JARI AND DEVELOPMENT IN THE BRAZILIAN AMAZON

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Jari Florestal e Agropecuária, Ltda. (subsequently referred to as Jari) has assumed an importance which goes far beyond the future fate of the roughly 1.4 million hectares [1] of the eastern Amazon occupied by this project of Daniel K. Ludwig of National Bulk Carriers, Inc. The operation is primarily a silvicultural plantation of pulpwood trees with an associated industrial complex and a smaller area for mechanized cultivation of irrigated rice. The importance of Jari comes from the fact that it has been suggested repeatedly among planners in Brazil as an appropriate model to be emulated on a large scale in other parts of the Amazon Basin. For example, Paulo de Tarso Alvim (1978a), an influential voice in Amazon development planning matters, claims that the results obtained by Jari "clearly demonstrate the enormous potential for commercial silviculture of the Amazon." The suggestion that Jari represents a model has been raised frequently at meetings concerned with development options in the Amazon, with the project either being endorsed as a "model" or more commonly described as representing an "experiment", with the implication that this mode of development should be recommended for other areas if the project proves itself by making a profit. Many journalists have also echoed this theme in the popular press. In an article entitled "Ludwig's Amazonian Tree Experiment", to give a typical example, a Jari official is quoted (or possibly misquoted) to imply that 70 per cent of the Amazon Basin could be so developed, which "would certainly shake the Canadian pulp and paper market a bit" (Kendall, 1979). While the notion is widespread that the type of development being undertaken at Jari could be applied to large areas elsewhere in the Amazon, there is an almost total lack of published research on the economic or ecological viability of the developments at Jari. This has been largely due to the company's tight control of access to the area.

We had the opportunity to make a four and one half day visit to Jari in August 1978 and observe the plantations, installations, and experiments in progress in the separate silviculture and agriculture sectors of the project. The objective of our trip was to identify research needs for the evaluation of Jari as a model for development in the Amazon as compared with other possible alternatives. In this paper some basic questions which must be addressed are raised; the answering of these questions can only be partial due to the scarcity of information about developments there. These questions are especially important for Brazil at a time when the future direction of forest policy in the Amazon is being debated and decided (Fearnside and Rankin, 1979).

Summary of Developments at Jari

Jari has its administrative headquarters and the majority of its technical staff for the silviculture sector located in Monte Dourado, a city of approximately 7000 inhabitants in 1978 [2] constructed by the company on the west bank of the Jari River. The company's holdings include land both in the State of Pará and the Federal Territory of Amapá, but all of the plantations and other operations, with the exception of a Kaolin mine, are located in Pará on the western side of the Jari River [3]. Approximately 100,000 hectares of the company's land had been felled from the project's first fellings in 1969 up to the time of our visit (seven percent of the total area), according to the company's technical personnel. The silviculture operation, located on *terra firme* or high ground, has 60,000 hectares planted as a monoculture of *Gmelina arborea* (Verbenaceae), a species of Asian origin known for its rapid growth (Palmer, 1973). Under ideal growth conditions, such as those in some *Gmelina*

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plantations in Africa, the technical staff of the silviculture operation expect that *Gmelina* would be harvested at the age of six years for use as pulp, or at ten years for use as wood. Growth has not been sustained for as long as this ideal schedule would indicate; trees have begun to senesce after as little as seven years on some sites, according to company foresters. The growth of *Gmelina* plantations at Jari has varied greatly depending on the soil, showing best results on clayey soils. Some of the oldest plantations were made on sandy soils resulting in poor growth (Figure 1), and have therefore been either abandoned or cleared for replanting with *Pinus caribaea*. *Gmelina* growth is expressed in terms of a "growth index", representing the expected height of the tree in meters at an age of 10 years. *Gmelina* growth indices at Jari range from 7 to 31; plantations with indices below 13 are abandoned, those with indices from 13 to 24 are used for pulp, and those over 24 are slated for future use as solid wood. Average production figures are reportedly 38 m^3 growth/ha/year for *Gmelina* and 27 m^3 growth/ha/year for *Pinus* (Alvim, 1977).

