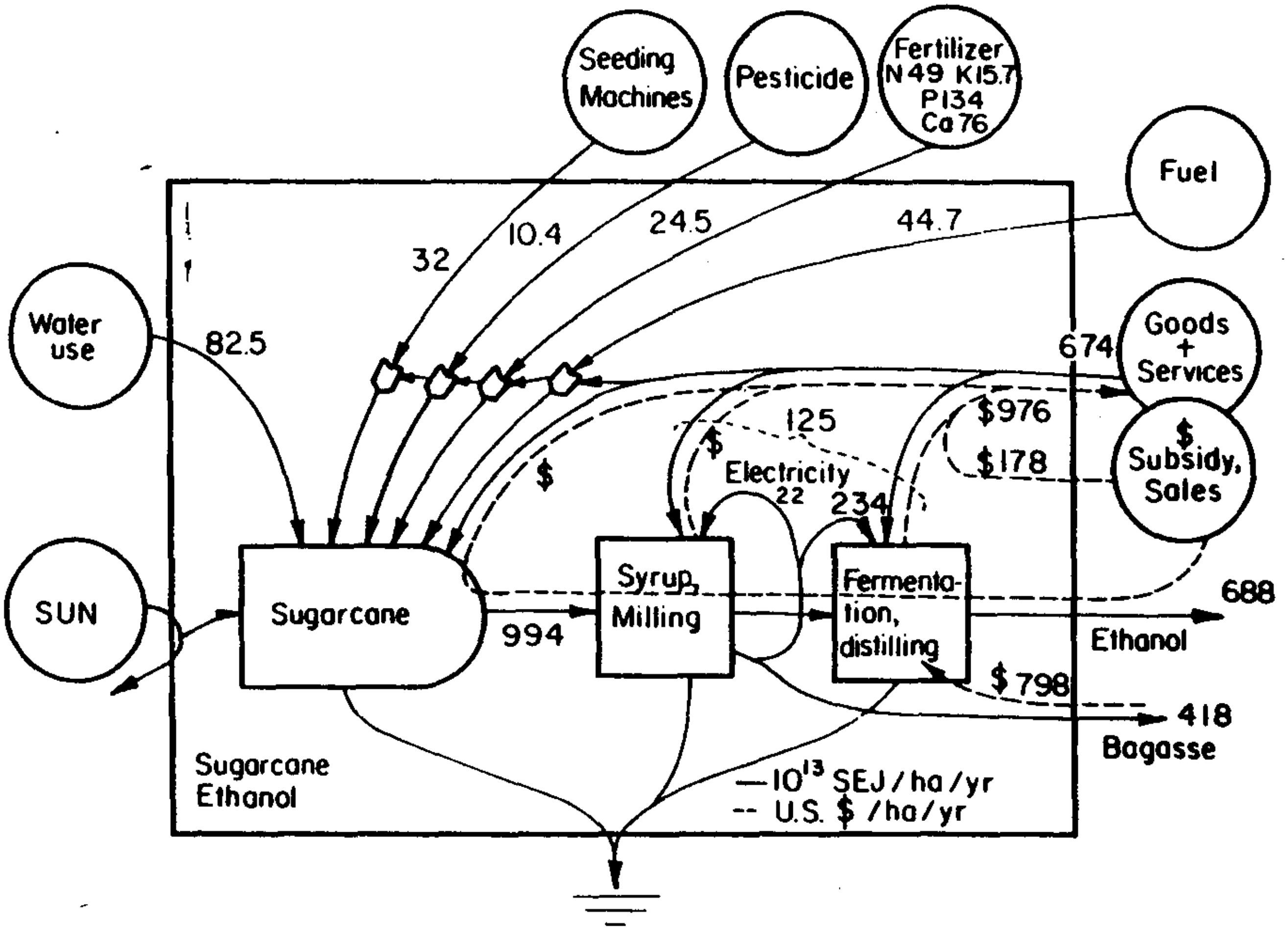


Figure 4. Energy analysis diagram of production of ethanol from sugarcane per hectare per year in Brazil in 1980. Numbers on pathways are flows of embodied solar energy; dashed lines are flows of U.S. dollars.

TABLE 4. ENERGY ANALYSIS OF SUGAR CANE IN BRAZIL (per hectare)

FOOTNOTE	ITEM	DOLLAR FLOW (1980$)	MASS FLOW	ACTUAL ENERGY	ENERGY TRANSFORMATION RATIOS			EMBODIED SOLAR ENERGY		NEW ETRs
		US$/y	g/y	J/y	SEJ/$	SEJ/g	SEJ/J	E13 SEJ/y	E10 SEKcal/y	SEJ/J
INPUTS TO AGRICULTURAL PHASE:										
1	Direct solar energy			5.4E13			1	5.40	1.29	
2	Water transpired			5.5E10			15000	82.50	19.71	
3	Nitrogen fertilizer		118000			4.19E9		49.44	11.81	
4	Potassium fertilizer		165000			9.5E8		15.68	3.74	
5	Phosphorus fertilizer		66885			2E10		133.77	31.96	
6	Calcium (lime)		289000			2.63E9		76.01	18.16	
7	Fuel in pesticide			1.58E9			66000	10.43	2.49	
8	Direct fuel use			6.77E9			66000	44.68	10.67	
9	Fuel:seed.,machines,fert.			4.85E9			66000	32.01	7.65	
10	Goods-services,agr. prod.	795.85			6.9E12			549.14	131.18	
0										
0										
0										
0										
11	Sum of purchased inputs							911.15	217.67	
12	Sum of total ag. inputs							993.65	237.38	
INPUTS TO PROCESSING PHASE:										
13	Input from cane product.							993.65	237.38	
14	Bagasse generated electr.			1.41062E9			159000	22.43	5.36	
15	Bagasse as process fuel			4.0905E10			62522	255.75	61.10	
16	Goods-services,processing	180.68			6.9E12			124.67	29.78	
17	Subtract internal bagasse							-278.18	-66.45	
18	Net bagasse feedback			-7.3E10			62522	-456.41	-109.03	
19	Sum of purchased inputs							579.41	138.42	
20	Sum of total inputs							661.91	158.13	
YIELDS:										
Agricultural yields:(sugarcane)										
21	Main crop yield (cane)			3.1136E11			New	993.65	237.38	31913
0										
Processing yields:										
22	Byproduct bagasse(gross)			1.2E11			New	661.91	158.13	62522
23	Ethanol		3208	7.5200E10			New	661.91	158.13	88020
MONEY FLOWS:										
24	Sales (domestic)	795.85			6.9E12			549.14	131.18	
25	Sales (foreign)	795.85			2.6E12			206.92	49.43	
26	Economic subsidies	178.2			6.9E12			122.96	29.37	

Footnotes:

---

1 Direct solar energy 5.4E13 SEJ/ha/y Ref: CEPEC weather department
2 Water transpired 1.1 m/y Ref: P.T. Alvim, CEPEC
(1.1 m/y)(1E10 g/ha/m)(5 J/g) = 5.5E10 J/ha/y
3 Nitrogen fertilizer 118000 gN/ha/y Ref: urea,ammon.sulphate;(CEPLAC,1984)
4 Potassium fertilizer 165000 gK/ha/y Ref: (CEPLAC,1984)
5 Phosphorus fertilizer 66885 gP/ha/y Ref: (CEPLAC,1984)
6 Lime fertilizer 289000 gCa/ha/y Ref: with 12600 gMg/ha/y (CEPLAC, 1984)
7 Fuel in pesticide 1.58E9 J/ha/y Ref: Herb.& insect.(Goldemberg,1983)
8 Direct fuel use 6.77E9 J/ha/y Ref: tractors,trucks(Goldemberg,1983)
9 Fuel:seed.;machines,fert. 4.85E9 J/ha/y Ref: (Goldemberg,1983)
10 Goods-services,agr. prod. 706 $/t Ref: (Vargas, 1981; 55 Cr/1980 $)
(706 Cr/t)(62 t/ha)/(55Cr/$) = 795.85 $/ha/y Ref: (Goldemberg,1983)
11 Sum of items 3-10, purchased feedbacks
12 Sum of items 2-10,all except solar
13 Same as footnote 12
14 Bagasse generated electricity 15.8 kw Ref: (Gemente,1982); 2.5 t/hr
(15.8)(3.6E6J/kwhr)(1hr/2.5t)(62t/y) = 1.41062E9
15 Bagasse used for fuel 2220 g/liter (Gemente,1983);5.17E3J/g wet bagasse
(2220 g/l)(5.17E3J/g)(3564 l/ha/y) = 4.1E10
16 Processing costs by difference (Goldemberg,1983); 55Cr/1980$
(.274 US$/l)(3564 l/ha/y) - (795.85$/ha/y) = 180.681
17 Subtract items 14 & 15 since bagasse is in feedback u se.
18 Subtract net bagasse from inputs 7.3E10 J/ha/y . Ref: (Goldemberg,1983) potential use
19 Sum, purchased inputs,items:11,16,&18
20 Sum, all inputs - net bagasse (sum,items:13 through 18)
21 Main crop yield,fresh weight: 62 t/ha/y Ref: (Goldemberg,1983);0.3 dry/fresh
(62 t/ha/y)(0.3)(1E6g/t)(16744 J/g) = 3.1136E11
22 Gross bagasse yield before use: 1.2E11
23 Ethanol yield (3564 l/ha/y) Ref: (Goldemberg,1983) 5050 kcal/l
(3564 l/ha/y)(2.11E7 J/l) = 7.5E10
24 Domestic sales for local $ 795.85 US 1980 $ using local embodied energy/$ ratio
25 Foreign sales for outside $ 795.85 US 1980 $ using foreign embodied energy/$ ratio
26 $ subsidy by Gov't US$/l: .05 Ref: (Goldemberg, 1983)
(.05 $/l)(3564 l/ha/y) = 178.2
27 Sugar Cane yield /purchased feeedbacks: item 20/item 11
28 Ethanol yield/purchased feedbacksk: item 22/item 18
29 Environmental loading:item 11/item 2
30 Environmental loading:item 19/item 2
31 Embodied energy return on sale: ratio item 24/ item 23
32 Embodied energy,foreign sale: ratio item 25/ item 23
33 Embodied energy return on 1984 foreign sale; export price, $262.54 US/t (Banco,1984)
Foreign sales for outside $ 819.72 US 1984 $ using US embodied energy/$ ratio,.2E13 SEJ/$
Ratio= foreign sales/item 23
34 Gasoline bought with ethanol $; gasoline price .33 1980 US $/liter
(3.81E7J/l)(6.6E4SEJ/J)/(.33)= 7.6E12 SEJ/$ of gasoline
Ratio = (7.6E12SEJ/$)($796/ha/y)/ 661.91SEJ/ha/y = .916253
35 Liquid fuel used per fuel produced: item 23 / (items 7,8 & 9)
36 3.5E13SEJ/$ Liberia / 6.8E12 SEJ/$ Ethanol= 5.0735294117
37 Return on purachase of 3 liters of gasoline:
(3 l/$)(2.5E12 SEJ/l gssoline) =
RATIO: 1.0870

After summing all the embodied energy inputs, with appropriate corrections to avoid double counting, the spread sheet calculated energy transformation ratios relating the solar energy required per unit energy of raw sugar cane, bagasse, and ethanol. The solar energy required increases as more processing is done, from left to right in the diagram in Figure 4. The value for ethanol (8.8 E4) is similar to estimates made earlier for other liquid fuels (Odum and Odum, 1983, p. 391). The value for bagasse (3.2 E4) is similar to those for fast-grown, low density wood.

Embodied energy values for the flows from Table 4 were included on the pathways of the energy diagram in Figure 4. Although there is a substantial fraction of the basis of production directly from water and fertilizers, the largest fraction is the embodied energy in services.

Table 3 contains useful indices and ratios also calculated by the spread sheet program. The net energy yield ratios for sugarcane ethanol are close to unity, which means that these products are not having much effect on the vitality of the economy. When liquid fuel is obtained at a low price, the net energy yield ratio may be 6 to 50, which means that the fuel use stimulates the rest of the economy by that factor. In Brazilian ethanol use the economic contribution is self supporting but not a net contribution to the rest of the economy.

The net energy yield ratio of sugarcane alcohol calculated in the same way for Louisiana is similar (Hopkinson and Day, 1980; Odum and Odum, 1983). Others have obtained higher values by omitting embodied energy in labor, fertilizer, and other required inputs (Lima and Malavolta, 1976).

If the yield ratio is calculated as fuel yielded for fuel used in the production process, the ratio is 7.6 (Table 3). Many people thinking narrowly use this ratio to imply that ethanol production is as good a net energy for stimulating the economy as petroleum products, but that inference is incorrect because it ignores all the indirect embodied energy inputs that were correctly included in Figure 4 and in the net energy yield ratio of Table 3.

The ratio of economic feedbacks to the environmental inputs (7 in Table 3) are fairly large, which means that the system has to be classified as an intensive agroecosystem.

Given also in Table 3 and illustratated in Figure 5 are the relative benefits from sale of ethanol on international markets including the effect of using the foreign currency obtained to buy liquid motor fuels on the international market. All of these ratios are less than one, which means that more stimulus goes to the economy of the buyer than that of the seller. To make an excess of liquid fuel than is needed locally and sell it at prevailing prices is to hurt the local economy so long as the embodied energy ratio is less than one.

Some liquid fuel is necessary to fundamental economic processes such as transportation, and the ethanol system supplies this necessity with a neutral effect on the economy. As discussed in the chapter on the Brazilian economy, the local, largely solar-based production is better than

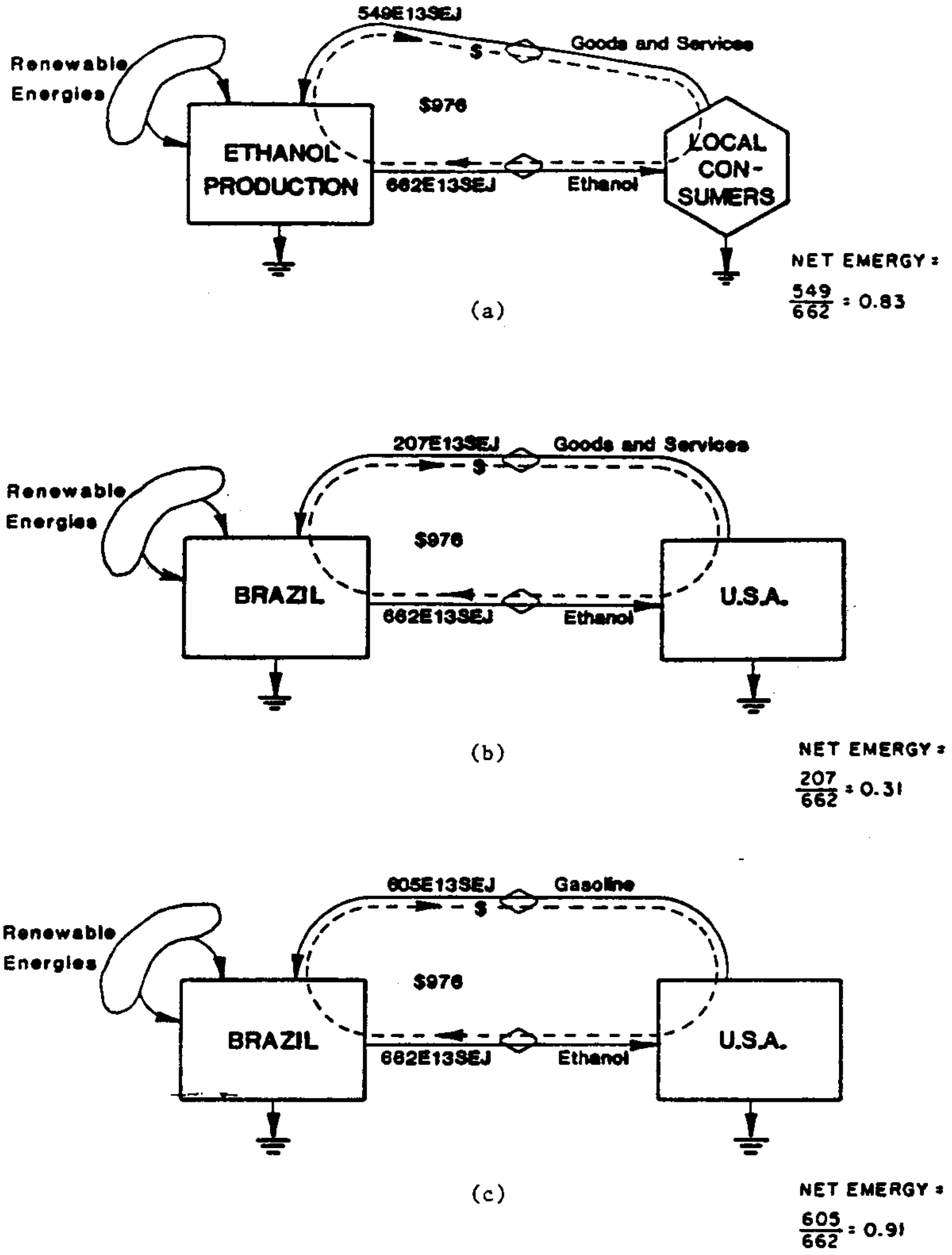


Figure 5. Exchanges of embodied energy that accompany sales of Brazilian ethanol yielded by one hectare in a year (1980). (a) Local sales within Brazil; (b) sale of ethanol to the United States at international price; (c) exchange for foreign gasoline on the basis of world prices of ethanol and gasoline.

purachase of liquid fuels abroad mainly because so much embodied energy is supplied to the outside supplier when Brazilian dollars are paid out at international currency exchange rates.

Conclusions from the analysis of the ethanol agroecosystem in Bahia using energy dollar ratios for Brazil as a whole apply also to the Amazon where the energy/dollar ratio is even higher.

Energy Analysis of Palm Oil Agroecosystem in Brazil

Many species of palms yield oils that are being tested for greater economic use by experimental programs in rain forest zones of many countries. The African oil palm is already in use in plantation agroecosystems in many countries with expanding plantings and oil press processing plants in both Bahia and the Amazon. Primarily used for cooking, the oil will also run diesel engines, and suggestions are made to under developed areas to substitute palm oils for foreign moter fuels. Here an energy analysis is made of African oil palm production and processing, using embodied energy evaluations to determine the contributions of this industry to an economy.

A diagram of the system as observed in Bahia, Brazil is given in Figure 6. Table 5 contains the evaluations of energy and embodied energy of the various input and yield pathways including labor. Some data on necessary inputs were taken from an energy analysis by Martin (1981) from plantations in Malaysia, where more machinery is used and less labor than in Brazil. However, Brazilian prices and dollar/ energy ratios were used to extrapolate the analysis to Brazilian conditions. A price of $.35/kg was used for Latin America for 1981 (Martin,1981).

The solar energy transformation ratio (solar energy required per unit of palm oil energy, 9.3 E4) is higher than for other fuels and more in the range of high quality foods, perhaps too valuable to use as a fuel.

The net energy yield ratio is close to unity, which means that it has a neutral effect on the rest of the economy, neither stimulating or draining other activities. If one only considers the liquid fuel yielded for each unit of liquid fuel directly used in the production process, the ratio is 3.5 which could be misconstrued as favoring oil palm development for motor fuel needs. However, there is little if any net energy when all inputs are included. In other words it does not compete so long as a higher net energy yield ratio is obtained by buying diesel oil from abroad. If diesel fuel were cut off entirely or becomes increasingly expensive to purchase abroad, the oil palm could supply necessary diesel without hurting the economy, but it will not stimulate the economy the way cheap fuels have done in the past.

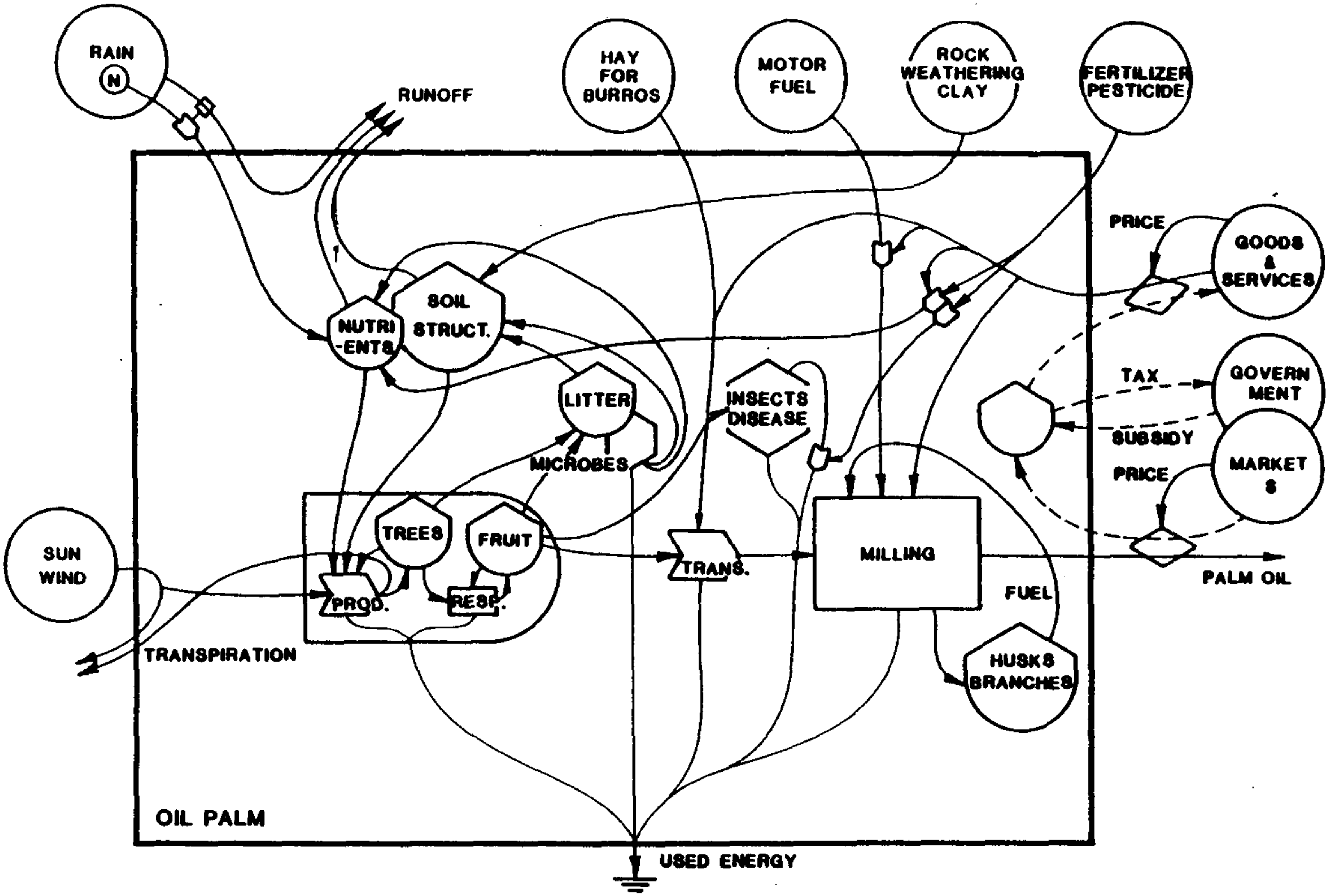


Figure 6. Energy analysis diagram of production of palm oil in Bahia, Brazil. See Table 5.

Table 5. Energy flows in system of production and extraction of oil from African oil palm, per hectare.* Data modified from Martin (1981).

Foot-note	Item	Actual Energy J, g, or $ per yr	ETR SE joules per J, or per $	Embodied Energy E13 SEJ
1	Direct solar energy	5.35 E13	1	5.4
2	Water transpired	6.75 E10 J	1.5 E4	101.
3	Nitrogen input	57 E3 g N	4.2 E9/g	24.
4	Potassium input	104 E3 g K	3.2 E9/g	33.
5	Phosphate input	15 E3 g P	2.0 E10/g	30.
6	Magnesium (59 E3 g MgO)	19 E3 g Mg		
7	Electricity used	1.43 E9 J	1.5 E5/J	21.5
8	Fuels used directly	8.4 E9 J	6.6 E4/J	55.
9	Fuels involved in capital equipment	46 E9 J	6.6 E4/J	303.
10	Fuels in fertilizers and other processes	6.8 E9 J	6.6 E4/J	45.
11	Services in $(1980)/kg	3.3 E3 $	6.9 E12/$	1195.
12	Total inputs not double counting			1814
13	Yield of oils	195.5 E9 J	9.3 E4	
14	Net energy yield ratio		1.06	
15	Liquid fuel produced over liquid fuel used		3.5	

Footnotes to Table 5

* Data from Martin (1981) from plantations and extraction mills in Malaysia.

1,2 Solar energy and transpired water were appropriate for Bahia, Brazil.

3-6 Fertilizer inputs from Martin (1981).

7 Electrical energy

(400 KWH/ha)(860 kcal/KWH)(4186 J/kcal) = 1.43 E9 J/ha/y

8-10 Direct and indirect fuel use from Martin (1981)

Services estimated from costs

Goods and services based on oil price in Bahia, Brazil, 1980, and Brazil's energy dollar ratio from Odum and Odum (1981)

Palm oil price (1980$), $.35/kg

(.35/kg)(4950 kg/ha) = $1732/ha/y

($1732/ha)(6.9 E12 SEJ/$1980) = 1.195 E16 SEJ

1980 price, 2000 Cr/ton (Cepec, 1983)
saw seeds

(4950 kg/ha)(0.036/kg)

12 Omitting direct solar energy because it contributes to item 2.

13 Yields (Martin, 1981) palm oil, 183 E6 k J/ha from 4620 kg plus 12.5 E6 k J/ha from palm 330 kg kernal oil. (9.5 kcal/kg palm oil and 9.07 kcal/g palm kernal oil.

$$\text{ETR} = \frac{\text{Total inputs in SEJ}}{\text{Yield in J}} = \frac{1814\ \text{E13 SEJ}}{1955\ \text{E9 J}} = 9.3\ \text{E4}$$

ETR is similar to that for diesel oil and this is a confirmation of the solar equivalents for oil.

14 Net energy yield ratio including all inputs as feedbacks except rain

$$\frac{1814\ \text{E13 SEJ}}{1708\ \text{E13 SEJ}} = 1.06$$

15 Net fuel including 8% of Brazilian services derived from fuel.

$$\frac{1814\ \text{E13 SEJ}}{(21.5+55+303+45+(0.08)(1195))}$$

$$\frac{1814}{520} = 3.5$$

Biomass Fuels from Solar Energy

The energy analyses reviewed in this chapter suggest that the uses currently observed are appropriate ones. Mature wood and plantation wood are capable of stimulating and supporting other economic activities. A completely wood-based economy will not compete until foreign fuels are depleted and their net energy ratio decreases to that of wood. Selling the wood abroad only benefits others. However, a wood based economy matched with imported embodied energy maximizes the economy by maximizing the available embodied energy. Converting wood to finished products for sale such as paper or furniture are examples.

Ethanol and palm oil are higher quality products capable of substitution for fossil fuels as motor fuels. However, such use carries little if any net economic stimulus to support additional economic activity. Sale abroad stimulates the foreign economies, depressing the local one, but use at home in limited quantities where high quality products are important amplifiers to industrial or consumer functions can provide effects commensurate with the large embodied energy incorporated in their production.

Although the net energy of biomass produced motor fuels is too small to compete with liquid fuels from fossil fuel for some time in much of the world, the dollar exchange situation for underdeveloped areas such as the Amazon reduces the net energy in buying foreign fuels. Because money is used as a measure of foreign trade value, areas such as the Amazon with more embodied energy per dollar cannot obtain the high net energy from foreign oil that developed countries do. Thus biomass produced fuels become competitive in underdeveloped countries much sooner than elsewhere. The public policy of developing biomass fuels to the extent of local demands seems correct, but the further development of biomass fuels for export hurts the home economy.

IV. TROPICAL FOREST

Whereas the previous sections examined the Amazon system on a large scale including the economic potentials and energy resources affecting its pattern, in Section IV we examine the principles operating in tropical forest systems on a smaller scale. First models are used to examine main processes and factors in natural forests and plantation management systems. Included is the question of the role and costs of diversity and evolution. Next are given simulation models of plantations at Jari and perspectives on the questions of fertilizer, rotation, and economic viability. Finally, tropical forest understory crop systems are considered using models, a simulation, and energy analysis of cacao as an example.

ENERGY SYSTEMS OVERVIEW OF PRINCIPLES OF TROPICAL FORESTS AND THEIR UTILIZATION

Howard T. Odum

In recent years studies of the overall productivities and patterns of tropical rain forests have determined the composition, productivity and chemical cycles of many tropical forests. The basic processes are like other forests, but the various functions invoke many more species, more organized biological inter-relationships and more storages of genetic information from past evolution. In this essay the essence of the major properties and processes of tropical forests and their utilization are sought with suggestions on improving the symbiotic relationships of humanity and tropical forest ecosystems.

The format used in this essay to represent concepts on tropical forest includes basic principles first given in words, then in systems models in diagrammatic form in energy language (Odum, 1971, 1983), and finally with graphs produced by simulating the models, calibrated with data from the forest at El Verde, Puerto Rico. Simple macroscopic-minimodels provide simultaneous overviews of structure and function that are simple enough to remember and whose time dimensions, verified with computer simulation, can be visualized from the structural diagram.

Like controlled experiments, models and simulations help indicate the roles of factors and relationships. These models show that relatively few causal mechanisms can represent major features of tropical forests in overview. However, showing the plausibility of simple theories in structural and temporal dimensions is no guarantee that additional principles may not be necessary for adequate overview rerpesentation. The use of macroscopic-minmimodels to improve the precision of theoretical discussion is still relatively new and hence the format is itself an experiment.

Let us begin with the gross features of productivity, nutrients, and biomass and then go to diversity, economic utilization, and evolution. The

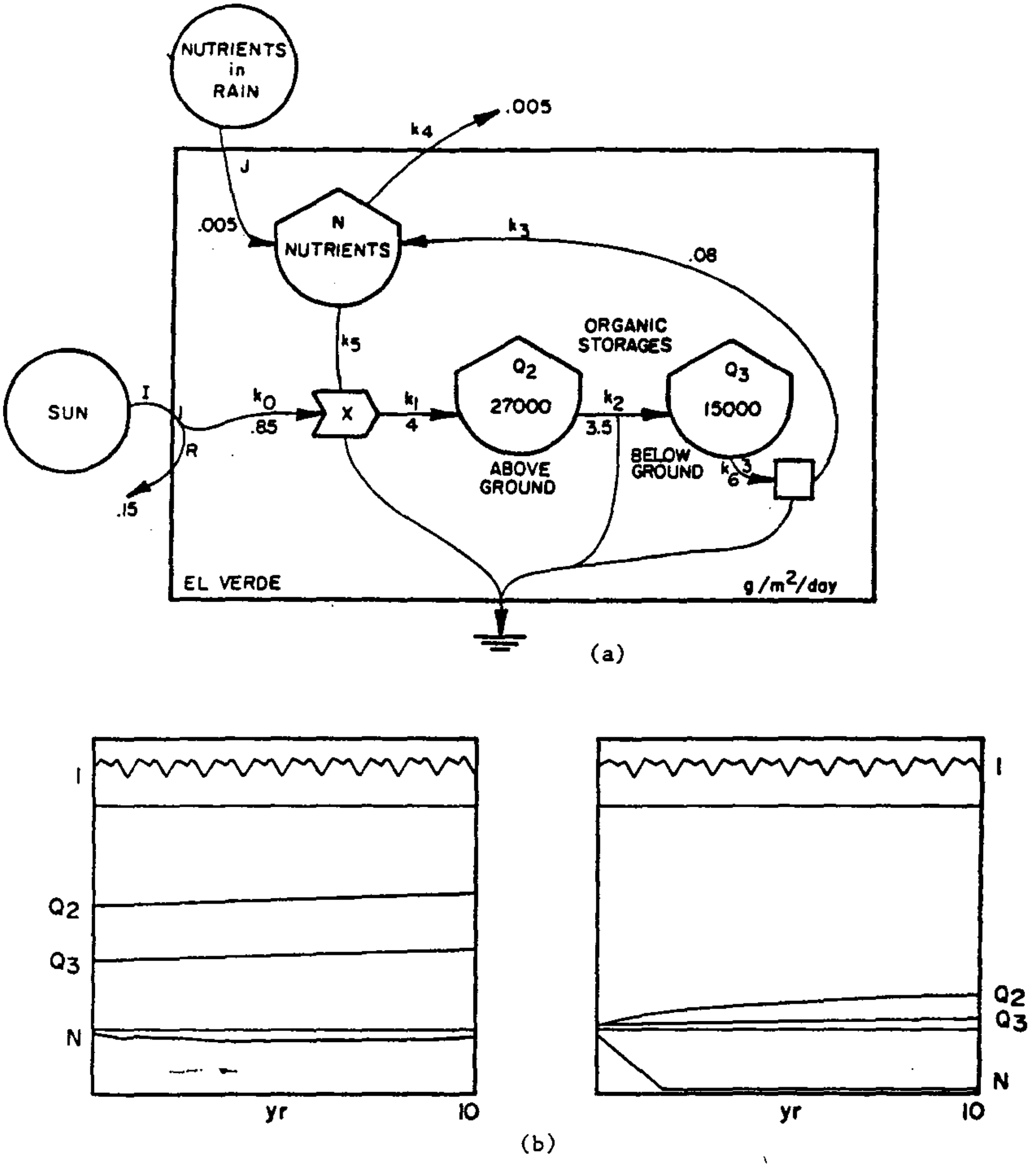


Figure 1. Overview model of production, respiration, nutrient cycle, and main storehouse of an ecosystem, calibrated with data from El Verde, Puerto Rico (Odum, 1970). (a) Model; (b) ten year simulation of mature forest to annual variations in light; (c) simulation of early succession.

Figure 1 (continued)

```
1   REM  EL VERDE P-R
2   HGR : HCOLOR= 3
3   HPLOT 0,0 TO 0,159 TO 279,159 TO 279,0 TO 0,0
4   HPLOT 1,30 TO 279,30
6   HPLOT 1,130 TO 279,130
10   DIM A(12)
11   DATA   3000,3800,4000,4200,4000,3800,3800,4000,4000,3500,
     3000,2800
12   FOR M = 0 TO 11
13   READ A(M)
14   NEXT
20 J = .005
30 Q1 = 50
40 Q2 = 27000
50 Q3 = 15000
60 K0 = 453
70 K1 = .53
80 K2 = 1.3E - 4
90 K3 = 5.3E - 6
100 K4 = 1E - 4
110 K5 = .0106
120 K6 = 2E - 4
127 X = 13
128 Z = 4
130 I = A(M)
140 R = I / (1 + K0 * Q1)
150 D1 = J - K4 * Q1 + K3 * Q3 - K5 * Q1 * R
160 D2 = K1 * Q1 * R - K2 * Q2
170 D3 = K2 * Q2 - K6 * Q3
180 Q1 = Q1 + D1 * Z
185  IF Q1 < .0000001 THEN Q1 = .0000001
190 Q2 = Q2 + D2 * Z
200 Q3 = Q3 + D3 * Z
210 T = T + Z
215 Y =  INT (T / 365)
218 W = 12 * Y
220 M =  INT (T / 30.4) - W
230  HCOLOR= 6: REM  BLUE:NUTRIENTS
240  HPLOT T / X,158 - (Q1 / 2)
250  HCOLOR= 1: REM  GREEN
260  HPLOT T / X,160 - ((Q2 / 500) + 30)
270  HCOLOR= 2: REM  VIOLET:DEAD BIOMASS
280  HPLOT T / X,160 - ((Q3 / 500) + 30)
290  HCOLOR= 5: REM   SUN
300  HPLOT T / X,160 - (I / 200 + 130)
310  IF T < 279 * X GOTO 130
```

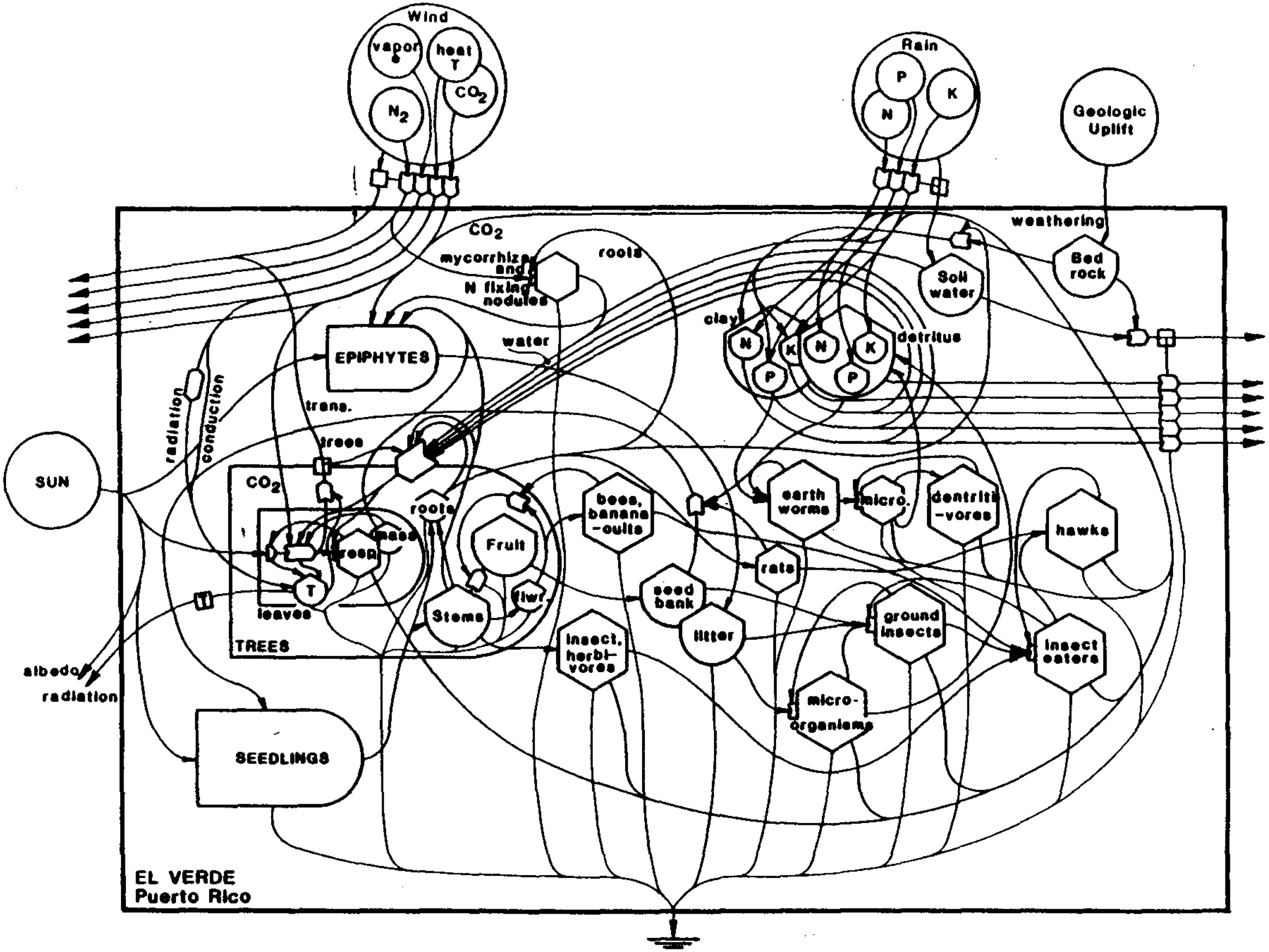
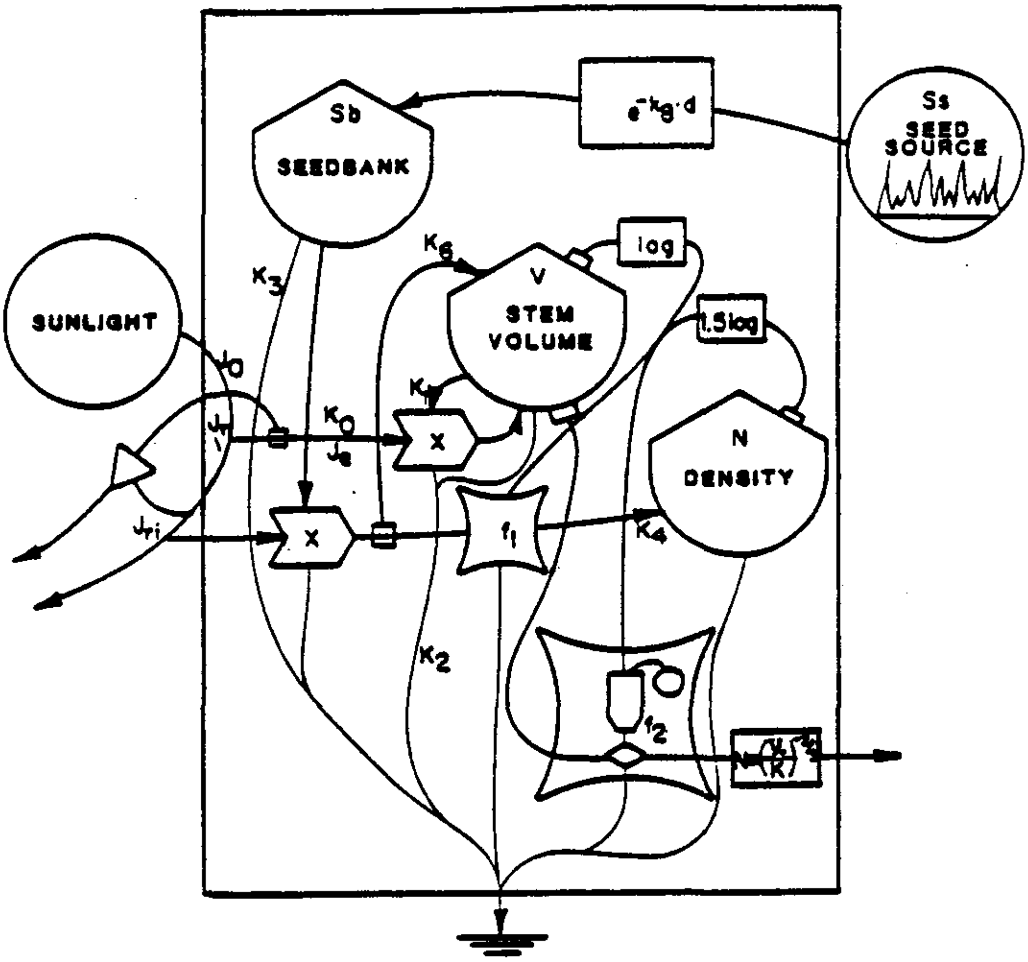
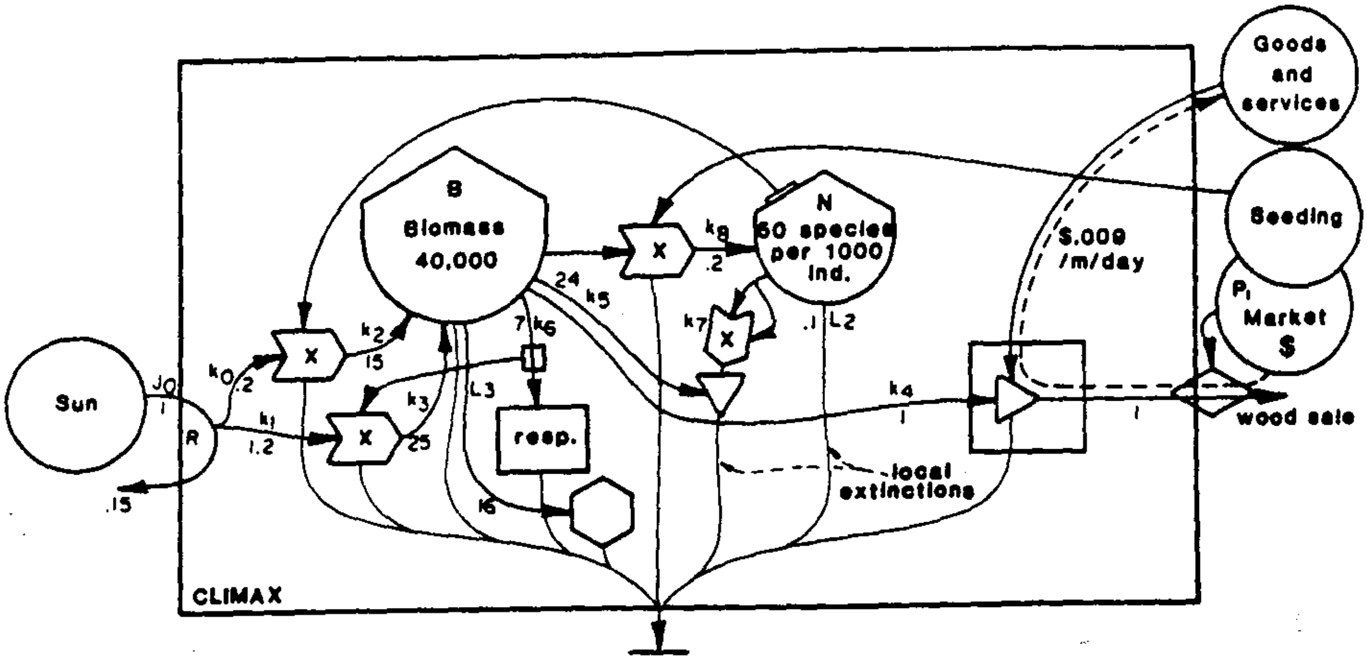