Fig. 1: - Sandy soils in some parts of the Jari estate resulted in poor growth of *Gmelina*, such as the eight-year-old stand on the right. Many of these poorly-located early stands are being erradicated, as in the cleared area on the left, for replanting with *Pinus caribaea*.

Various insects and diseases have attacked the plantations of *Gmelina*, but up to the present time none of them have apparently had serious effects on the project. The rapid defoliation of 300 hectares of *Gmelina* in 1974 by an unidentified lepidopteran larva caused temporary concern among the technical staff. In the four following years such losses have been restricted to small areas, but populations of this caterpillar and other pests continue to be found in the plantations every year. We observed unidentified lepidopteran larvae (different from the defoliators of 1974) feeding on *Gmelina* leaves in one of the observation plots which had been established in areas affected by the 1974 outbreak (block 72-6). This is shown in Figure 2. All trees in the area showed some (<15%) leaf damage, but trees in all three of the defoliation observation quadrats we observed appeared generally healthy (blocks 69-2, 72-6, and 74-2). The deciduous *Gmelina* trees were also nearing the end of their annual cycle and were beginning to drop their current set of leaves.

A fungus (*Ceratocystis fimbriata*), which kills the *Gmelina* trees, has also appeared in several restricted areas since 1976 (Muchovej *et al.*, 1978). The cancre caused by this fungus does pose a threat to the *Gmelina* plantations since the infestation is still increasing both in the observation plot which we visited (I-502, block 76-3) and on average for the ten observation plots for the disease wbich have been maintained in infested areas since 1977 (See Figure 3). It has also been found at a number of locations outside of the observation plots. The causative agent is in the same genus as *Ceratocystis ulmi*, which produces Dutch elm disease in temperate regions. In general the areas attacked to date by pests and diseases at Jari appear to be small in comparison with the total area of the estate, but in the long term this does not guarantee that such problems may not affect large areas. The fact that *C. fimbriata* has been found as a pathogen on native and introduced host species with Amazon-wide distributions, such as mango (*Mangifera indica*), rubber (*hevea brasiliensis*), coffee (*Coffea* spp.), and cacao (*Theobroma cacao*) (Muchovej *et al.*, 1978) suggests that it could be difficult to exclude this pathogen from *Gmelina* plantations which might be established elsewhere in the Amazon. At present chemical control of *C. fimbriata* is considered impractical and uneconomic (Muchovej **et at.**, 1978).

Pinus caribaea var. *hondurensis*, the other species being planted in monocultures on a large scale in Jari, is expected to have a cycle of 16 years. The oldest experimental plantations (Figure 4) had been extant for eight years at the time of our visit. Commercial scale plantations began in 1973. The principal pest of *Pinus* is the leaf cutter ant (*Atta* spp.), which is being controlled with applications of pesticides, principally Mirex (Ribeiro and Woessner, 1978). *Atta* can kill *Pinus* seedlings up to two years old, and reduce growth by an undetermined amount (Ribeiro and Woessner, 1978). *Atta* also attacks *Gmelina*, but the effects are less damaging since only reduced budding in seedlings, and reduced growth rates result (Ribeiro and Woessner, 1978).

Other problems common to *Pinus* plantations everywhere include some loss to fire (totalling about 2000 ha by 1978), and "foxtailing", or spindally branchless shoots which result from uncontrolled seed quality. Depending on provenance, foxtailing rates at Jari range from 0 to 15%, with the average among provenances being 7% (Woessner, 1979a). The seeds of *Pinus*, which cannot be propagated at Jari itself due to rain during the flowering period, are being imported from various sources outside of Brazil. In the future, it is planned to supply seeds for the Jari plantations from *Pinus* seed trees at another Ludwig operation located in the State of Minas Gerais in south-central Brazil.