Figure 2. A diagram of principal components and processes prepared for organization of research.



$$J_e = k_o \cdot V \cdot J_r$$
$$J_r = J_o/(1+k_o \cdot V)$$
$$J_f = J_r - J_{ri}$$
$$J_{ri} = J_e \cdot 0.11$$
$$dV/dt = k_6(k_4 \cdot S_b \cdot J_f) + k_1 \cdot V \cdot J_r - k_2 \cdot V$$
$$dS_b/dt = S_s \cdot e^{-k_8 \cdot d} - k_3 \cdot S_b - k_4 \cdot S_b \cdot J_f$$
$$dN/dt = f_1(k_4 \cdot S_b \cdot J_f)$$
$$N = f_2(V/K)^{-2/3}$$
$$f_1 = 0 \text{ if } \log V + 1.5 \log N > 4.05$$
$$f_1 = 1 \text{ if } \log V + 1.5 \log N \leq 4.05$$
$$f_2 = 0 \text{ if } \log V + 1.5 \log N < 4.05$$
$$f_2 = 1 \text{ if } \log V + 1.5 \log N \geq 4.05$$

Figure 3. Models of seed dispersal by McClanahan (1984).



(a)

$$R = J_o - k_o RN - k_1 RB$$

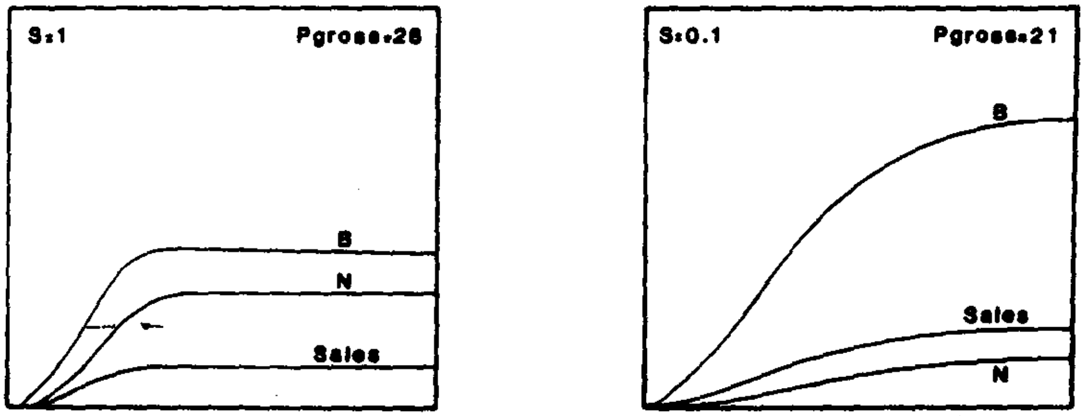
$$R = \frac{J_o}{(1+k_o N+k_1 B)}$$

$$\text{Sales} = P_1 k_4 B$$

$$\dot{B} = k_2 RN+k_3 RB-k_5 N^2-k_6 B-L_3 B^2-k_4 B$$

$$\dot{N} = k_8 SB-k_7 N^2-L_2 N$$

$$P_{gross} = (k_2 RN+k_3 RB)$$



(b) (c)

Figure 4. A model of rain forest production and diversity. (a) Model; (b) simulations of growth with available species seeding S = 1 generates more gross productivity; (c) simulation with poor seeding S = 0.1 generates more biomass and sales but less gross production.

Figure 4 (continued)

```
4  REM  CLIMAX
5  HGR : HCOLOR= 3
6  HPLOT 0,0 TO 0,159 TO 279,159 TO 279,0 TO 0,0
7  HCOLOR= 5
10  REM  COEFFICIENTS
12 I = 20
14 TO = 20
15 BO = 500
17 NO = 1
20 MO = 5E - 5
25 P1 = 3.6E - 4
30 P2 = .01
33 KO = 2.7E - 2
35 K1 = 2E - 4
37 K2 = 2
39 K3 = 4.17E - 3
42 K4 = 2.5E - 5
44 K5 = .01
46 K6 = 1.75E - 4
48 ~~K7 = 4E - 5~~
49 K8 = 5E - 6
50 L1 = .1
54 L3 = 1E - 8
90 S = 1
100  REM  INITIAL CONDITIONS
110 JO = 1
120 B = 100
140 N = 1
200  HCOLOR= 3
212  HPLOT T / TO,160 - N / NO
215  HCOLOR= 1
230  HPLOT T / TO,160 - B / BO
234  HCOLOR= 2
235  HPLOT T / TO,160 - JM / MO
241 R = JO / (1 + KO * N + K1 * B)
250 DN = K8 * B * S - K6 * N - K7 * N * N
260 JM = P1 * K6 * B
265 DB = K2 * R * N + K3 * R * B - K6 * B - K4
          * B * S - K5 * N * N - L3 * B * B
270 B = B + DB * I
280 N = N + DN * I
295 T = T + I
297  PRINT "R="R,"GROSS P="(K2 * R * N + K3 * R * B)
300  IF T / TO < 279 GOTO 200
```

first models illustrate the way a few principles operate, and then more aspects are introduced.

Simple View of Production, Consumption, and Recycle

The simplest model often used for an ecosystem is the production-consumption model which has production, respiration, nutrient recycle, and storages of biomass and total available nutrients. Sometimes this model is abbreviated: P-R model (photosynthesis-respiration). A version was applied to the rain forest ecosystem at El Verde, Puerto Rico earlier and simulated with analog computer (Odum, 1970; Burns, 1970). Slightly more complex is the version in Figure 1a which has source-limited energy sources for light, and separate storages for live biomass and dead soil organic matter. When real values of light and nutrients are inflowing with month to month variations, variation in main storages is hardly discernable because the large time constants filter out the variations in input. Even though the rates of production and consumption are very high as compared with other ecosystems, the dense green mantle of life seems to be very constant to the observer, and the model shows why (Figure 1b). If the model is run with small inital storages at the start, a very long time is required to build up to mature states. Figure 1c shows small accumulations in the first 10 years. Many more years are required to reach the condition in Figure 1b. The available nutrients are maintained at higher concentrations after the build up of biomass storages, because of the increased cycling in the more mature state.

Research Overviews of the Rainforest at El Verde

During the systems ecology studies of the rainforest at El Verde 1957-1970 a viewpoint as to the main parts and processes was developed that was used to organize research and raise research questions. This overview is given as a model diagram in Figure 2. Thinking about the forest was like a zoom microscope shifting back and forth between the aggregated view in Figure 1 and the view of medium complexity in Figure 2. Figure 2 is like an inventory of items which were studied, are worth studying in reasonable priority, ~~and the~~ main categories of division of labor above the species level of aggregation. In most respects this complex diagram can represent rain forests generally. Different values for the coefficients make a particular forest different.

Models of Dispersal

In order to maintain conditions for maximum longrange productivity, diversity and rotation need to be arranged to rapidly reseed lands that are turned back to the restoration phase of the cycle. Seed sources are little disturbed plots of vegetation which are retained among the lands that are alternately rotated between restoration and short term plantation and crop use. If the plots are too small they don't produce enough seeds or enough birds and animals to spread and plant them. If the plots are too few they are not close enough to many areas ready for seeding. If the seed source areas are too large, they take too much land out of the production cycle from the point of view of economic yields and costs. Given in Figure 3 are models of dispersal which show the relationship of some of the factors. Detailed studies of the dispersal process were made by McClanahan (1984) with preliminary applications to succession in mined areas in Florida.

Combining Diversity with Production

So far in the models of Figures 1 and 2 the most distinctive feature of tropical rainforests, the diversity, was not included. In Figure 4a diversity is included as an aggregated quantity. Although there are alternative views on the relationships of diversity and production held by other schools of ecology, the following relationships were built into Figure 4a:

(a) Basic production is modelled to generate forest biomass.

(b) Since biomass is an index of available structure for supporting niches, biomass interacts with available species dispersing into the system to establish diversity in excess of species lost by local extinction.

(c) Species are also lost by competitive exclusion as part of the interactions among species (the N squared pathway = N^2), and some local extinctions are proportional to diversity (the linear extinction pathway). Fitting of rain forest diversity data to permutation and quadratic expressions was given earlier (Odum,1970, 1971).

(d) Diversity draws from the produce for its special costs in proportion to the square of the number of the species in the species diversity index.

(e) Higher diversity helps to convert more of the input source into produce. This diversity-driven production is beyond that necessary to equal the depreciation of the biomass.

(f) Included in the uses of the biomass is the economic use in proportion to the biomass. Most rain forests which have non-destructive users yield a steady output of products such as selected woods, fruits, and organic chemicals.

(g) A flow of dollar earnings is generated in proportion to the outflow of economic products.

As show in Figure 4b, simulation of the model calibrated with data from El Verde generates the kind of long increase in mass and then species diversity that is observed in tropical forest succession. The production and structures are ultimately limited by the inflow of resources and by the quadratic nature of the increasing energy use by diversity relative to its diminishing returns in augmenting production. This model generates high diversity so long as there are diverse populations available to seed the system from adjacent areas. If there is no diversity pool to draw from, a low diversity, lower mass, less productive ecosystem results with lower gross production.

However, the biomass (B) that develops when diversity is limited may be greater because the gross production goes into storage instead of into use by consumers. Compare Figure 4b with Figure 4c.

Rainforest Plantations

The overview of plantations planted for yields is not unlike the rainforest without available species (Figure 5a). With the plantation, efforts are made to limit species, maximize net production without building long range structure, deriving yields and earning income of money as quickly as possible. Whereas nutrients were not made limiting in the successional model of the high diversity forest, the plantation yield forest has to have a replacement for the nutrients removed in the product. The plantation forest has a low respiration rate with less and lower quality young structures to maintain. In the model the plantation is cut when a threshold is reached. Money is received for wood sales and is the capital used for replanting, fertilizing, and keeping operations solvent until the next harvest. This model was evaluated for plantation Cadam trees at El Verde previously (Odum, 1970).

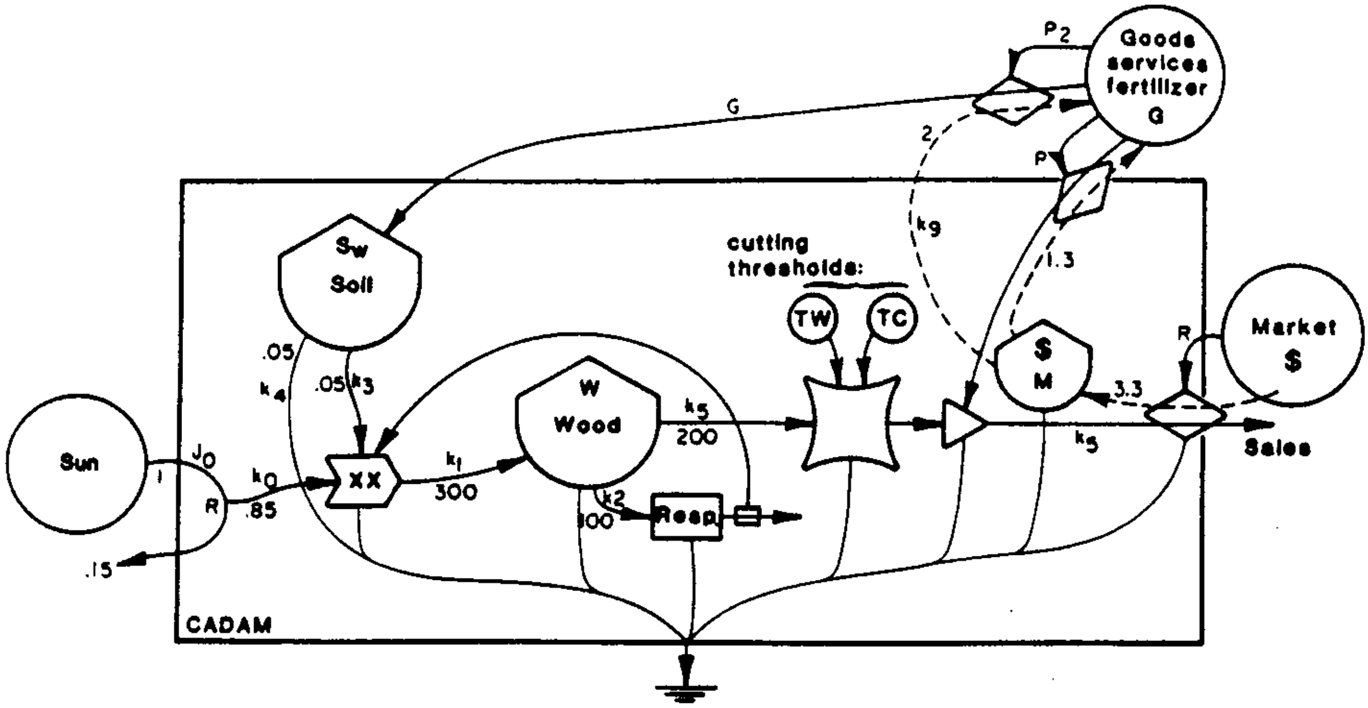
The simulations in Figure 5b show the pulsing steady state that is the economic user's concept. The plantation model in Figure 5 assumes the features of simplicity that the user wants. In real tropical forest conditions, however, the ability to sustain the soil nutrient steady state is usually in question and the availability of diversity, operating as in Figure 4, threatens the crop.

Plantations with Diversity Plots

A more realistic overview of plantation yield system in tropical rain forest conditions includes the two systems of Figure 4a and Figure 5a together, both trying to operate on the same resources. Figure 6a has the plantation model and the available diversity growing in competition. Added also is the economic expenditure on pesticides, weeding, etc.

Whereas it might be reasoned that eliminating available diversity would eliminate the economic costs of dealing with competition and consumption from wild species, a worse problem may be epidemic consumer pests which tend to be suppressed by diversity. The combined model of plantation and diverse plots in Figure 6a includes a diluting effect of diversity on plantation pests.

In the simulation of competition between the two systems, the wild system overgrows the plantation if little energy inputs are provided from the economy outside, but with larger economic inputs, the plantation prevails as long as the soil basis is available.



$$R = J_o - k_o S_W W R$$

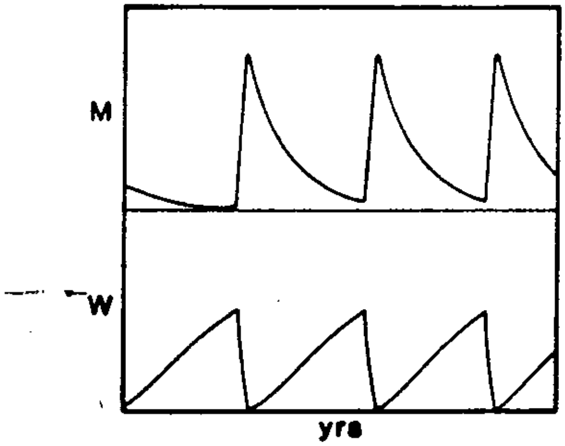
(a)

$$R = \frac{J_o}{(1+k_o S_W W}$$

$$\dot{M} = \overbrace{P_1 k_5 W}^{\text{If } W > TW} - P - k_6 M$$

$$\dot{W} = k_1 R S_W - k_2 W - \overbrace{k_5 W G}^{\text{If } W > TW}$$

$$\dot{S_W} = \frac{k_6 M}{P_2} - k_4 S_W - k_3 R S_W W$$

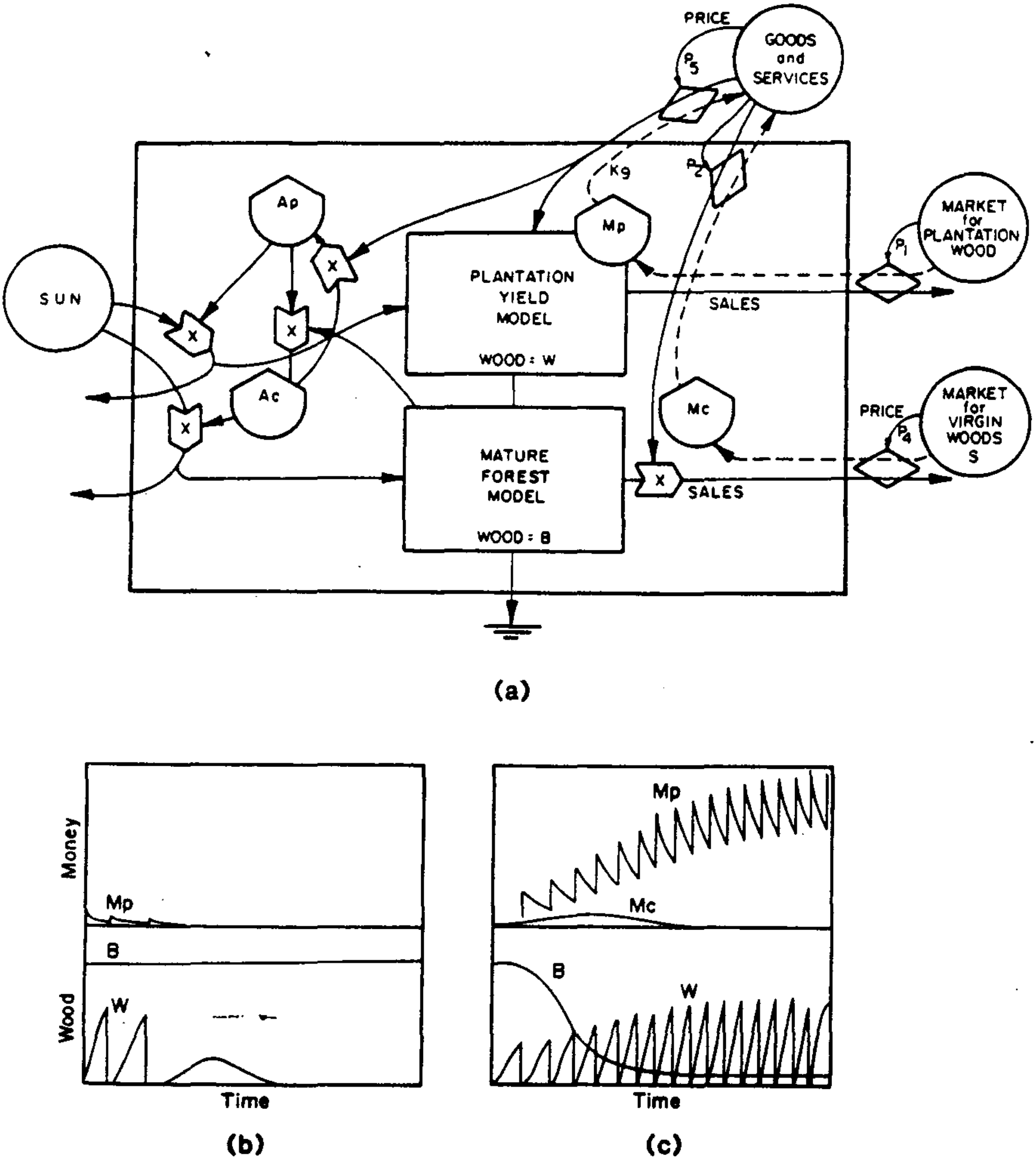


(b)

Figure 5. A plantation model which generates economic returns representing a concept of renewable yield. Wood is harvested when accumulation reaches a threshold. (a) Energy diagram; (b) simulation of several cutting cycles.