Experimental plantations of several other tree species have been installed. Among these, growth appears best with *Anthocephalus chinensis* and

Eucalyptus deglupta, but the plantations are still young and the company has not yet analyzed data on the experimental stands. With the exception of *Eucalyptus deglupta*, for which planting has begun on a moderate scale in 1979, there is currently no plan to use any of the other species being tested on a commercial scale. Even so, these plantations deserve close attention; tests with *Eucalyptus deglupta* at the Brazilian government's Superintendency for Development in the Amazon (SUDAM) experimental reserve at Curuá-Una in central Pará have shown high mortality after four to eight years of excellent growth (Dubois, 1971). Plantations of *Anthocephalus* at Curuá-Una, which we observed in August 1978, also show mortality after a few years of good growth. It is clear that a long experimental period would be needed before the utilization of these species could be safely promoted on an industrial scale.

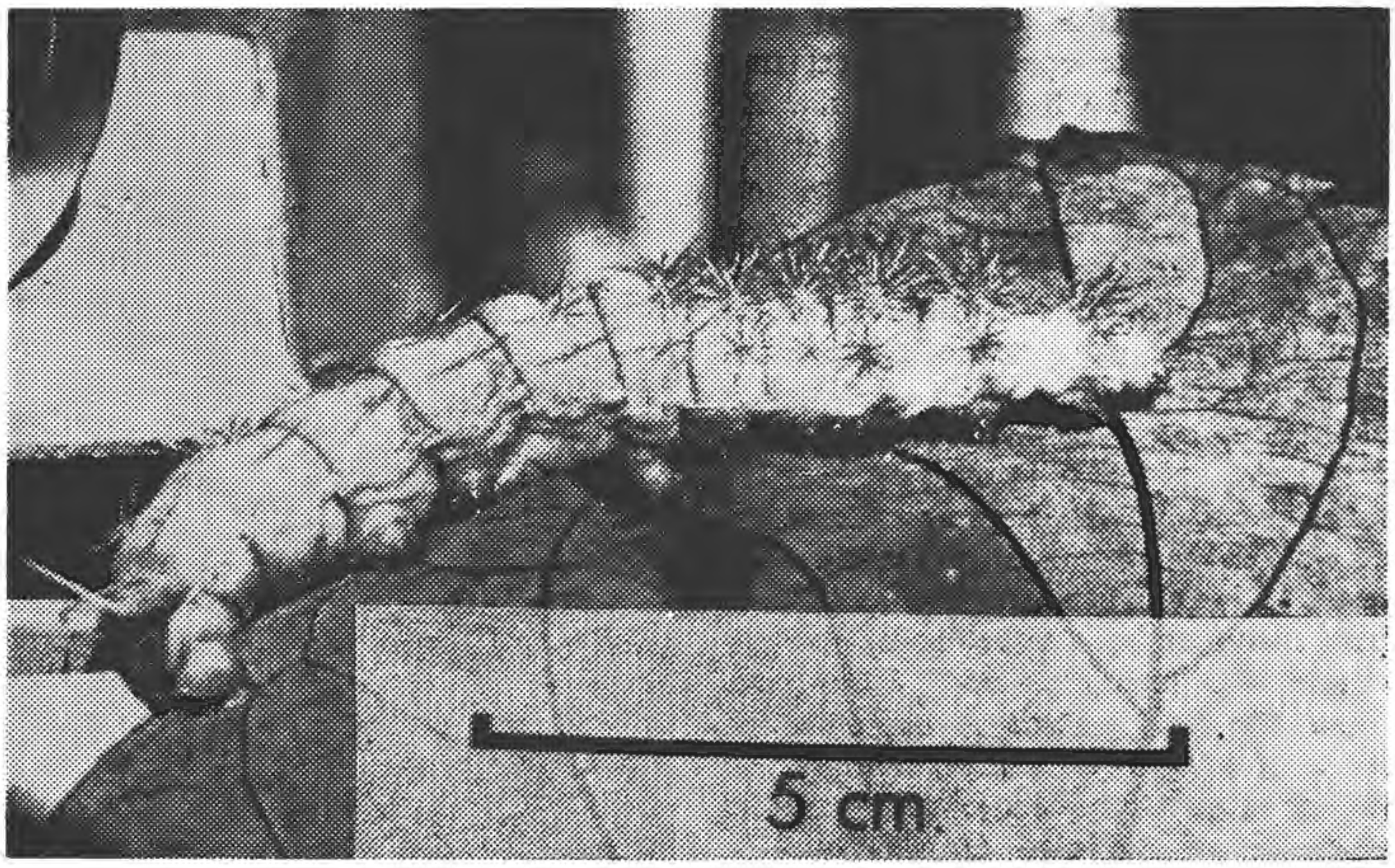

Fig. 2: - An unidentified lepidopteran larva feeding on a *Gmelina arborea* leaf. Outbreaks of insect pests have so far been controlled or remained at economically insignificant levels, although the susceptibility of tropical monocultures to pest attack is a cause for caution.