Figure 5 (continued)

```
4   REM  CADAM
5   HGR : HCOLOR= 3
6   HPLOT 0,0 TO 0,159 TO 278,159 TO 278,0 TO 0,0
7   HCOLOR= 5
10  HPLOT 0,80 TO 278,80
20 JO = 1
25 P = 1.3
30 P2 = 1
40 P1 = .2
50 SW = 2
60 W = 100
65 M = 10
70 TW = 2000
75 TC = 100
80 K0 = 2.83E - 3
90 K1 = .66
100 K2 = .05
110 K3 = 6.6E - 5
120 K4 = .03
130 K5 = .2
145 K7 = .4
147 K8 = .03
148 K9 = .2
150 I = .2
160 TO = .2
170 MO = 1
180 WO = 50
190 SO = 1
200  HCOLOR= 1
201  HPLOT T / TO,160 - W / WO
210  HCOLOR= 2
211  HPLOT T / TO,80 - M / MO
230  GOTO 300
231  HPLOT T / TO,160 - SW / SO
300 G = K9 * M / P2
315  IF W > TW THEN X = 1
320  IF W < TC THEN X = 0
325 R = JO / (1 + K0 * SW * W)
330 DW = K1 * R * SW * W - K2 * W - X * K5 * W * G
340 DS = K8 * G - K3 * R * SW * W - K4 * SW
350 DM = X * K5 * P1 * W - X * P - K9 * M
400 SW = SW + DS * I
405  IF SW < 0 THEN SW = 0
410 W = W + DW * I
415  IF W < 10 THEN W = 10
420 M = M + DM * I
490 T = T + I
500  IF T / TO < 279 GOTO 200
```



(a)

(b)

(c)

Figure 6. Model combining models of diverse forest plots (Figure 4) and plantation plots (Figure 5) as systems competing for land use. (a) Energy diagram; (b) simulation with very low sale prices so that wild forest prevails; (c) simulation with high sale prices so that plantations prevail. AP = area of plantation, AC = area of mature forest, MP = money, MC = money.

Figure 6 (continued)

```
2  REM  PLANTATION OR CLIMAX
3  REM  FIRST RUN-SALE AT LOW PRICE
4  REM  THEN TYPE CONT FOR HIGH PRICE RUN
5  HGR : HCOLOR= 3
6  HPLOT 0,0 TO 0,159 TO 278,159 TO 278,0 TO 0,0
10  HPLOT 0,80 TO 278,80
20 J0 = 1
25 P = 1.3
28 P1 = .01
30 P2 = 10
40 P4 = .0005
41 P5 = 20
42 AC = 1
44 AP = 1
46 A = 2
50 SW = 1
55 B = 3E4
60 W = 100
65 MP = 10
70 TW = 2000
75 TC = 100
78 KL = 5E - 7
80 K0 = 2.83E - 3
85 KA = 1.5E - 3
87 KS = 5E - 5
90 K1 = .66
100 K2 = .05
110 K3 = 6.6E - 5
120 K4 = .03
130 K5 = 2
140 K6 = 3.3
145 K7 = .4
147 K8 = .007
148 K9 = .2
150 I = .2
160 T0 = .2
170 M0 = 3
180 W0 = 50
190 S0 = 1
195 B0 = 500
197 N0 = 1
200 LH = 1E - 8
210 KV = .2
220 L0 = 2.7E - 2
225 L1 = 1E - 4
230 L2 = .93
235 L3 = 4.17E - 3
240 L4 = 2.5E - 4
245 L5 = .01
247 L6 = .02
250 L7 = 4E - 5
255 L8 = 5E - 6
260 LN = .1
265 N = 50
270 S = 1
280 MC = 1
```

Figure 6 (continued)

```
300  HCOLOR= 1
301  HPLOT T / TO,160 - W / WO
305  HPLOT T / TO,80 - MP / MO
310  HCOLOR= 2
311  ~~HPLOT T / TO,80 - MC / MO~~
331  HPLOT T / TO,160 - B / BO
400 G = K9 * MP / P2
405 DA = KA * G * AC - KL * AP * B
415  IF W > TW * AP THEN X = 1
420  IF W < TC * AP THEN X = 0
425 RP = JO * AP / (1 + KO * SW * W)
427 RC = JO * AC / (1 + LO * N + L1 * B)
430 DW = K1 * RP * SW * W - K2 * W - X * K5 * W
440 DS = K8 * G - K3 * RP * SW * W - K4 * SW + KS * DA * B
450 DM = X * K5 * P1 * W - X * P - K9 * MP
460 DN = L8 * B * S - LN * N - L7 * N * N
470 DB = L2 * RC * N + L3 * RC * B - L6 * B * KV * MC / P5 - L4 * B * S - L5 * N
480 DV = P4 * L6 * B * KV * MC / P5 - KV * MC
500 SW = SW + DS * I
505  IF SW < 0 THEN SW = 0
510 W = W + DW + I
515  IF W < 10 THEN W = 10
520 MP = MP + DM * I
525  IF MP < .0001 THEN MP = .0001
530 AP = AP + DA * I
540 AC = A - AP
550 B = B + DB * I
555 N = N + DN * I
560 MC = MC + DV * I
590 T = T + I
600  IF T / TO < 279 GOTO 300
650  END
700 WO = 100
705 MO = 10
710 T = 1
715 SW = 1
720 B = 3E4
722 AP = 1
724 AC = 1
726 MC = 1
730 W = 100
740 MP = 10
750 P1 = .2
760 P2 = 1
770 P4 = .005
780 P5 = 1
790  HGR : HCOLOR= 3
795  HPLOT 0,0 TO 0,159 TO 278,159 TO 278,0 TO 0,0
797  HPLOT 0,80 TO 278,80
800  GOTO 300
```

Rotation

Both in simple agricultural practice and in developed practices, sustained use of tropical rain forests for yield purposes seems to require a rotation between the yield crop or plantation and the high diversity system which rebuilds storages, soils, and protective diversity for a new cycle. It is too soon to know if there will be exceptions. The need for rotation may be another case of the principle that maximum power (productivity) is generated by alternating periods of net production with periods of net consumption (Odum,1982).

The model in Figure 7a considers the general concept of rotating human consumers with tropical forest restoration. Here humans are within the model and money is omitted. The simulation starts with an overshoot until the ratio of land in restoration gets in steady state balance with that in human use. Each parcel of land is pulsing as it alternates from restoration to use, but the view of the model from the larger scale represents the oscillations as a steady state. One can always represent pulsing phenomena as a steady state by choosing a large enough scale.

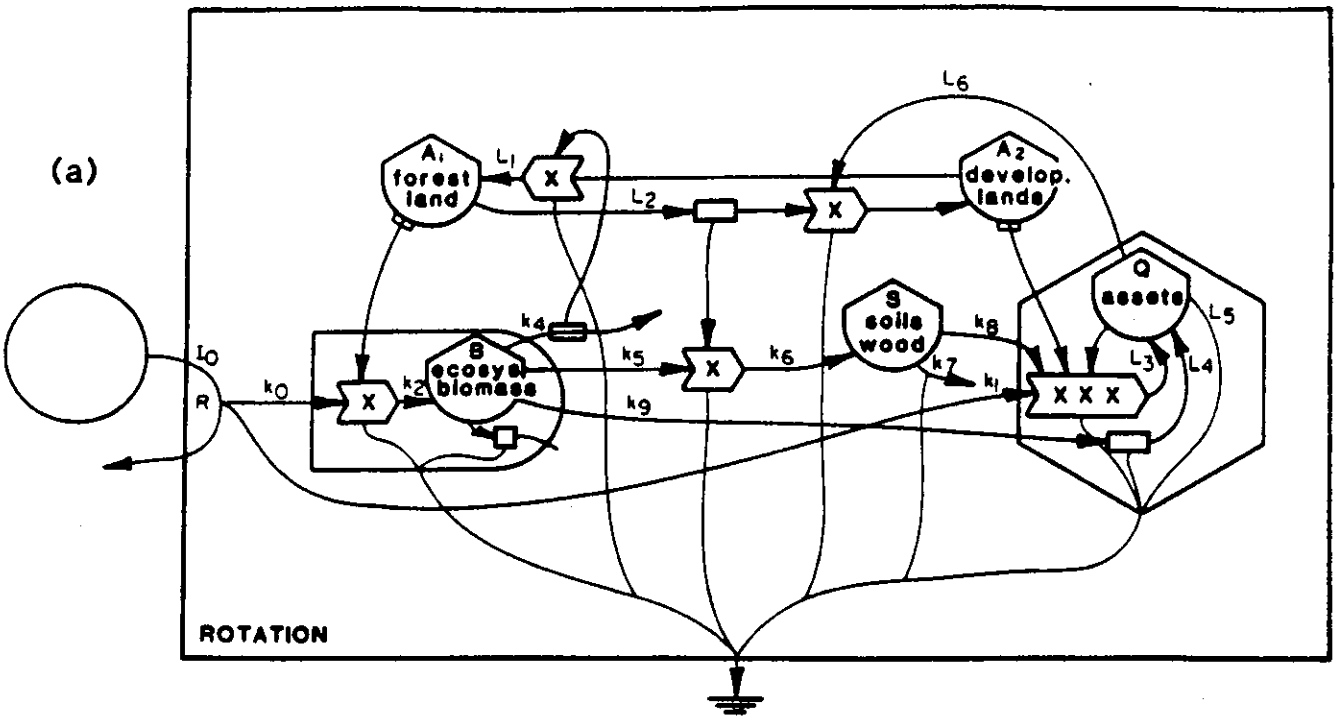
In Figure 8a is a less abstract rotation model that provides dollar returns for forest yields. Here economic yields depend on rapid restoration of soil conditions, and this requires diversity to be rapidly seeded from forest plots that contain a pool of diverse plant species with the animals that pollinate, manage and distribute propagules. In this model maintaining plots of forest diversity is necessary to maximize economic benefits.

Whereas Figure 8a was calibrated with data from Puerto Rico (Odum, 1970), a much more detailed model with studies of a real economic activity was done by Christianson (1984) with the forest plantations at Jari, Brazil as given in another chapter.

Long-term Tropical Forest Production, Species Availability, and Species Evolution

The symbiosis between species diversity and tropical forest productivity was given with the concept model in Figure 4 and simulated with times appropriate to seeding, succession, and self organization. A similar model gives us insights regarding the longer times appropriate for evolution of new species, for storing information in previously evolved species, and connections between productivity and evolution.

In Figure 9a the production-diversity model is calibrated for longer scales of time and distance. The biomass storage is replaced with a flow since the time scale of simulation is much longer than the time constant of biomass storages. Availability of species is provided with an inverse square dispersal pathway so that islands at varying distances can be used to calibrate the role of distance and time. The model includes formation of new species by evolution requiring a energy diversion (use) over a long period. Here species are formed by the energy spent maintaining populations



$R = I_o - k_oAR - k_1SQA_2$

$R = \dfrac{I_o}{(1+k_oRA_1+k_1SQA_2)}$

$A_1 + A_2 + 1$

calibrated with 50% as
as steady state

$\dot{B} = k_2RA_1 - k_3B - k_4B - k_5BA_1 - k_9B$

$\dot{S} = k_6BA_1 - k_7S - k_8SRA_2Q$

$\dot{A} = L_1A_2B - L_2QA_1$

$\dot{Q} = L_3QA_2SR + L_4S - L_5Q - L_6A_1Q + L_7QA_2SR$

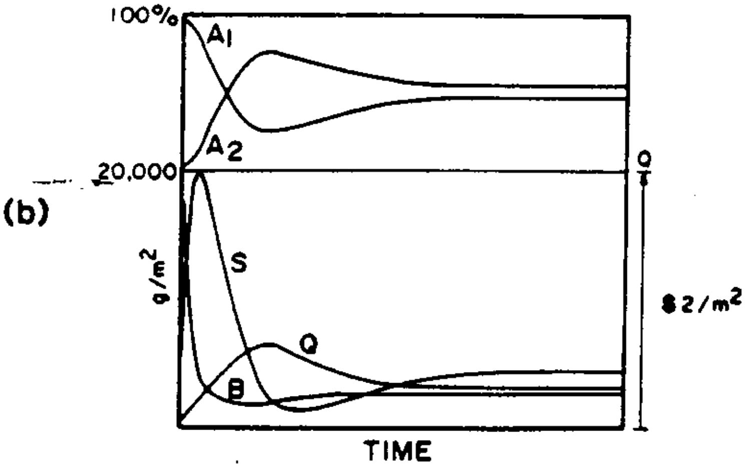
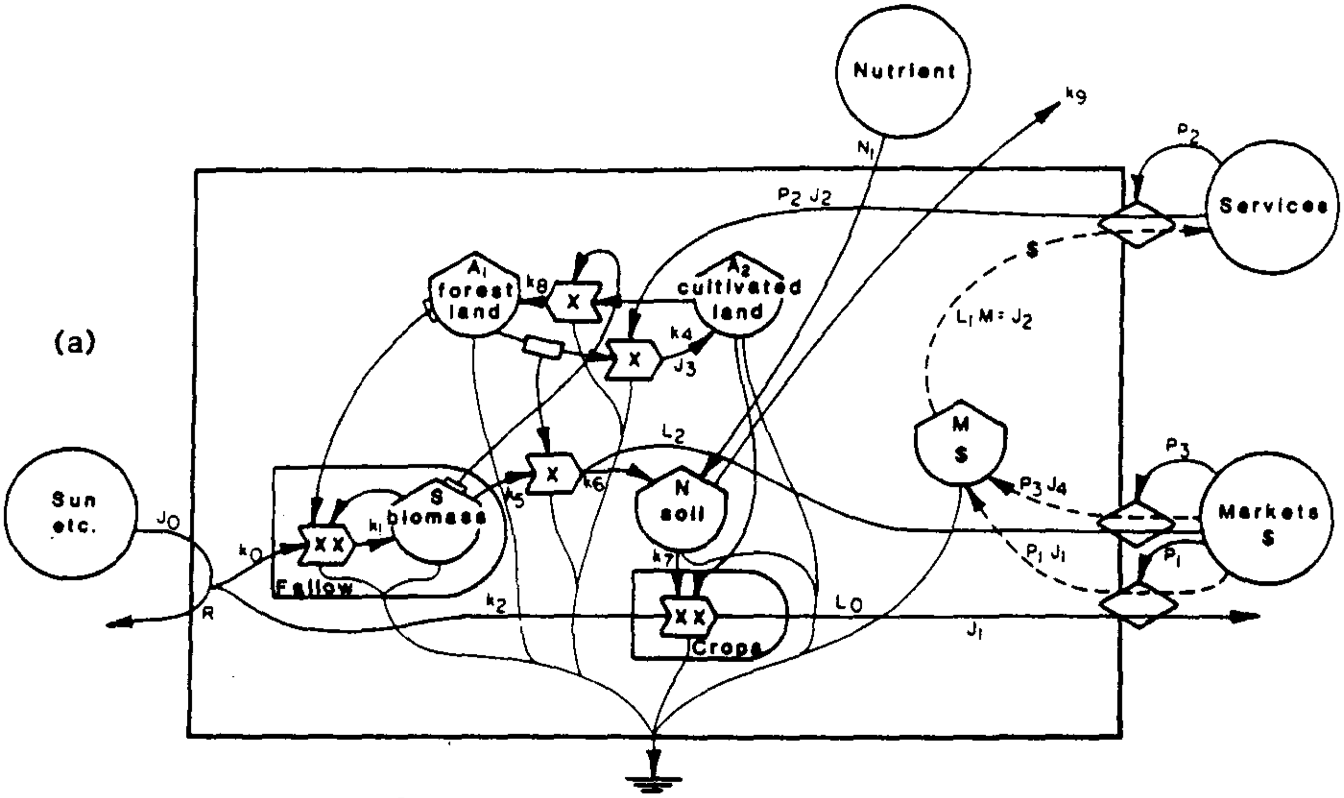


Figure 7. A generalized model of human settlement, rotating lands between economic uses and restoration plots. (a) Energy diagram; (b) simulation that starts with only a small area of human use (A2) and a large area initially in mature wild forest (A1).

Figure 7 (continued)

```
5  REM  RQTATION=NOV.12,1984
10  HGR : HCOLOR= 3
20  HPLOT 0,0 TO 0,159 TO 278,159 TO 278,0 TO 0,0
25  HPLOT 0,60 TO 279,60
28 I = 3
30 A0 = 1.7
40 T0 = 10
45 S0 = 2
50 Q0 = 2
55 B0 = 2
60 I0 = 100
65 A = 100
70 A1 = 100
75 B = 100
80 S = 2
90 Q = 10
100 K0 = .18
105 K1 = 8E - 5
110 K2 = 3.2E - 3
115 K3 = 4E - 3
120 K4 = 2E - 3
125 K5 = 2E - 4
130 K6 = 2E - 4
135 K7 = 4E - 3
140 K8 = 3.2E - 7
145 K9 = 2E - 3
150 L1 = 2E - 4
155 L2 = 2E - 4
160 L3 = 2E - 7
165 L4 = 1E - 3
170 L5 = 1E - 3
175 L6 = 4E - 5
200  HCOLOR= 1: REM   GREEN
215  HPLOT T / T0,160 - B / B0
220  HCOLOR= 2: REM   BLUE
230  HPLOT T / T0,60 - A2 / A0
235  HPLOT T / T0,60 - A1 / A0
240  HCOLOR= 3: REM  WHITE
250  HPLOT T / T0,160 - S / S0
260  HCOLOR= 5: REM  RED
270  HPLOT T / T0,160 - Q / Q0
300 A2 = A - A1
310 R = I0 / (1 + K0 * R * A1 + K1 * S * Q * A2)
320 DB = K2 * R * A1 - K3 * B - K4 * B - K5 * B * A1 - K9 * B
330 DS = K6 * B * A1 - K7 * S - K8 * S * R * A2 * Q
340 DA = L1 * A2 * B - L2 * Q * A1
350 DQ = L3 * Q * A2 * S * R + L4 * S - L5 * Q - L6 * A1 * Q
360 A1 = A1 + DA * I
370 B = B + DB * I
380 S = S + DS * I
385 Q = Q + DQ * I
390 T = T + I
500  IF T / T0 < 279 GOTO 200
```



$$R = \frac{J_o}{1+k_oA_1S+k_2NA_2} \qquad A_1 + A_2 = A$$

$$\dot{S} = k_1RA_1S-k_3S-k_5SJ_3 \qquad \text{Yield: } J_1 = L_oRNA_2$$

$$\dot{M} = P_1J_1+P_3J_4-J_2 \qquad J_3 = k_4P_2J_2A_1$$

$$\dot{A}_2 = J_3-k_8A_2S$$

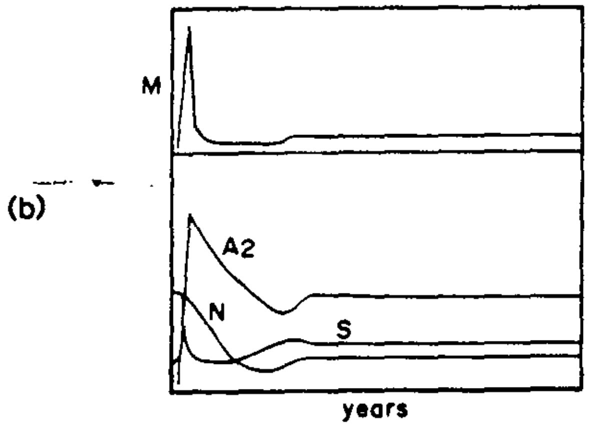
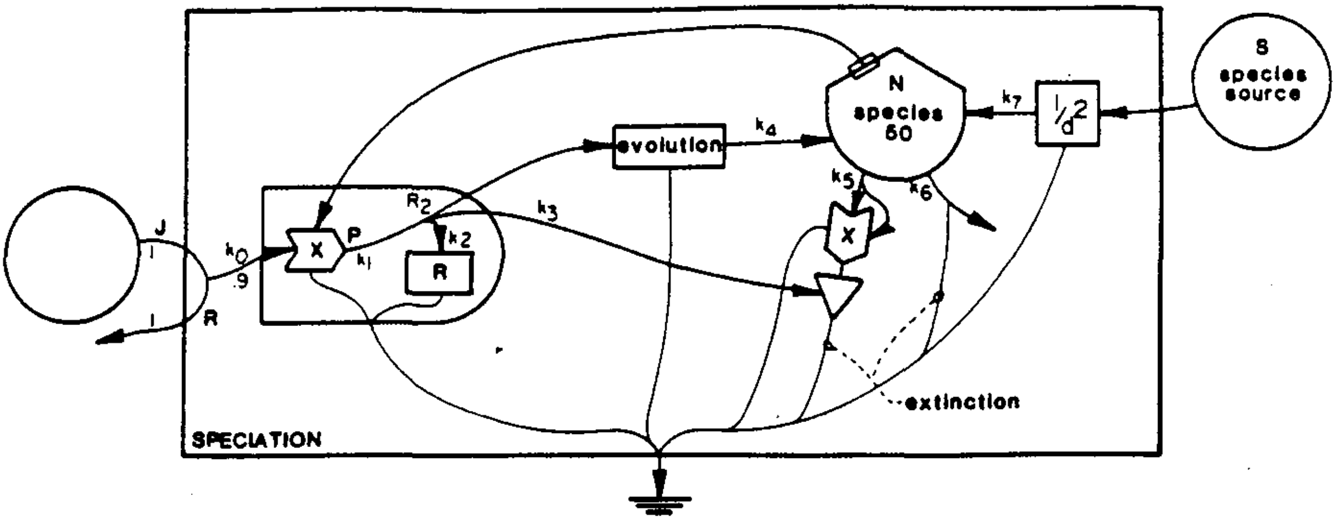


Figure 8. A model of rotation of land between diverse ecosystem restoration and the economic yields from crops or forest plantation. (a) Model; (b) simulation.

Figure 8 (continued)

```
4  REM  SHIFT AG--NOV.1984
5  HGR : HCOLOR= 3
6  HPLOT 0,0 TO 0,159 TO 279,159 TO 279,0 TO 0,0
8  HPLOT 0,60 TO 279,60
10 J0 = 1
15 R = .18
20 S = 200
25 M = 10
30 N = 2.5
40 A = 1
50 A2 = .05
60 N1 = .01
70 J1 = 1
80 J2 = 651
90 J3 = .019
100 J4 = .5
110 P1 = 121
120 P2 = 1.5
130 P3 = 500
140 K0 = 6E - 2
150 K1 = .416
160 K2 = 1.8
170 K3 = .019
180 K4 = 5.1E - 5
190 K5 = .99
200 K6 = 4.4E - 2
210 K7 = .556
220 K8 = 4.75E - 4
230 K9 = .8E - 4
240 L0 = 4.4
250 L1 = .65
260 L2 = .329
265 I = 1
270 T0 = 1
280 S0 = 5
290 A0 = .01
300 N0 = .2
310 M0 = 100
315 A1 = A - A2
320  HCOLOR= 1: REM  S IS GREEN
330  HPLOT T / T0,160 - S / S0
340  HCOLOR= 5: REM  LAND IS RED
350  HPLOT T / T0,160 - A2 / A0
360  HCOLOR= 3: REM  N IS WHITE
370  HPLOT T / T0,160 - N / N0
380  HCOLOR= 2: REM  MONEY IS VIOLET
385  IF M / M0 > 60 GOTO 410
390  HPLOT T / T0,60 - M / M0
400 R = I / (1 + K0 * S * A1 + K2 * N * A2)
410 R = J0 / (1 + K0 * S * A1 + K2 * N * A2)
425 A1 = A - A2
430 J1 = L0 * R * N * A2
435 J2 = L1 * M
440 J3 = K4 * P2 * J2 * A1
445 J4 = L2 * S * J3
450 R = I / (1 + K0 * S * A1 + K2 * N * A2)
460 DS = K1 * S * A1 * R - K3 * S - K5 * S * J3
470 DN = K6 * J3 * S + N1 - K9 * N - K7 * N * R * A2
480 DA = J3 - K8 * A2 * S
490 DM = P1 * J1 + P3 * J4 - J2
500 S = S + DS * I
510 N = N + DN * I
520 A2 = A2 + DA * I
530 M = M + DM * I
540 T = T + I
550  IF T / T0 < 279 GOTO 320
```

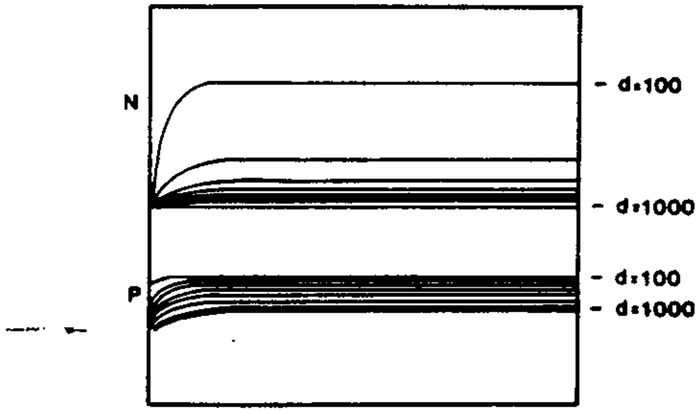


(a)

$$R = J - k_o RN \qquad R_2 = k_1 RN - k_2 R_2 - k_3 N^2$$

$$R = \frac{J}{(1 + k_o N)} \qquad R_2 = \frac{(k_1 RN - k_3 N^2)}{(1 + k_2)}$$

$$N = k_4 R_2 + k_7 \frac{S}{d^2} - k_5 N^2 - k_6 N \qquad \text{Production:} \quad P = k_1 RN$$



(b)

Figure 9. A model of long-term tropical forest production and diversity limited by species availability and accompanied by species evolution. (a) Energy diagram; (b) simulation of diversity (N) and productivity (P) for distances from species sources ranging from 100 to 1000 km.

Figure 9 (continued)

```
1  REM  SPECIATION--NOV.12,1984
5  HGR : HCOLOR= 3
6  HPLOT 0,0 TO 0,159 TO 279,159 TO 279,0 TO 0,0
7  HPLOT 0,80 TO 279,80
8  HCOLOR= 5
10  REM  COEFFICIENTS
12 I = 5
14 TO = 4
16 PO = 200
18 NO = 1
20 N = 1
25 J = 1
27 S = 1
30 D = 100
35 K0 = 1.26666
40 K1 = 13333.33
45 K2 = 2.5
50 K3 = 17
60 K4 = 5E - 6
65 K5 = 2E - 4
70 K6 = .01
75 K7 = 1E4
200  REM  PLOTTING
220  HCOLOR= 1
230  HPLOT T / TO,160 - P / PO
240  HCOLOR= 2
250  HPLOT T / TO,80 - N / NO
300  REM  EQUATIONS
350 R = J / (1 + K0 * N)
360 R2 = (K1 * R * N - K3 * N * N) / (1 + K2)
362  IF R2 < 0 THEN R2 = 0
365 P = K1 * R * N
370 DN = K4 * R2 - K5 * N * N - K6 * N + K7 * S / D / D
380 N = N + DN * I
390 T = T + I
400  IF T / TO < 279 GOTO 200
410 D = D + 100
425 T = 0:N = 1
430  IF D < 1000 GOTO 200
```

over a larger enough area and time to generate choices from which selection accumulates enough microevolutionary genetic differences for species separation.

In the simulation for an isolated island (Figure 9b) where diversity is limited by dispersal, new species are provided by evolution, and thus productivity is limited by evolution. It may be postulated that productivity is developed more rapidly than on islands by better dispersal in most places in the world. However, if the gene pools are lost or are available only at great distances, productivity may become limited the way islands may be, and time required for rotations to rebuild resources for another round of yield increased.

Tropical Forest Diversity for Maximum Economic Vitality

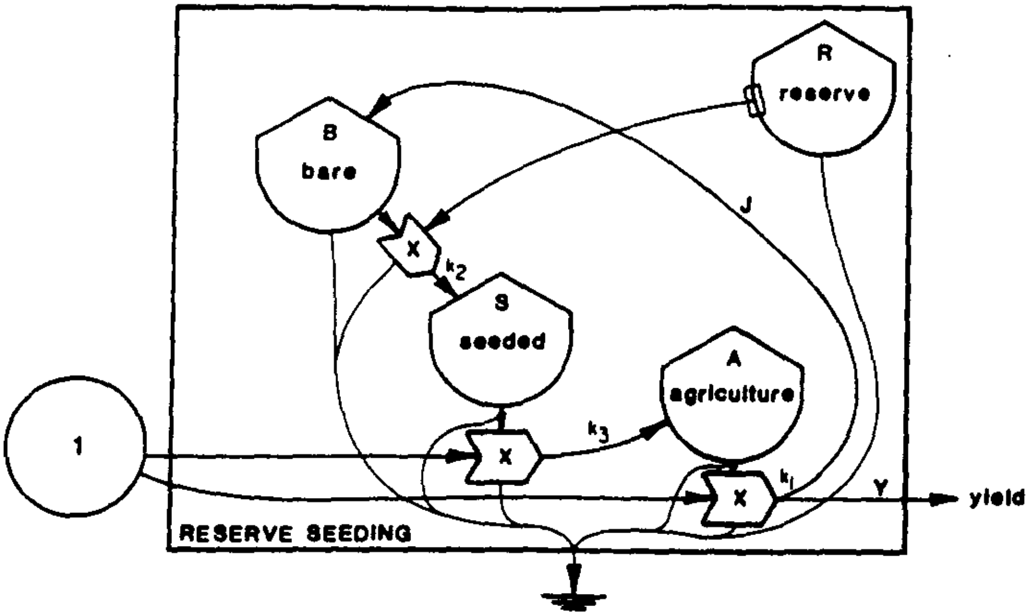
Although the research efforts of those concerned with tropical forest species and those doing tropical forest production studies have often been separate, even competing for funds and attention to their concepts, models like those in Figure 4 and 9 show the unity and symbiosis of the metabolic processes and diversity when considered in aggregated holistic overview. Whereas most arguments for conservation of tropical forest species are made in terms of values and potential values of organisms, aesthetics, or soils, establishing a causal linkage between diversity pools and the long term economic vitality of human settlements may enlist larger economic forces to back the cause of human balance within the biosphere. Perhaps, a simple rotation plan given next can be used to illustrate ways of fitting human economy to tropical forest for maximum power and survival of the combined system.

Proportions of Land Use Areas for Yield, Seed-source, and Restoration

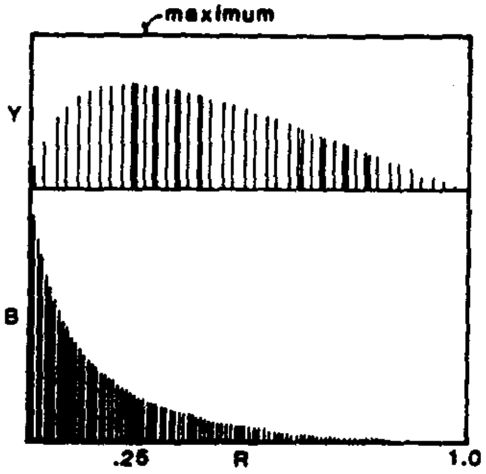
In considering rotation, reseeding, and gene pool preservation, proportions of land in diversity reserves and distances become important in recommending plans for maximum economic vitality.

Given in Figure 10a is a model for relating seed dispersal and seed source areas to the long range level of economic production in a land rotation pattern. Land in agricultural or plantation use (L2) is rotated back to fallow state (L1) for restoration of soils, etc., after 30 years of farming. Natural growths are allowed to develop for 30 years plus whatever delay is required for natural high diversity reseeding. Reseeded area each year is that area that constitutes a peripheral zone around permanent diversity plots saved for this purpose. The more of the diversity plots, the faster the reseeding.

Net economic benefit for saving the diversity plots is the hectare-years of land returned to economic use minus the hectare years of



(a)



$R + B + S + A = 1$

$F + A/S$

$\dot{B} = k_1A - k_2BR$

$\dot{S} = k_2BR - k_3S$

$\dot{A} = k_3S - k_1A$

Steady state: $\dot{B} = \dot{S} = \dot{A} = 0$

$$A = \frac{k_2R(1-R)}{k_1 + (k_2 + \frac{k_1k_2}{k_3})R}$$

$Y = k_4A$

(b)

Figure 10. Economic yield (Y) and bare land (B) in steady state as a function of area of land plots used for reseeding restoration during rotation (R). (a) Model of the rotation of land; (b) simulation of the model after coefficients were calibrated with bare area, .1; reserve area, .1; seeded area, .4; and agricultural area, .4 and cycle time (J) 60 years. Curves are for successively increased coefficient of forest clearing (k_3 = .001 to .3).

Figure 10 (continued)

```
4   REM  RESERVE SEEDING
5   HGR : HCOLOR= 3
6   HPLOT 0,0 TO 0,159 TO 279,159 TO 279,0 TO 0,0
7   HPLOT 0,60 TO 279,60
12  I = .01
14  TO = 1
20  T = 60: REM   TIME FOR CYCLE
21   REM  PUT IN VALUES OF R,B,S,A,AND J SO THAT COEFFICIENTS ARE CALCULATED

25 J = 1 / T
30 A = .4
32 S = .4
37 R = .1
40 B = 1 - S - R - A
45 Y = 1E7
60 K1 = J / A
65 K2 = J / (R * B)
70 K3 = J / S
75 K4 = Y / A
85 R0 = 1 / 279
90 A0 = .01
92 B0 = .01
94 F0 = .2
95 Y0 = 4E5
97  REM  BELOW THIS A,B,&F ARE PLOTTED AS A FUNCTION OF R
100 R = .01
102 K3 = .001
107 A = (K2 * R * (1 - R)) / (K1 + R * (K2 + K1 * K2 / K3))
109 B = 1 - A - R - (K1 / K3) * A
110 F = A / ((K1 / K3) * A)
120 Y = K4 * A
220  HCOLOR= 1
240  HCOLOR= 2
250  HPLOT R / R0,60 - Y / Y0
260  HCOLOR= 3
270  HPLOT R / R0,160 - B / B0
300 R = R + I
400  IF R / R0 < 279 GOTO 107
405  PRINT "RATIO OF A/S ="F
410 K3 = K3 + .03
420 R = .01
500  IF F < 6 GOTO 107
```

land held out from the economic rotation cycle. In Figure 10b simplified equations are given for the geometry of increased seeded area with increased number of plots. Equations were normalized - expressed in percentages of the land area. An Apple computer program was run that graphs the economic benefits as a function of increased number of reserve plots. As the area of reserve plots is increased, the area of arrested succession due to inadequate reseeding decreases until there are no areas without prompt seeding. Adding reserves beyond this point pulls more economic yield out of production than it facilitates by accelerated restoration. One computer run is given in Figure 10c. Diversity plots were taken as 100 m. As the simulation suggests, there is an optimum area of seed source reservation that maximizes economic vitality.

This exercise may help us visualize the principles involved in maximizing an economy based on a good utilization of lands and an interface of human development and environment, but the optimum area found in this particular graph may not be anywhere near the correct one since the various coefficients used were arbitrarily assumed. The calculation only considers one size realm of biota. The actual situation has some components with much wider ranges of dispersal and some with less. In this exercise one size of reserve plot was used, whereas larger plots sustain higher diversities. Also, let us hasten to caution that this model considers only one of the types of contributions of the forest to the regional economy. Others are the climatic regulation of temperature and rainfall and the role in storing species with valuable biochemical systems ultimately useful in pharmaceuticals, nutrition, industry, etc.

Symbiosis of Human Economy and Tropical Forest Perpetuity

In the preceding paragraphs principal mechanisms for sustaining the health of tropical forests and their diversity were examined including the long range economic use. Considered altogether, a rotation system, which retains three land uses may maximize the combined economy so that forest and economic components survive. In the particular computer run in Figures 10a and 10b, retention of about 25% in permanent reseeding gene pool areas maximized the economy. The relative areas of the fallow, yield, and reserve areas will depend on many coefficients not adequately evaluated yet, but the models calibrated with plausible values suggest that there will be an optimum reserve area for maximum economic benefit.

Once a concept is clarified by models, we are often surprised to find that its predictions are already a fact. The models help us recognize phenomena which were previously ignored amidst the complexity and noise of the real world. In the Atlantic rainforest region of Bahia, Brazil around Itabuna, the landscape already has the pattern of rotation with at least a third of the region in second growth forest of moderate diversity, perhaps fifty years old, which is now another cutting and planting rotation. There are some high diversity plots, but perhaps not enough to maximize the regional economic vitality of the region. In much of the Amazon, too, previous shifting agriculture has left a mosaic of patches of many ages that already implements the suggestions of the mode. With a more conscious recognition of the model in Bahia and in the Amazon, more economic efficiency can be achieved and with it more of the ideals of biological conservation as well.

SIMULATING LAND ROTATION IN PLANTATIONS AT JARI, BRAZIL

R. A. Christianson

Model of Forest/Plantation System

A computer model of shifting land use is simulated to analyze questions of long-term utilization of tropical moist forests for cropping systems. A strategy of alternating periods of active use with periods of fallow, nonuse is considered. Data were taken from the pulpwood plantations at Jari, Brazil.

Model Description

The Land Rotation model is given in Figures 1 & 2. Included in the system boundaries are natural forest growth and the plantation operations. Inputs include: 1) Solar inputs to the native forests and plantations; 2) rain and its nutrient content; 3) fuels, goods, and human services to perform the labor necessary to harvest native timber, manage plantations, harvest plantation wood, and transport the wood to the point of next use (in this case the nearby pulpmill); and 4) money from outside the boundaries to pay for above goods and services. The inputs include investment of money into the working capital of the forestry operation by the owners of the project and money in return for both the harvested wood from the native forest and the pulpwood from the plantation.

Outputs include: 1) Output of pulpwood from the plantations, 2) harvested native forest timber; and 3) money to pay for the inputs of fuels, good, and services.

State variables (storages) include phytomass (above-ground biomass plus roots) within the native forest; area of native forest; area of plantation forest; nutrients within the plantation system (calibrated as available phosphorus); dollars in available working capital within the system (this represents approximately enough funds to cover nine month's expenses); and (I) dollars in an account storage into which profits from the project are stored. This storage is an indicator of the 'health' of the economic part of the system.