A 750 metric ton/day capacity kraft pulp mill has been installed at Monduga, south of Monte Dourado on the west bank of the Jari River. When operating at full capacity, the present mill requires approximately 4000 m^3 of pulpwood per day. Energy for the present mill comes from burning 540,000 m^3 /year of wood from the native forest in the current early stages, and will come from wood from the plantations in the future. Energy production requires four hectares of native forest per day according to company statements at the Eleventh Congress of the Brazilian Association of Cellulose and Paper (Frota Neto, 1978). A second mill, which will use a thermo-mechanical process for newsprint manufacture, will have a larger pulpwood demand than the present chemical process mill. This is planned to begin operation in 1983.

The project has a kaolin mine with reserves reported to be 50 million metric tons (Vasconcelos, 1979), and a 500 metric ton/day processing plant (Briscoe, 1979). Currently all of this fine clay mined is exported from the area, but this will also supply paper sizing for production of light weight coated papers at Jari if long term industrial proposals being discussed are realized. Plans for the proposed expansion include construction of 829 metric ton/day newsprint mill and a 200 megawatt hydroelectric dam. The hydroelectric project is currently awaiting approval due to its requiring flooding of land not belonging to Jari, its location in a "national security area", and the need for special permission from ELECTRONORTE, the government-owned bulk power monopoly in Amazonia. Power would be used in the proposed paper mill at Jari, and possibly in a factory for producing brickettes of firebrick bauxite to be located at a mine site in Serra do Caracuru in the western part of Jari (not to be confused with the separate Ludwig-owned metalurgical bauxite deposits in the Rio Trombetas area, about 500 km further west) (Pinto, 1979).

The paddy rice operation is located in a *várzea* (Amazonian floodplain) area in São Raimundo, about 50 km south of Monte Dourado. There is no terrestrial link between the bases of operation of the rice and silviculture projects. The rice project had an area of 3283 ha under cultivation in 1978, and is being increased to 14,165 ha, 4000 has been the target for the harvest of 1979. The rapidity of the harvest using a fleet of 42 combines (Figure 5), followed by speedy planting with six airplanes, allows the harvesting of two crops per year within the period of maximum insolation. Although experimental plantings have been reported to produce three harvests per year (Senna, 1973: 16), only two crops are harvested annually in the commercial operation due to the lower yield of the third crop during the months with less intense insolation (C. H. Wang, personal communication, 1978).

Fertilization and application of pesticides in the rice project are also done by air. Water management requires a system of diesel pumps transporting one million liters of water per minute for both filling and emptying the paddies. Average yields are of the order of 4500 kg/ha/harvest (*Jarilino*, março 1978) [4]. Experiments with rice are being undertaken at an experimental station with technical personnel from IRI Research Institute, Inc. of New York and financial support from D. K. Ludwig. The experimental program has made valuable contributions to the production effort, including identifying a sulfur deficiency problem which was cheaply corrected by changing the nitrogen source applied (Wang *et al.*, 1976). New port facilities are planned, and a road and canal linking São Raimundo with the new port site on the Amazon River were under construction at the time of our visit.

Experimental plantings of various crops have been installed on *terra firme*, including cacao, oil palm, and manioc. Of these, only manioc is being considered for possible expansion. If manioc is planted on a larger scale in the future, it will be only for the production of alcohol to help meet Jari's operational fuel needs, and not for sale outside of the Jari area according to company personnel.

An attempt to produce patchouli (*Pogostemon cablin* Benth. Syn. *P. patchouli* Pellet., Latiatae), an exotic shrub used in the perfume industry, is being made on 2000 ha of the silvicultural area. No preliminary experiments were conducted to test the potential of patchouli in the area, although some experience elsewhere in Brazil has given hopeful results (Magalhães *et al.*, 1976).

A sawmill for tropical hardwoods with a 6000 m^3 capacity is under construction, and is now sheduled for completion by the end of 1979 (Pinto, 1979). This will presumably saw wood from the native forest for some time. Small experimental plantings of some hardwood species have been tried, but none have been planted on a commercial scale. Teak (*Tectona grandis*, verbenaceae) growth in two-year-old trials was judged "encouraging enough to warrant expansion of the provenance testing program" (Woessner, 1977b). The high value of wood or veneer from hardwood plantations should help compensate for their slow growth as compared with pulpwood species.

Jari also possesses a herd of 5500 water buffalo and 6500 zebu cattle. The ranching operation, as well as plantations of several other crops being raised on a smaller scale, is strictly for supplying the food needs of the personnel working in Jari. There are approximately 30,000 persons in the company area, including workers employed by firms which have been contracted by the company.

Basic Questions

1) *Economic Health*

As a first step in evaluating whether Jari-type projects will be good investments, it is essential to know whether the Jari Project itself is economically healthy. If Ludwig were not able to realize an adequate return on his investment in the Jari Project there would probably be few potential developers who would consider Jari to be a good model for other large-scale projects. There is some reason to believe that Ludwig's decisions to make the initial outlays and accept the associated risks may not have been based entirely on the standard business criteria of maximizing expected returns on the money invested. Elmer Hann, one of Ludwig's highest aides, is quoted as having said "I don't know whether Jari is supposed to be economically viable in the sense of recovering a billion-dollar investment" (Gall, 1979: 130). Other entrepreneurs considering similar ventures would probably not include non-economic motives to a significant degree in their evaluations of acceptable returns and risks, and so would require higher returns and more security than would Ludwig.