Simulation Results with Fertilizer

The behavior of the land rotation model in Figure 1 with initial calibration values is given in Figure 3 where the effect of five levels of development intensity are shown. Each graph is the result of differing land use intensities, or rates of conversion from native land to plantation. The various intensities are as follows:

a) intensity = 2,000 ha/yr
b) intensity = 9,000 ha/yr
c) intensity = 16,000 ha/yr
d) intensity = 23,000 ha/yr

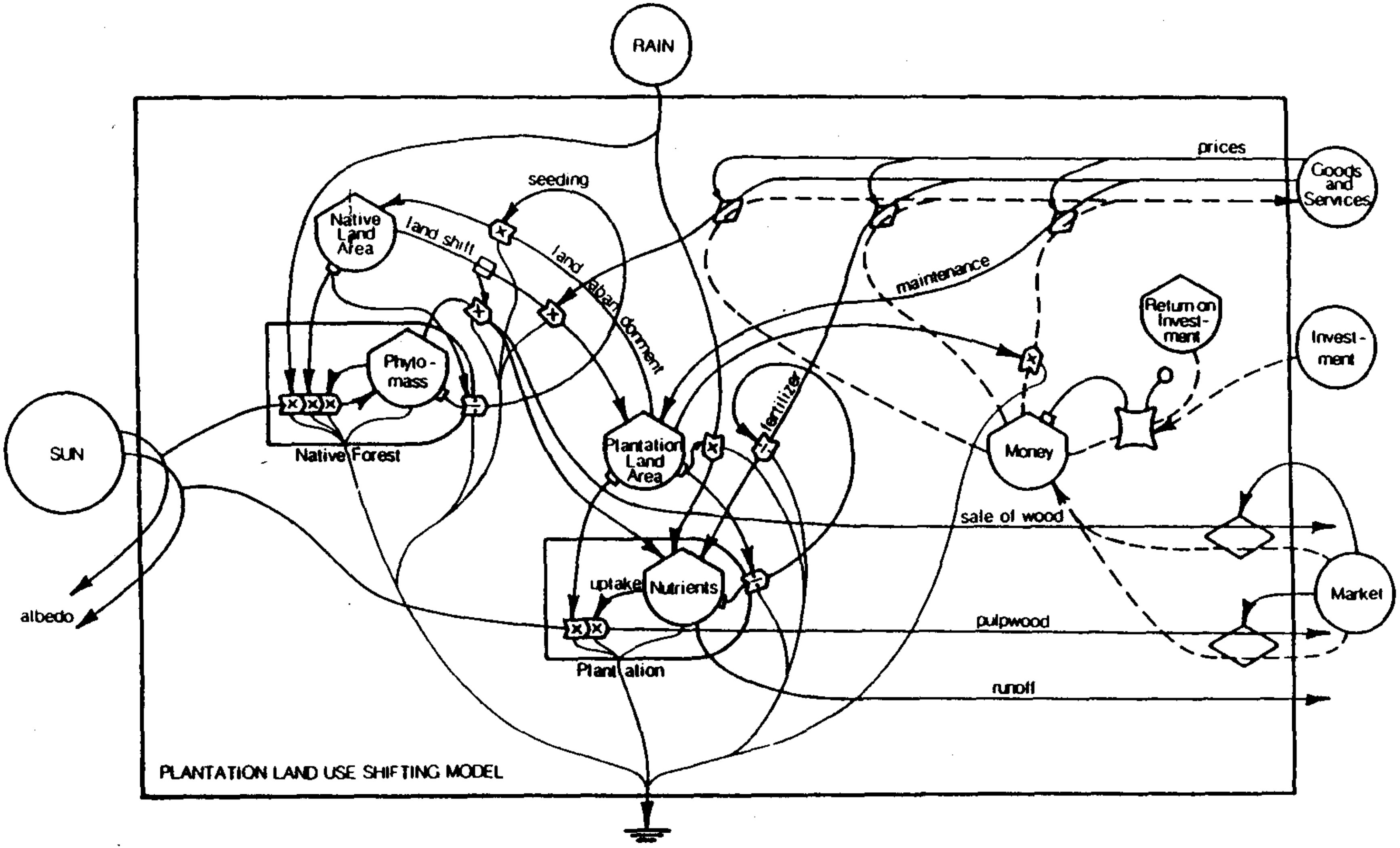


Figure 1. Land rotation model, showing native forest, plantation, and land areas. Imported goods and services control the rates at which lands are shifted from native land to plantation land and maintenance on plantation forests.

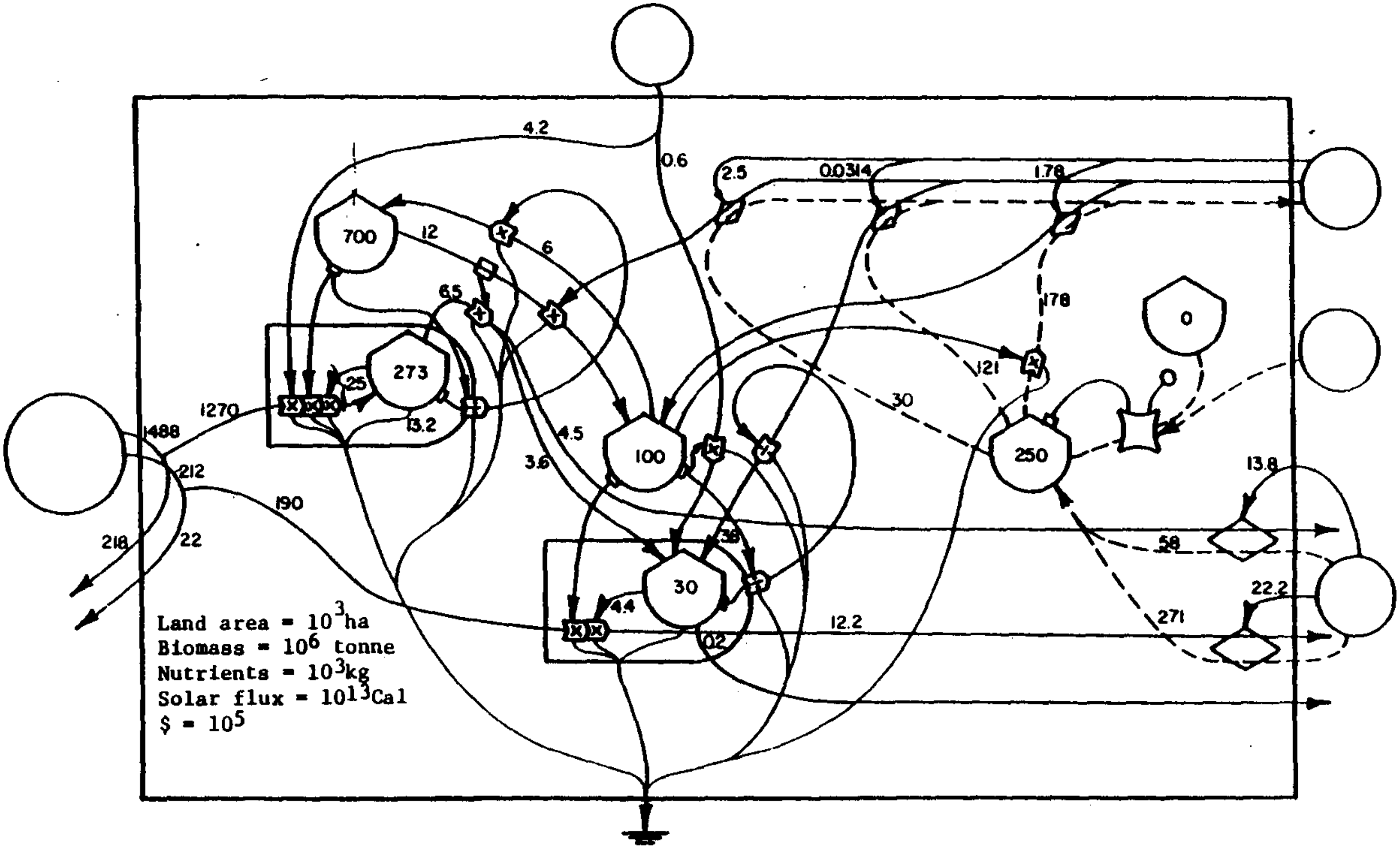
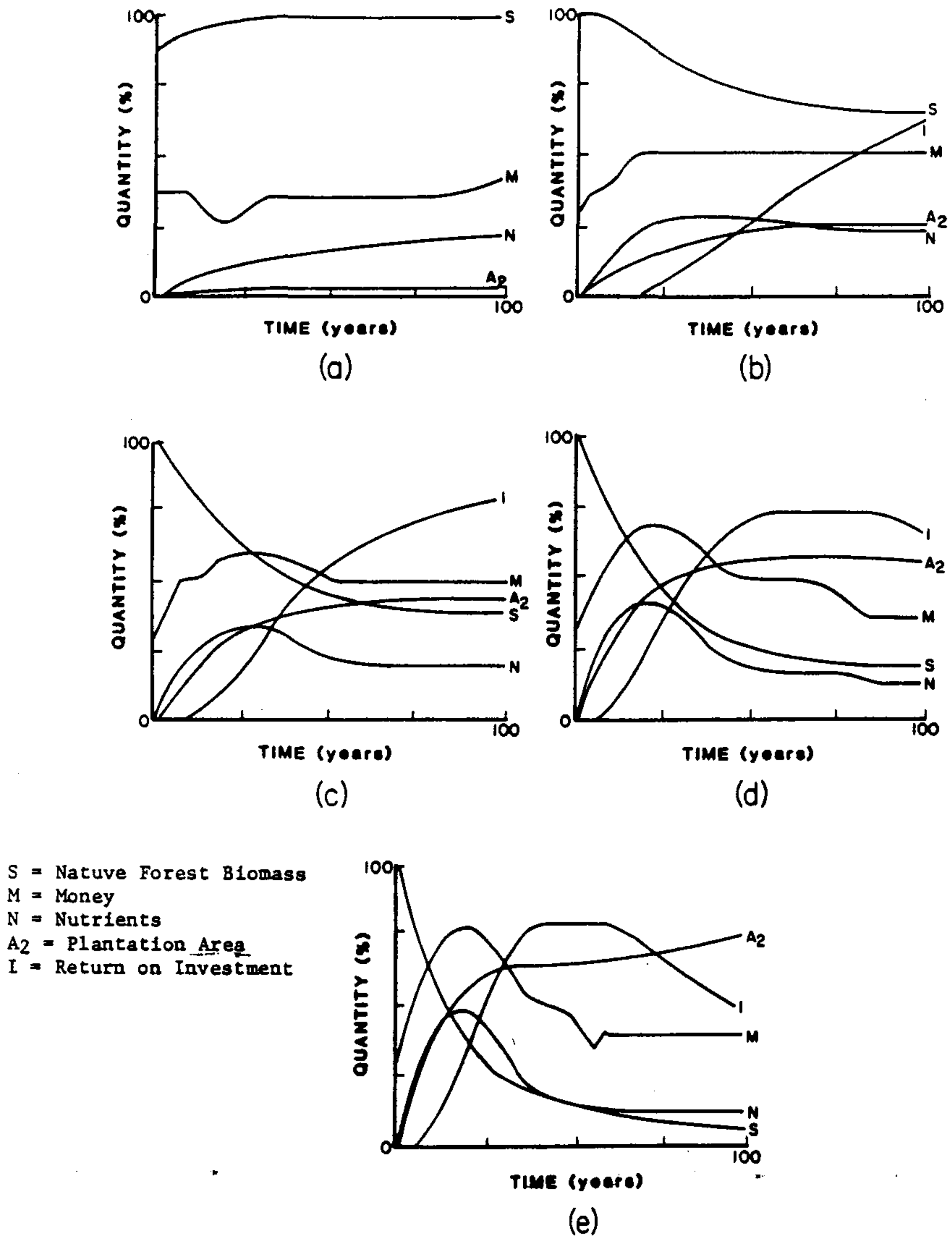


Figure 2. Model in Figure 1 with pathways and storages evaluation. All flows are on a yearly basis.



S = Natuve Forest Biomass
M = Money
N = Nutrients
A_2 = Plantation Area
I = Return on Investment

Figure 3. Simulation results of the model in Figure 1 under five different development intensities. Maximum values for parameters are as follows: S = 5E8 tonnes; M = 70E6\$; N = 24E6kg; A_2 = 800 E3Ha; I = 1E9\$.

e) intensity = 30,000 ha/yr

In these simulation runs, fertilizers are bought from outside markets to maintain plantation nutrients. At very low levels of development intensity (Figure 3a). Return on investment is practically nonexistent, indicating that such low levels of development are outside the monied economy. In 3b, levels of development are such that by about the 20th year a return on investment is realized. Native forest is decreased to about 70% of original area and nutrients remain fairly stable. Simulation results suggest this level of development (about 30%) is the most stable. Higher levels begin to show increasing instability, and while allowing large returns on investment do not seem to have long term sustainability.

Simulation Without Fertilizer Inputs

Once calibrated, the model was simulated with no fertilizer available from outside sources. In this manner, the model resembles the traditional slash and burn pattern of land use in which lands are rotated from cultivated use to fallow allowing nutrients to replenish. Simulation results are given in Figure 4.

The optium level of development intensity was .375% of land area per year converted to plantation uses. This level maintains a sustainable system with a steady-state plantation area of 7.75% of total area. Turnover time of plantation of 15.5 years, and fallow time of approximately 13 years.

Discussion

It appears that, with the availability of fertilizers at current relative prices, pulpwood can be supplied by plantations at levels adequate to supply present demands for the pulpmill at Jari. Development of plantations beyond that areal extent would result in declining marginal returns on investment dollars. Without fertilizers, model simulations suggest that adequate supplies of pulpwood could not be produced without long-term degradation of the nutrient status of soils.

Sustainable Proportion of Land in Plantation Use

The optional scenario in the forest/plantation model was determined as the peak rate of return at the fiftieth year of development, 7E3 ha/yr. With fertilizer, the optimal ratio of developed land to native land was 0.23. This corresponds to 18.75% of the total land area in plantations at one time. With this level of development and with fertilizer available, the average production would be 12.2 E5 tonne pulpwood per year. Internal rate of dollar return on dollar investment would be about 5% above inflation at 50 years. Interest payments for investments into the plantation operation were not explicitly accounted. According to model behavior, development beyond a total of 1.5E5 ha at Jari would result in declining marginal returns.

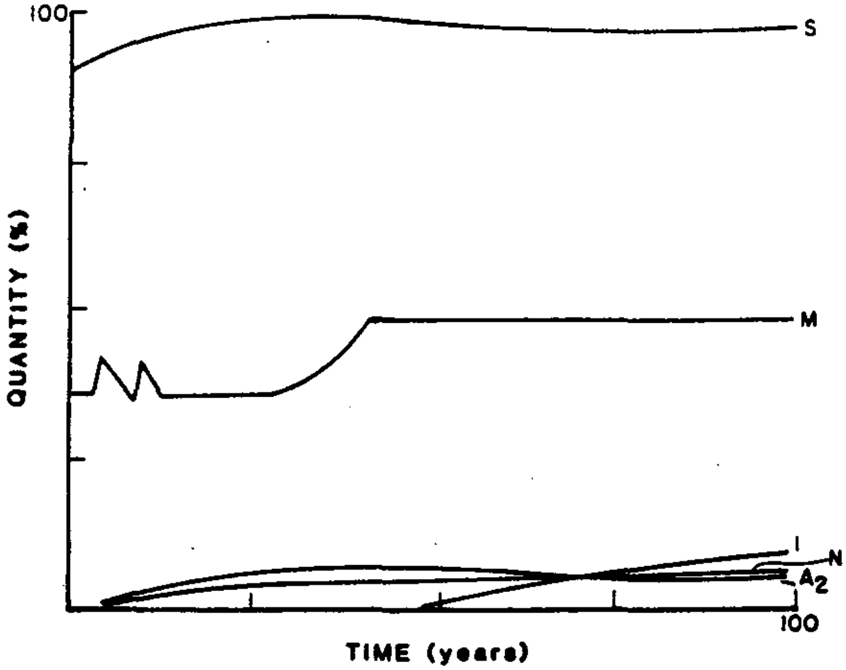


Figure 4. Simulation run of land rotation model without fertilizer and with development intensity at an optimal level of 3 E3 ha/yr. Native phytomass (S), money (M), plantation nutrients (N), plantation area (A_2) and return on investment (I).

Carrying Capacity for Shifting Agriculture

Structurally, traditional shifting agricultural systems are not unlike the forest/plantation model without fertilizers. Native forest land is cleared and cultivated for one or two harvests, after which land is abandoned to ecosystem successional forest regeneration. The optimal ratio of develped land to total land in the model without fertilizers was determined to be 7.75. By multiplying the maximum sustainable population density in slash and burn agriculture, 10 individuals per km^2 (Goodland 1980) times the ratio of land in active cultivation per individual for the same sort of agricultural systems, 0.71 hectares per individual (Carter and Snedaker 1969), the ratio of active land use to total land is 7.1%. The application suggested is that structually similar systems may yield similar patterns of organization, such as optimal land use shifting in this case.

ENERGY ANALYSIS OF CACAO

Howard T. Odum

One of the main types of agroecosystems successful in tropical forest regions uses an understory tree crop to yield high value food or medicinal products, while retaining some of the structure and processes of the diverse forest. These are Partial Forest Agroecosystems. Overstory trees maintain transpiration and stable mineral cycles, moderate light regimes and stable microclimate, root mats and stable soil conditions, and some diversity protection from epidemics. The producing tree is usually one that occurs in small numbers within the natural, high diversity forest. It can be grown as an understory tree with relatively little effort and without many costly inputs. This type of management channels environmental energies into an economic product while retaining part of the natural forest work. This methodology is potentially suitable for the hundreds of unique rainforest products yet to be developed for food, pharmaceuticals, and other uses. A more intensive version of these understory tree crops can be managed for higher yields by removing the overstory trees, but much greater efforts and inputs costs are required for this option.

One of the most important of these partial forest agroecosystems in the Amazon is cacao, a tree whose products ultimately become chocolate. Through the initiative of Dr. Paulo T. Alvim, a working visit was arranged in 1984 by the Cacao research organization, CEPEC (CENTRO DE PEQUISAS DO CACAU) at Itabuna, Bahia, Brazil, during which an overview model, energy analysis, and preliminary simulation of the Cacao agroecosystem were developed. Although the analyses were based on CEPEC data on cacao practices in the Atlantic rain forest belt of Brazil, they may be somewhat representative of the cacao in the Amazon also.

Energy Systems Diagrams of the Cacao Agroecosystem

A systems diagram of the cacao agroecosystem is given in Figure 1 using energy language symbols (Odum,1971,1983). Sources of outside inputs are circles arranged from left to right in order of their energy transformation ratio from sunlight (ETR). The diagram shows the soil and climate factors interacting with the trees on the left to generate the fruits. From left to right the fruits are processed separating husks, juice, and seeds each of which is used differently, the fermented and dried seed being exported to chocolate manufacturers around the world.

A more aggregated diagram of the main inputs and processes is given in Figure 2. By evaluating the embodied energy of the environmental and economic inputs to the process, the relative importance of each input to the final product can be compared.

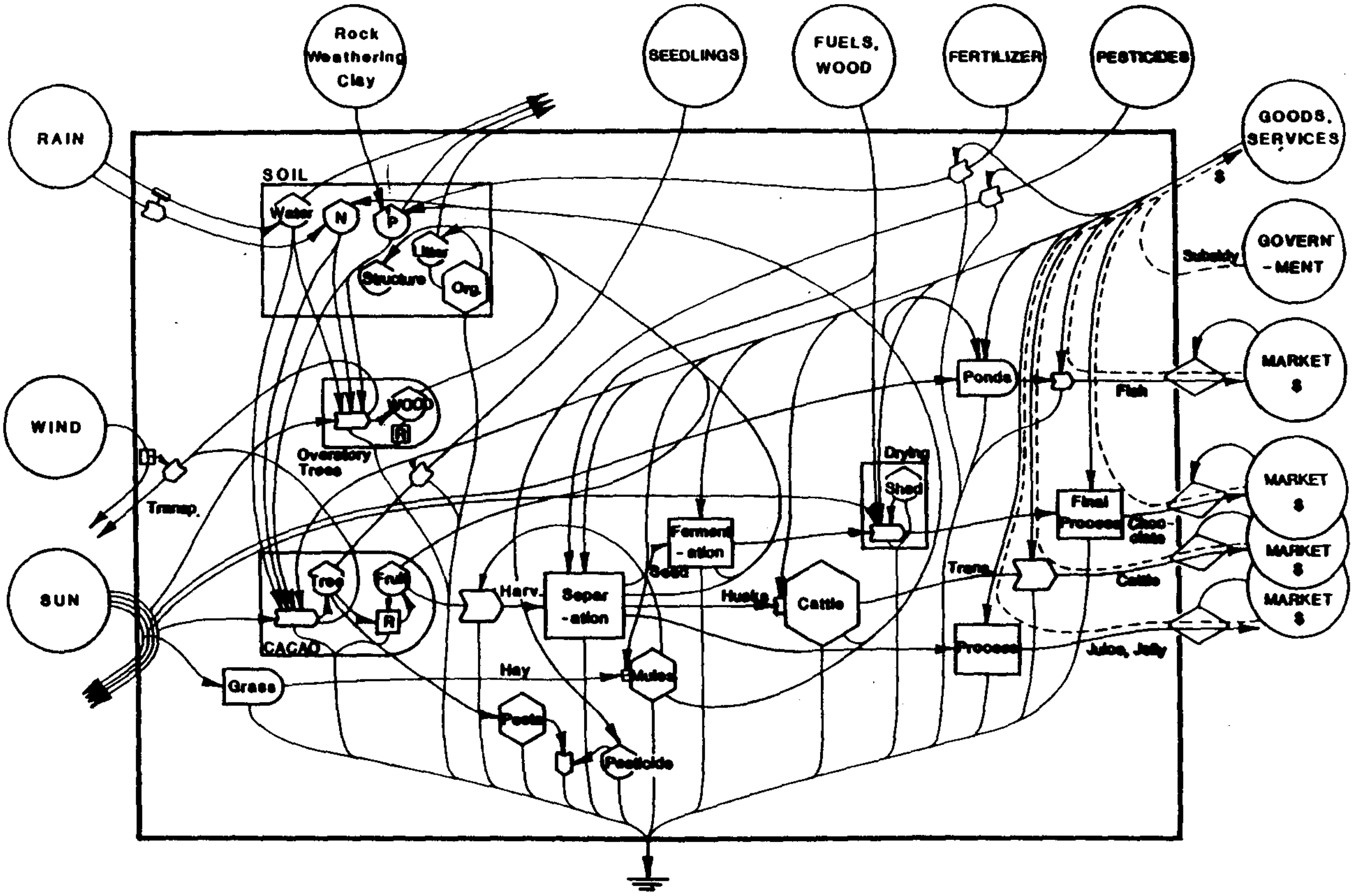


Figure 1. Complex diagram of the agroecosystem of cacao in Brazil.