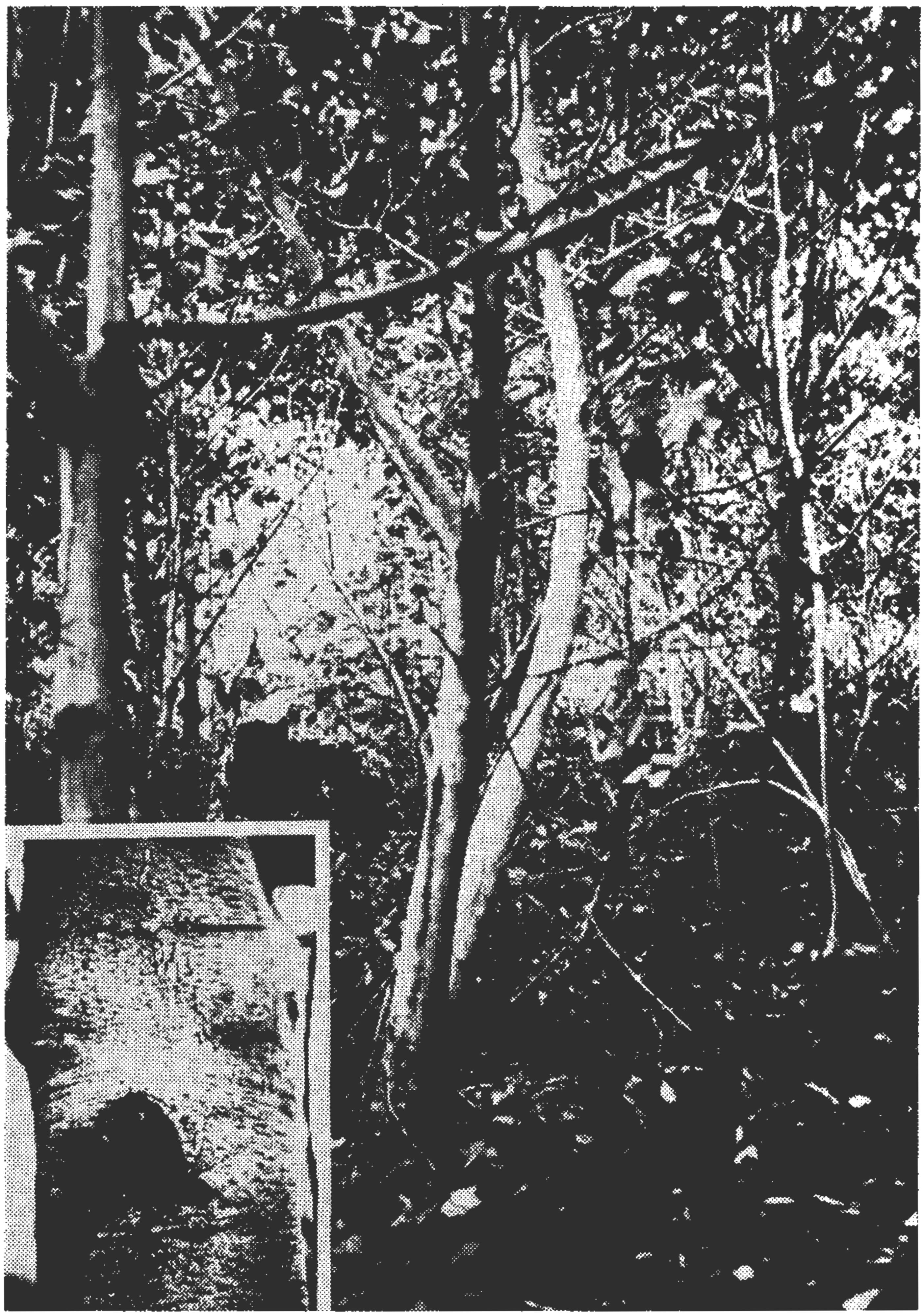

Fig. 3: - *Gmelina arborea* plantation at Jari attacked by the fungus *Ceratocystis fimbriata*, which kills affected trees. Inset shows trunk cancre and fungal fruiting bodies.

If the economic success of Jari should be judged adequate, there would be many further conditions which would have to be present for other projects of this type to achieve the same level of economic success. One of these conditions is the availability of enormous quantities of capital. The total investment in Jari so far is reported to be US$780 million (Time, September 10, 1979). The investment has been increasing rapidly, the company having released a figure of US$493,592,000 for investments up to the end of 1978 (A Crítica (Manaus), 5 de janeiro de 1979). The second phase, which includes the plans for the paper mill and hydroelectric dam, will require an additional US$532 million by 1985 (Skillings and Tcheyan, 1979: 30). Original estimates were for a total investment of only US$300 million by 1981 (Realidade, 1971 cited by Lima, 1973: 133).

Until pulp production began in April 1979 the investments at Jari were all made before realizing any return in the silvicultural part of the project, which accounts for the vast majority of the investment to date. In addition to the size of the investment required for a project like Jari, calculations of economic acceptability of comparable ventures must also include the prospective entrepreneur's other financial reserves as compared with those of D. K. Ludwig. Ludwig's net worth, reported to total over US$ 3 billion, making him the wealthiest man in the United States (Time, Sept. 10, 1979), helps to make the risks of loss on the scale of Jari acceptable, and also to make it possible to meet the many unexpected expenses which have arisen due to technical or biological problems or delays. The pulp mill, originally scheduled for installation by 1975 (Realidade, 1971, cited by Lima, 1973: 133), was not installed until 1979 due to a variety of delays.

A number of factors, in addition to Ludwig's extensive reserves of liquid capital, enhance the probability of Jari being a profitable venture as compared with other development schemes patterned on the Jari model. This is particularly true in comparing Jari with the prospects for mounting a similar project through a government agency or governmental enterprise. Jari operates without restrictions on efficiency due to limitations on fuel or other resources. Jari also operates without salary and other restrictions which would limit its capability to employ the best persons available for positions at all levels. In addition, Jari has been able to operate on the assumption that management will remain stable over a long period —plantations have to be installed, maintained, and harvested without failures due to bureaucratic reorganizations, fluctuations in the availability of funds, etc. Ludwig's policies have remained relatively constant despite frequent personnel changes at the operating director level. This may change in the case of Jari itself with the eventual death of Ludwig, now 81. Jari Florestal e Agropecuária, Ltda. is now owned by a Swiss-based cancer research foundation, and control will presumably pass to this organization following Ludwig's death.