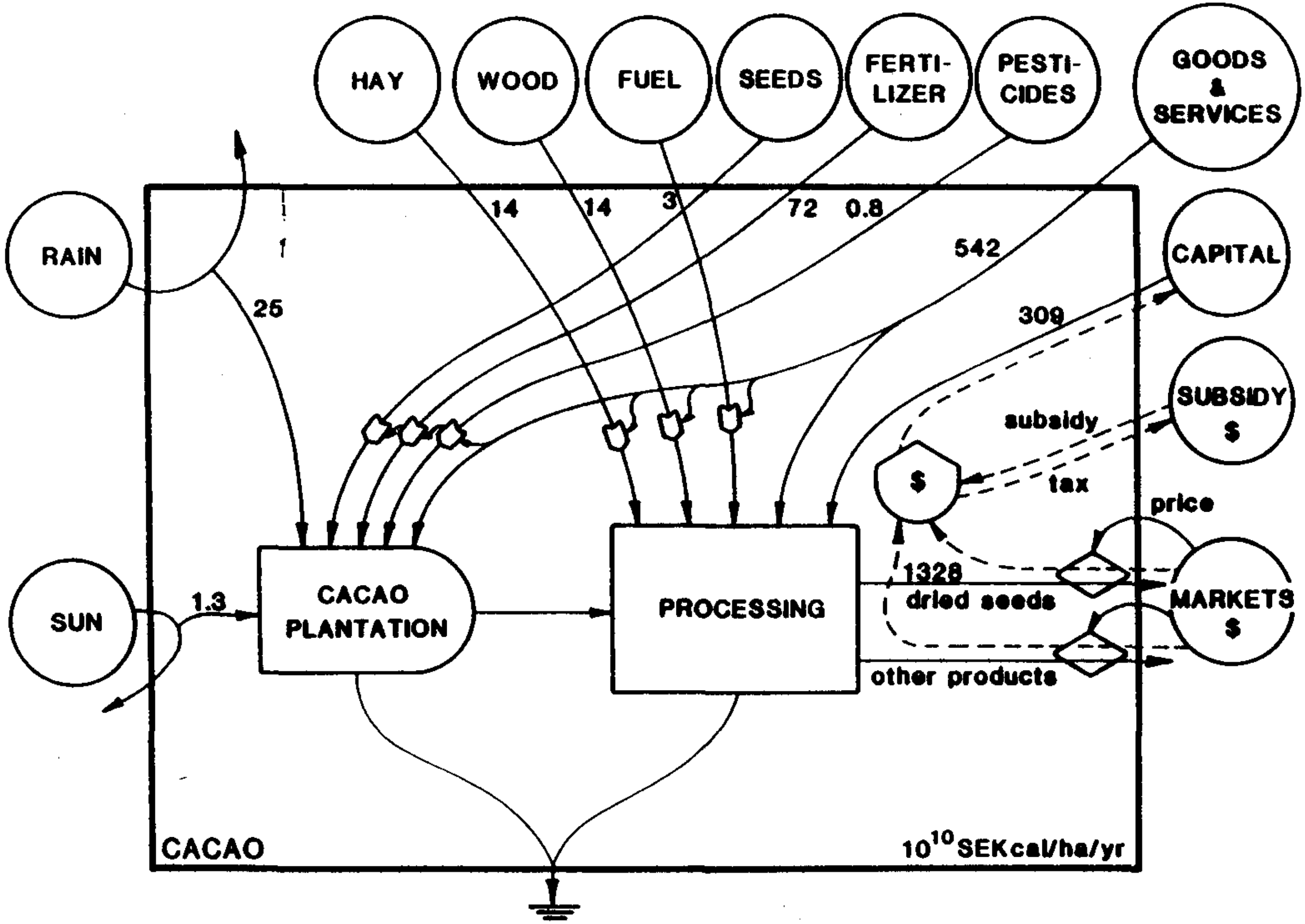


Figure 2. Aggregated diagram of the cacao agroecosystem with flows of embodied solar energy per hectare per year written on the pathways.

Energy Analysis of Cacao Production and Processing

Table 1 contains the energy analysis of cacao production as diagrammed in Figure 2. In the table each input is listed. In the first numerical column each energy flow is calculated as shown in the footnotes. The second column has energy transformation ratios expressing the solar joules required to generate a joule of that type of energy. The numbers in the third column were obtained by multiplying those in the first and second columns. These are the embodied solar energy in the inputs, and these numbers are written in the pathways in Figure 2.

The embodied energy in the work done by the environment as part of the production of Cacao is substantial, especially the transpiration contribution to the plant function. However, the embodied energy of the human efforts in the many steps in the processing of the fruits is even larger. The energy transformation ratio of processsed cacao (3.3 E6 solar Calories/Calorie) is high for a food product representing the many energy inputs that were shown in Figures 1 and 2. Products of high embodied energy per unit weight may be appropriate for trade requiring long distance transportation.

The net energy yield ratio of cacao seed is 1.4, which is not large since cacao is not a fuel.

The investment ratio for the dried seed export (17) indicates a high ratio of economic inputs relative to the environmental inputs, most of which comes after the gathering of the fruits. In the processing there is a high ratio of purchased inputs involving a large flow of money. In other words, the processing constitutes an intensive economic activity. From the point of the view of the environment, the loading by economic activity is relatively high. In the Amazon the ratio of free resource inputs to most economic activity is still so large, that the average ratio of embodied energy purchased to embodied energy free from nature tends to be small. For processes in which the investment ratio is higher than average, the question may be raised whether this much investment would yield more in some other industry.

There is a slight embodied energy advantage for export of dried cacao seeds. Especially if sale of cacao generates foreign exchange that is used to buy fuel ~~or~~ other raw products with high embodied energy ratio to dollar cost, the trade constitutes a definite economic stimulus to the home economy. There is a positive balance of trade as expressed in units of embodied energy.

Most of the further processing to chocolate and cocoa retail products takes place abroad in Austria, Switzerland, U.S.A., etc. The dried seed exports have a very large embodied energy that goes to the advantage of the purchasers abroad. Questions are often raised as to why more of the finished processing is not done within Brazil. The reason may be because the developed countries obtain a higher net energy yield in buying fuels on world markets than Brazil. Thus, they can do final processing that is based directly and indirectly on fossil fuels more competitively. See discussion on page 103.

Table 1. Energy flows in cacao, per hectare per year.

Footnote	Item	Quantity Various Units	Actual Energy kcal	Energy Transformation Ratio SE kcal/kcal	Embodied Energy SE kcal/g E10
1	Solar insolation	--	1.258 E10	1	1.26*
2	Transpired rain (rain and wind)	1.35 E10 g	1.61 E7	1.54 E4	24.8
3	Fertilizer				
	Lime (CaJgCO$_3$)	6.75 E5 g	--	2.5 E5 SE kcal/g	16.9
	Nitrogen in urea	5.72 E4 g	--	1.0 E6 SE kcal/g N	5.7
	Potassium	3 E4 g	--	2.3 E5 SE kcal/g	0.7
	Phosphorus (super P)	1 E5 g	--	4.8 E6 SE kcal/g	48.
4	Clay from weathering	3.1 E5 g	--	4.1 E5 SE kcal/g	12.7*
5	Fuels				
	Wood	1024 kg	4.1 E6	3.5 E4	14.4
	Motor fuel	49.8 1	4.5 E5	6.6 E4	3.0
	Transport - mules, hay	--	4.5 E6	3.0 E4	13.5
6	Pesticide (not counting services embodied)				
	Fungicide, 4% $Cu(OH)_2$	0.77 kg	--	1 E7 SE kcal/g	0.77
	Insecticide, 1.5% BHC	0.45 kg	4.05 E3	1 E5	0.04
7	Goods and Services including materials				
	Estimated from costs plus tax			1.65 E9 SE kcal/1980 $	542
	Subsidies of interest at 70% of inflation			"	300
	Machinery	150 g		1.48 E6 SE kcal/g	0.02
8	Seedlings planted	30	--	1.65 E9 SE kcal/1980 $	51
9	Capital costs - driers	1861 Cr 1980		"	307
	Total excluding double counters				
10	Yield	690 k4	4.14 E6	3.2 E6	1327.83

* Not included to avoid double counting.

Footnotes for Table 1 on Cacao

1. Solar insolation from unpublished data of climatology division of Cepec Divisão de Ciências Sociais Estatística, Mean, 3447 kcal/m^2/d.

   (mean of 1980, 3474; 1981, 3551; 1982 3501)

   $(3.447\ E3\ kcal/m^2/d)(365\ d)(1\ E4\ m^2/ha) = 1.258\ E10$

2. Transpiration of cacao plantations with overstory trees; estimate supplied by P. Alvim, CEPEC, 3.7 mm/day

   $(3.7\ mm/d)(365\ d)(1\ E3\ g\ H_2O/m^2/mm)(1\ E4\ m^2/ha) = 1.35\ E10$ g water/ha/g

   $$\frac{(1.35\ E10\ g\ H_2O/ha/y)(5\ J/g\ water)}{4186\ J/kcal} = 1.61\ E7\ kcal/ha/y$$

3. Fertilizer

   - (296 kg Adubo/ha/g)(130 g N/kg) = 3.85 E4 g N

     (80 kg urea)(14/60 g N/g urea) = 1.87 E4

     Total N = 5.72 E4 g N/ha/y

   - (296 kg Adubo/ha)(350 g P/kg) = 1.03 E5 g P

     (296 kg Adubo/ha)(100 g K/kg) = 2.96 E4 g K

   - 450 1 lime (Ca, Mg, CO_3) @ density assumed 1.5 g/cm^3

     $(450\ E3\ cm^3)(1.5\ g\ cm^3) = 6.75\ E5$ g/ha

   - Energy transformation ratio of calcium carbonate (provisional pending better geologic data):

     Rate of uplift and limestone rock circulating in continents, 7.7 E15 g/y; global energy responsible, 1.91 E21 SE Cal/y (Odum and Odum, 1983)

     Energy transformation ratio on weight basis:

     $$\frac{1.91\ E21\ SE\ Cal}{7.7\ E\ 15\ g/y} = 2.5\ E5\ SE\ Cal/g$$

4. Soil

Soil formation rate

$$\frac{(0.5\ \text{m})(1.4\ \text{E6 g/m}^3)}{500\ \text{y}} = 1400\ \text{g/m}^2\text{/y}$$

Soil runoff $(1400/\text{m}^2/\text{y})(1\ \text{E4 m}^2/\text{ha}) = 1.4\ \text{E7 g/ha/y}$

kg/ha/y:Ca, 2.16; mg 1.32; k 4.85; N 5.86; P 0.35

Runoff, 293 - 692 m^3/ha/y

Earth uplift generates clay: $(31.2\ \text{g/m}^2\text{/y})(1\ \text{E4 m}^2/\text{ha}) = 3.12\ \text{E5 g/ha/y}$

If nitrogen runoff is 5.86 kg/ha/y and topsoil is 0.10% N

$$\frac{5.86\ \text{E3 g N/ha/y lost}}{0.0010\ \text{g N/g topsoil}} = 5.86\ \text{E6 g soil/ha/y or}$$

$$\frac{(5.86\ \text{E6 g soil/ha/y})}{(2\ \text{g cm}^3\ \text{density})(1\ \text{E8 cm}^2/\text{ha})} = 0.029\ \text{cm/y soil lost}$$

5. Fuels used per hectare (Cepec, 1984) for weeding, 2 l; for spraying, 45 l; oil, 2.78 l; estimate fuel energy as octane:

(49.8 l/ha/y)(0.7 g ml)(13.0 kcal/g)(1 E3 ml/l) = 4.54 E5 kcal/ha/y

- 1.6 kg wood used/kg cacao (Brandão, 1977)

(640 kg cacao)(1.6 kg wood/kg cacao) = 1024 kg wood

(1.024 E6 g wood)(4 kcal/g) = 4.1 E6 kcal wood used

- Transport mean distance 500 m with mules eating hay:

3 boxes @ 21 kg/box/animal trip; 441 kg/trip

$$\frac{\text{yield 690 kg/ha/yr}}{441\ \text{kg/trip}} = 1.56\ \text{trip/ha}$$

$$\frac{2400\ \text{trips/animal/yr}}{1.56\ \text{trips/ha}} = 1538\ \text{ha/animal}$$

2.4 mules/ha required for transport

(Brandão and Tafani, 1976)

(40 kg/mule/d)(365 d)(2.4 mules)(0.10 dry)(3.5 kcal/g) = 12264 kcal/ha/d

(1.23 E4 kcal/ha/d)(365 d) = 4.49 E6 kcal hay/ha/y

6. Pesticide used, Cepec 1984; ETR assumed from Austria study pending better data

   Fungicide (19.2 kg/ha)(0.04) = 0.77 kg Cu $(OH)_2$; ETR assumed higher than P

   Insecticide (30 kg/ha)(0.015) = 0.45 kg

   Organic pesticide (0.45 kg/ha)(9 kcal/g)(1 E3 g/kg) = 4050 kcal

7. Services including social costs (not including discount)

   531, 648. Cr (1984) from Cepec (1984)

   1980 energy/dollar for Brazil 6.9 E 12 SEJ/$

   $$\frac{6.9\ \text{E12 SEJ/\$}}{4186\ \text{J/kcal}} = 1.65\ \text{E9 SE kcal/\$ in 1980}$$

   From inflation table, ratio of March 1980/1984 is $\frac{3339}{9777} = 0.34$

   [5.317 E5 Cr (1984)][0.34 1980/1984] = 180,773 Cr (1980)

   $$\frac{(1.808\ \text{E5 1980 Cr})}{(55\ \text{1980 cr/\$}}= (1.65\ \text{E9 SE kcal/\$}) = 5.42\ \text{E12 SE kcal embodied in Services}$$

   Subsidies in loans at less interest than inflation

   231% inflation; interest 70% of inflation = 161%:

   (231 - 161%)(430,684) = 3.0 E7 Cr (1984)

   (3.0 E7 Cr 1984)(0.34 Cr 1980/1984) = 1.02 E7 Cr 1980

   $$\frac{1.02\ \text{E7 Cr (1980)}}{55\ \text{Cr 1980/\$}} = 1.86\ \text{E5\$}$$

   (1.86 E5)(1.65 E9 SE kcal/$) = 3.0 E14

   Machinery

   ETR includes goods and services and embodied fuels and earth work to concentrate iron ore. See G. Bosch, Appendix 13 (Odum and Odum, 1983)

   6.94 E7 SEJ/1

   $$\frac{(23.6\ \text{E22 SEJ})}{(4186\ \text{J/kcal})(38\ \text{E12 g end products})} = 1.48\ \text{E6 SE kcal/g}$$

Machinery used in drying sheds, spraying equipment, etc.

Steel in heating furnace

6 m x (2.7)(3.14)(0.3)(0.005 m)(5 g/cm^3)(1 E6 cm^3/m^3) = 2.82 E5 g steel

(6 x 6 m^2)(0.002 m)(0.2 steel)(5 g/cm^3)(1 E6 cm^3/m^3) = 72000 g steel = 0.72 E5

(2.82 + 0.72) E5 = 4.54 E5 g steel

$$\frac{4.5 \text{ E5 g}}{30 \text{ yrs}} = 15000 \text{ g/shed /yr}$$

needed per ha $\left(\frac{0.37}{36}\right)$(15000 g/shed /yr) = 150 g steel end products/ha/y

8. Seedlings

$$\frac{750 \text{ seedlings/ha}}{25 \text{ years}} = 30 \text{ seedlings/ha/yr}$$

Assume nursery prices for hybrid trees 10 US$/seedling

(30)($10)(1.7 E9 SE kcal/1980$) = 51 E10

9. Capital cost; wood-fired drier, 30 yr life

1728 kg yield/m^2 of drier; 640 kg/ha of trees

$$\frac{640 \text{ kg/ha trees}}{1728 \text{ kg/m}^2 \text{ drier/yr}} = 0.37 \text{ m}^2 \text{ drier/ha}$$

Drier 6 m x 6 m cost 16 E6 Cr (1984)

$$\frac{16 \text{ E6 (1984 Cr)}}{36 \text{ m}^2} = 4.44 \text{ E5 Cr 1984/m}^2$$

(4.44 E5 Cr 1984/m^2)(0.37 m^2 drier/ha) = 1.64 E5 Cr 1984/ha

$$\frac{1.64 \text{ E5 Cr 1984}}{30 \text{ yrs}} = 5476 \text{ Cr/1984/ha/y}$$

(5476 1984 Cr/ha/y)$\left(0.34 \frac{1980}{1984}\right)$ = 1861 Cr 1980/ha/y

$$\frac{(1861 \text{ 1980 Cr/ha/y})(1.65 \text{ E9 SE kcal 1980 \$})}{(55 \text{ Cr/\$})} =$$

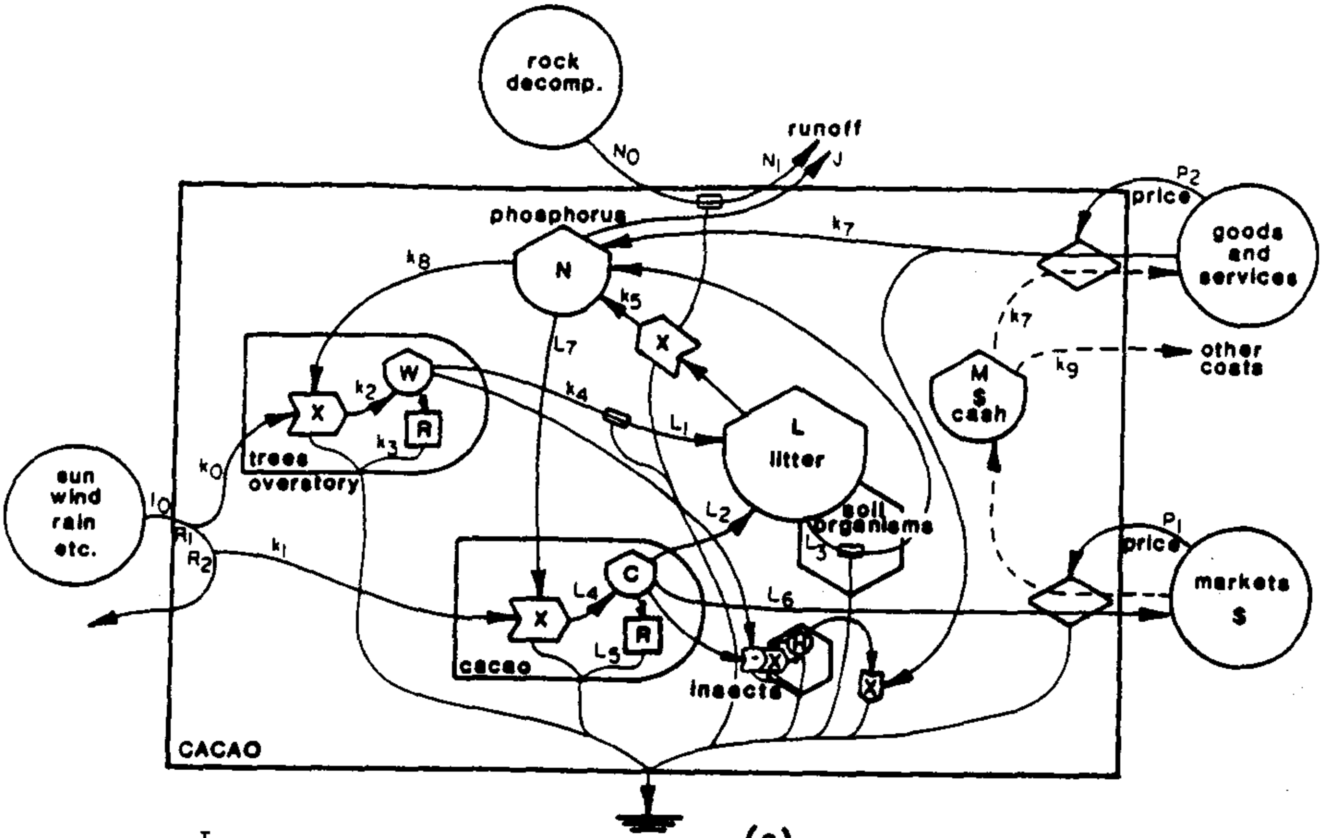
10. Yield (Cepec, 1984)

46 arrobas = 690 kg dried beans

(690 kg)(6 kcal/kg) = 4140 kcal dried beans

Seed content, 54% fat;

assumed 6 kcal/g dry seed



(a)

$$R_1 = \frac{I_o}{(1+k_oN)} \qquad R_2 = \frac{R_1}{(1+k_1N)} \qquad N_1 = \frac{N_o}{(1+L_9L)}$$

$$\dot{W} = k_2R_1N-k_3W-k_4W \qquad C = L_4R_2N-L_5C-L_6C-L_2C$$

$$\dot{L} = L_1W+L_2C-L_3L \qquad \dot{N} = k_5N_1L+k_6L+\frac{k_7M}{P_2} - k_8NR_1-L_7NR_2-JN$$

$$\dot{M} = P_1L_6C-k_4M \qquad \dot{H} = S_1(1-S_2W)CH-S_3H-S_4HM$$

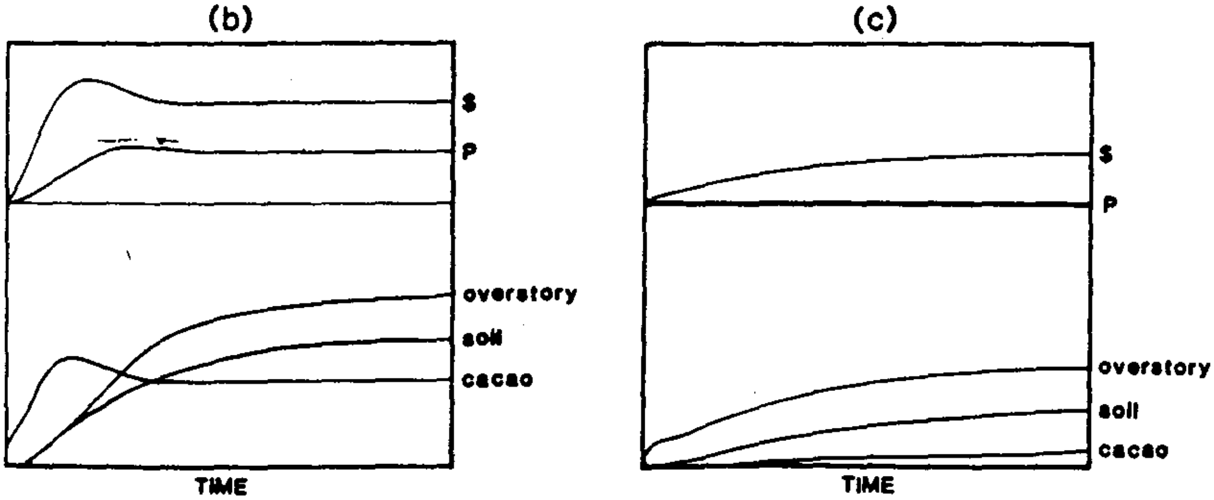


Figure 3. Preliminary simulation model of cacao growth and processing. (a) Energy diagram and equations; (b) simulation with present availability of inputs and prices; (c) simulation with lower sale prices and higher costs of fertilizer. P is phosphorus fertilizer.

Preliminary Simulation Model of Cacao Agroecosystem

The diagram of the cacao agroecosystem in Figure 3 is even more aggregated than that in Figure 2 and shows mechanisms of interactions explicitly in mathematical terms so that equations for simulation can be written. The resulting model includes the environmental inputs of sun, wind, rain, and rock weathering, and inside recycle of nutrients, and the flows of money generated by sale of the product. The simulation in 3b shows the buildup of stocks in a cacao plantation when prices are high and fertilizer used. Figure 3c shows the effect of higher fertilizer costs in diminishing fertilizer use and cacao yield.

The energy analysis showed the high quantity of purchased inputs in cacao processing. There was an important difference between obtaining these inputs locally compared to purchasing them abroad, because of disadvantages in embodied energy balance when raw commodities are sold. Recent discoveries of phosphate fertilizer reserves in Brazil will make a large net increase in embodied energy and thus economic viability of Brazilian crops such as cacao.

The much greater yields of the more intensively cultivated cacao depend considerably on substitution of fertilizer for the natural overstory cycle. The simulation model shows the way the mechanisms of recycle and external fertilization are related. Changing the availability of fertilizer by varying the price produced the sharp contrast now observed between the primitive and intensive cacao farming. The cacao example illustrates the critical role of foreign exchange in controlling the intensity of agricultural production.

V. PERSPECTIVES ON THE FUTURE

Salati and Vose (1984) describe the Amazon Basin in a a steady state climatic equilibrium with the flow of equatorial air flow from the east across the basis delivering rains, receiving evpotranspiration that is delivered as more rain, all facilitiated by the enviornmental stabilization and work processes of the green forest cover.

Gibbs (1967) and Meade (1979) describe the Amazon in a geological steady state with uplift of the Amazon rocks on the west, weathering, eroding, and flowing into the Amazon Basin where some is deposited into the Amazon basin isostatically matching the subsidence of deeper strata, and other sedimentars are carried out of the Basin into coastal seas.

While discussing the increasing participation of native Amazon people in market economies, Gross et al. (1979) describe earlier patterns of steady state among the human settlements with low density peoples in shifting cultivation. Their activities were part of the larger scale of forest replacement and renewal, contributing to the heterogenous patchiness, increasing the regional diversity of habitats and biota. Although pulses and cycles are also characteristic of these component climatic, geologic, biotic, and human subsystems of the Amazon Basin, the overall steady state model is a useful one for documenting reference base lines of properties with which to compare change. On the larger scale of time and space, production of environmental storages of soils, woods, biota, diversity, etc. were equal to or greater than the total consumption. Now this is changing.

Like the rest of the world, the Amazon is now being drawn into a larger scale pulse of resource consumption in excess of production driven ultimately by the pulse of human consumption of world fuels and minerals. New systems of environmental use are now replacing the old ones in the Amazon because they combine the local resources with additional energies that ultimately originated with the world fuel consumption invested from outside through economic mechanisms. Agroecosystems, plantations, cities, power plants, develop first using up the "virgin" storages that were maintained by the earlier steady state. First is the flush of large economic activity based on consumption of Amazon storages in excess of production and based on the world's use of stored fuels that contribute to the investments in the Amazon. Then total activity decreases again to a level that can be sustained by production and consumption balance or to a period where production exceeds consumption, rebuilding storages for another surge of consumption and economic growth later.

Even during the flush of economic, consumption-based growth, diligence in developing good interfaces between resource use and human development is more competitive. The development of oil by Andean countries pumping it up and over the mountains may be balanced by more use of the oil as the basis for development eastward from the Andes, even though international boundaries may delay this natural organization.

After the downtrend, the premium for economic vitality is on efficiency and maximizing effective use of the environmental renewable resources as the non-renewable consumption becomes less important.

Suggested land rotations that can maintain a modern if smaller long range economy in the Amazon are consistent with the present and important for the future. That Amazon soils cannot support modern cultures with agroecosystems and plantations is probably nonsense but rotation and understory managements may be required. That growth of population and cities can continue past the carrying capacity of world fuel availabilities is also probably nonsense.

For the same reason mentioned before that international currency exchange rates undervalue money from an undeveloped area, loans to finance projects work with a three fold negative effect which is equivalent to the effect of paying back three times what one borrows. Thus requirements that investments supply equal exchange of embodied energy should and probably will replace the economic policies that depress the local economy while stimulating the economy of developed centers elsewhere. A recognition of this principle could avoid the years of disruption while workable international relationships and relationships between the Amazon and outside cities are being found by trial and error.

Considering spatial patterns of future development, the availability of soil renewal fertility, hydroelectric power, and minerals from the Andes should generate centers of hierarchy on the west that complement the ones already developing where foreign trade, fuels, and converging rivers facilitated centers at the coast.

Because of the embodied energy disadvantage of underdeveloped rural areas in foreign trade, the limitations of growth are felt first in these areas and their adaptation to sensible longer range environmental patterns based on agriculture, fisheries, forestry, and biomass fuels are forced sooner. In this sense the Amazon and its surrounding countries may be the ultimate leaders in showing a world of declining fuel economy how to reorganize a culture and landscape for balance of production and consumption. If the principle that economic necessity requires maintaining biotic diversity is correct as suggested by our models, then the feared disastrous loss of great values of Amazon species may not occur if the lesson can be learned soon enough. There have been many patterns of rich human culture in balance with their environmental basis in the past and the overview of models suggests it may be in the making again for the near future. This is not a bad image to offer as the next stage to a region which still has the pioneer growth ethic, is oblivious to the long range patterns, but deeply disturbed by economic difficulties that are not understood.

APPENDIX A

BASIC COMPUTER PROGRAM OF THE SIMULATION MODEL OF ECONOMIC DEVELOPMENT IN THE AMAZON BASIN

```
1 REM PLOTTING FUNCTIONS-----PRINT FNP$(C,X,Y) FOR PLOTTING POINTS
2 REM AND PRINT FNV$(C,X,Y) FOR PLOTTING VECTORS. C=COLOR(1-7)
3 PRINT "DO YOU WANT GRAPHICS ON" @ INPUT Q$
4 IF Q$<>"Y" GO TO 7
5 PRINT CHR$(27)+"PpS(E)W(R,I(G),P1,N0,A0,S0)S(A[0,479][767,0])"
6 DEF FNV$(C,X,Y)="W(I"+STR$(C)+")V["+STR$(X)+","+STR$(Y)+"]"
7 DEF FNP$(C,X,Y)="W(I"+STR$(C)+")P["+STR$(X)+","+STR$(Y)+"]V[]"
8 DEF FNT$(C,N,A$)="W(I"+STR$(C)+")T(S"+STR$(N)+")'"+A$+"'"
9 DEF FNB$(C,X,Y,X1,Y1)=FNP$(C,X,Y)+FNV$(C,X,Y1)+FNV$(C,X1,Y1)+FNV$(C,X1,Y)+FNV$
(C,X,Y)
10 DIM E1(62,8)
11 DIM E2(62,6)
60 RANDOMIZE
70 DEF FNX(X)=INT((X-150)/2.5)+70
71 DEF FNY(Y)=INT((Y-540)/3)+50
100 E5=1
101 E6=E5
140 OPEN "ROAD2.DAT" FOR INPUT AS FILE #3
290 REM
295 B=0
296 X8=.2
297 X7=530000
298 M=0
299 T9=1
300 L0=6.78700E-03
305 K0=4.76900E-11
310 S=3.70000E+09
315 L=26
320 W=1
325 R1=0
330 R2=4010
335 F=128000
340 A=7138
345 I=4203
350 P0=3.71176E+12
355 R=1
360 S1=1
365 S2=1
370 A1=.85
380 A2=.85
385 P1=6
390 P2=.0859
395 P3=1.40600E-03
400 Q1=3.9
405 Q2=1724
410 X1=142
415 X2=39000
420 X3=1.89000E+08
425 J1=1.65000E+07
430 J2=1.50000E+07
```

```
435 J3=3.00000E+06
440 J4=488
445 J5=20670
450 J6=1.2
455 M5=.26
460 J7=12000
465 J8=138
470 J9=12600
475 B0=1100
480 B1=.5
485 B2=291
490 B3=100
495 B4=2155
500 B5=144
505 B6=.6
510 B7=143
515 B8=0
520 B9=220
525 C0=4010
530 C1=4010
535 C2=2.10000E+08
540 C3=.5
545 C4=3.9
550 C5=39000
555 C6=142
560 C7=9760
565 C8=130000
570 C9=1724
575 D0=125
580 D1=1.89000E+08
585 F1=.053
590 F2=.017
595 F3=.92
600 Z=0
700 K1=J1/(A1*S)
705 K2=J2/S
710 K3=J3/(S*A)
715 K4=J4/S
725 K5=J5/(L+(A2*L))
730 K6=J6/(S*A)
735 N3=M5/L
740 K7=J7/(A2*L)
745 K8=J8/(I*F1)
750 K9=J9/(F*F)
755 G0=B0/P0
760 G1=B1/W
765 G2=B2/P0
770 G3=B3/S
775 G4=B4/(S*A)
780 G5=B5/(A*A)
785 G6=B6/(L*A2)
790 G7=B7/(A*S)
795 G8=B8/(I*F2)
805 H0=C0/(I*F3)
```

```
810 H1=C1/P0
820 H3=C3/W
825 H4=C4/P0
830 H5=C5/(A*S)
835 H6=C6/P0
840 H7=C7/(A*S)
845 H8=C8/(A2*L)
850 H9=C9/P0
855 L=0
856 F=0
857 A=0
860 GO TO 1015
899 R1=1.72400E+11
900 H2=C2/(A*R1)
905 N0=D0/(A*R1)
910 N1=D1/(A*R1)
911 G9=B9/R1
915 PRINT CHR$(7)
920 GO TO 1015
1000 IF R1>1 GO TO 1015
1010 IF T=170 GO TO 899
1015 A1=S1/(1+(K0*S))
1020 A2=S2/(1+(L0*L))
1025 X1=H6*P0
1030 X2=H5*A*S
1035 X3=N1*A*R1
1040 I=(X1*P1)+(X2*P2)+(X3*P3)
1045 Q1=((G1*W)-(H4*(Q2+F)*A*R2))/(1+(H4*(Q2+F)*A))
1050 Q2=((G4*S*A)-(H9*F*(Q1+R2)*A))/(1+(H9*(Q1+R2)*A))
1055 P0=(Q2+F)*(Q1+R2)*A
1060 S9=K1*A1*S-K2*S-K3*S*A-K4*S+K5*(L+A2*L)-H7*A*S+H8*A2*L+X7*B
1065 L9=K6*S*A-N3*L-G6*L*A2
1070 F9=K7*A2*L+K8*I*F1-K9*F*F-G0*P0
1075 W9=R-G1*W-H3*W
1080 A9=G2*P0+G3*S+G8*I*F2-G5*A*A-G7*A*S-N0*A*R1
1085 Z9=-H2*A*R1-G9*R1
1090 X9=H0*I*F3+G9*R1
1091 IF L9<0 THEN M9=L9*-1
1092 M=M9-X8*B
1093 B=B+M
1095 S=S+S9
1100 L=L+L9
1101 IF L>705 THEN L=705
1102 L8=L8+L9
1105 F=F+F9
1110 W=W+W9
1115 A=A+A9
1116 A8=A8+A9
1120 R1=R1+Z9
1125 R2=X9
1130 T=T+1
1131 IF T=150 THEN E5=2
1132 IF T=170 THEN E5=3
1133 IF T=180 THEN E5=4
```

```
1134 IF T=190 THEN E5=5
1135 IF T=200 THEN E5=6
1136 Y5=Y5+1 @ REM CITY PLOT COUNTER
1137 IF E5>=3 THEN Y5=Y5+1
1150 Z=Z+1
1155 IF Z=3 GO TO 1200
1160 GO TO 1250
1200 PRINT FNP$(2,T/T9,(A/1000))
1210 PRINT FNP$(4,T/T9,S/7.50000E+07)
1220 PRINT FNP$(6,T/T9,L/4)
1240 PRINT FNP$(7,T/T9,F/5000)
1245 Z=0
1250 IF T<300 GO TO 1000
1255 GO TO 9999
9999 PRINT CHR$(27)+"@"
10001 END
```

APPENDIX B

BASIC COMPUTER PROGRAM OF MODEL OF LAND ROTATION IN PLANTATIONS AT JARI, BRAZIL

```
5 REM  ST
10 PLOT 12
20 J= 1700
25 KS= 250
26 KN= 32
30 JS= 1450
35 JN= 180
40 A1= 800
45 A2= 100
50 S= 273
55 N= 30
60 M= 300
65 SP= 25
70 SE= 13.2
75 AA= 9
80 SO= AA* .54
85 AE= 6
90 SN= AA* .3
95 SM= AA* .175
100 N1= 0.6
105 NE= 0.2
110 NP= 4.4
115 NM= 12.2
120 MN= 121
125 MP= 178
130 MA= 30
132 P2= 3.4
135 REM  CALCULATION OF COEFFICIENTS
140 K0= JS/ KS/ A1/ S
145 K2= JN/ KN/ N/ A2
150 K1= SP/ KS/ A1/ S
155 K3= SE/ S
156 S= 384
157 A1= 700
160 K5= SO/ AA/ S* A1
165 K4= AA/ A1/ M
170 K6= SN/ AA/ S* A1
175 L2= SM/ AA/ S* A1
180 K7= NP/ KN/ N/ A2
185 K8= AE/ A2/ S* A1
190 K9= NE/ N
195 L0= NM/ KN/ N/ A2
200 L3= MN/ M/ A2* N
210 L4= 2.5
212 L5= MP/ A2
214 L6= MI/ M
215 P1= 27.6
220 P2= 3.4
```

```
225 P3= 22.2
227 P4= 0.0314
230 REM  INITIALIZATION FOR THIS RUN
231 I= 1
232 K= 1
235 T= 1
240 A2= 0.05
245 A= 800
250 S= 0.5458* (A- A2)
255 N= 0.3* A2
260 M= 0
265 REM  START LOOP (TO) AND SCALE OUTPUT
270 TO= 2
275 DT= .5
280 SO= 4.5
290 AO= 8
300 NO= 2.4
310 MO= 7
312 IX= 100
315 GOSUB 1000
320 PLOT 29,18:REM  S IS GREEN
330 PLOT 2,T/ TO+ 27,S/ SO+ 27,255
340 PLOT 29,17:REM  LAND IS RED
350 PLOT 2,T/ TO+ 27,A2/ AO+ 27,255
360 PLOT 29,20:REM  N IS BLUE
370 PLOT 2,T/ TO+ 27,N/ NO+ 27,255
380 PLOT 29,21:REM  MONEY IS VIOLET
390 PLOT 2,T/ TO+ 27,M/ MO+ 27,255
395 PLOT 29,22:REM  I IS LIGHT BLUE
397 PLOT 2,T/ TO+ 27,I/ IX+ 27,255
400 REM  CALCULATION OF FLOWS
405 A1= A- A2
410 KN= J* (A2/ A)/ (1+ K2* N* A2)
412 KS= J* (A1/ A)/ (1+ KO* S* A1)
415 SP= K1* KS* A1* S
420 SE= K3* S
425 AA= K4* A1* M
430 SO= K5* AA* S/ A1
435 SN= K6* AA* S/ A1
440 SM= L2* AA* S/ A1
445 NP= K7* KN* N* A2
450 AE= K8* A2* S/ A1
455 NE= K9* N
460 NM= LO* KN* N* A2
465 MN= L3* M* A2/ N
470 MA= L4* AA
471 N1= 0.006* A2
```

```
472 MP= L5* A2
474 T5= A2/ 200
475 IF T* DT< = 10THEN T5= 1
476 T3= 0
477 IF M< 250THEN T3= 1
478 IM= T3* T5* 200
480 T4= 0
482 IF M> 350THEN T4= 1
484 MI= T4* (M- 250)
485 DS= SP- SE- SO
490 DN= SN+ N1+ P4* MN- NE- NP
495 DA= AA- AE
496 AK= AK+ AA
500 DM= P3* NM+ P1* SM+ IM- MN- MP- MA- MI
501 IF IM< ITHEN DI= MI- IM:DP= 0:GOTO 505
502 DI= MI
504 DP= IM
505 S= S+ DS* DT
510 N= N+ DN* DT
512 IF N< 0.1THEN N= 0.1
515 A2= A2+ DA* DT
520 M= M+ DM* DT
530 I= I+ DI* DT
535 P= P+ DP* DT
536 IF M> 0THEN GOTO 540
537 TE= - M:M= 0:I= I- TE
540 T= T+ 1
545 IK= IK+ I
546 NK= NK+ NM
550 IF T/ TO< 100GOTO 320
552 I= I+ 20* A2
560 END
1000 PLOT 29,23
1010 PLOT 2,27,127,242,27,27,127,27,255
1020 PLOT 2,28,102,28,77,28,52,52,28,77,28,102,28,255
1022 PLOT 3,34,29:PRINT "TIME"
1024 PLOT 3,59,26:PRINT 100* DT* TO
1030 PLOT 3,0,5
1032 PLOT 29,18
1035 PRINT "NATIVE"
1040 PLOT 3,0,6
1045 PRINT " BIOMASS"
1050 PLOT 3,0,7
1052 PLOT 29,21
1055 PRINT "MONEY"
1060 PLOT 3,0,8
1062 PLOT 29,20
1065 PRINT "PLANTATION"
1070 PLOT 3,0,9
1075 PRINT " NUTRIENTS"
```

```
1080 PLOT 3,0,10
1082 PLOT 29,17
1085 PRINT "PLANTATION"
1090 PLOT 3,0,11
1095 PRINT " AREA"
1100 PLOT 3,0,12
1102 PLOT 29,22
1105 PRINT "$ RETURNED"
1200 RETURN
READY
```

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