Jari has had a number of advantages over any other venture, public or private, which might conceivably attempt to emulate Jari's example. Jari has a network of multinational connections to attend to the needs of the project capable, for example, of supplying seeds and other inputs to the project with the advantages of reliability, quality, regularity, and price. The scale of the operation, and the diverse but interrelated activities which allow the enterprise to control so many of the links between constructing and supporting its physical plant, and producing, processing, shipping and marketing its products, make Jari very different from any enterprise which might attempt to replicate only a part of the scheme. Such an enterprise would be deprived of both Jari's economies of scale and the security and economy afforded by the vertical integration which Ludwig has arranged.

Fig. 4: - Caribbean pine (*Pinus caribaea*) has been planted in the silvicultural area for saw log production. Growth, as in this eight-year-old stand, is considered good in the first 16-year cropping cycle currently underway.

A very important feature of Jari is that it enjoys certain concessions from the Superintendency for Development of the Amazon (SUDAM). Both the silviculture and rice culture parts of Jari have been granted complete exemptions from income tax and from taxes on the importation of foreign industrialized products (Brasil, SUDAM, 1977: 35-36). These concessions confer a particularly great advantage in Brazil, where import duties reach 200%. The viability of any attempt to emulate Jari elsewhere will have to take into account whether such concessions would be in effect for the contemplated project. Finally, the location of Jari was very carefully chosen based on such criteria as a tropical climate, soils of reasonable quality, availability of a large intact area of land, and possibility of installing a deep water port (Briscoe, 1978). Such areas are becoming increasingly rare.

The Jari Project began its plantations in 1969 under conditions of cheap land, labor, and petroleum. The changes in the values of these basic inputs since 1969, and the likelihood of continuing changes in the future, mean that the calculations of anyone considering launching a similar venture would clearly be different. For example, in Trinidad there are many plantations of *Pinus caribaea* which have been abandoned because the high price of labor does not make it economic to control weeds. The benefit from maintenance operations must continually be weighed against their costs; pruning of *Gmelina* trees at Jari, for example, was discontinued in 1979. Relative prices of petroleum in the future will have a profound effect on the economic viability of projects patterned after Jari. Jari completed a substantial portion of its initial investment before the petroleum price increases of 1973.

Among other ways in which the context of such projects is likely to change in the long term, future projects will have to take into account demographic pressures which are not presently affecting Jari.

One factor about which there exists no information is the important question of how much time a project like Jari needs to operate before arriving at the financial position at which the project's resources could be withdrawn and invested elsewhere, possibly in some other part of the world. In the case of Jari itself, expansion plans will necessitate that all income generated be reinvested in the operation for a period of time whose length is estimated at from 15 years (Skillings and Tcheyan, 1979: 31) to 20 years (Briscoe, 1979). More time than this would, of course, be necessary to recoup the entire range of investments made and contemplated. While Jari itself is not showing indications that it intends to abandon its operations at some future date, this type of decision is quite common in the operations of large enterprises. In the field of mining, to use the most obvious example, developers must inevitably plan to have discounted their investments before the day when deposits are exhausted. If an eventual withdrawal of resources should be a part of the calculations made by anyone considering mounting other schemes in the Amazon similar to Jari, the degree of freedom such an enterprise would have to move its resources to other regions or countries would be of prime economic importance. In the case of Jari itself, Ludwig will be free of government restrictions on the removal of capital after 1989, according to Brazil's Minister of the Interior (Veja, 31 de outubro de 1979: 109).

Fig. 5: - Mechanized rice harvest in Jari's *várzea* (Amazon floodplain) area.

The question remains of whether or not Jari itself will prove profitable, remembering the many reasons indicating that attempts to follow Jari's example as a model elsewhere in Amazonia would be likely to be less profitable. The pulp mill presently operating is expected to produce 262,500 metric tons/year of bleached kraft pulp, expected to be worth US$100 million in 1977 dollars for 1985 through 1990 (Skillings and Tcheyan, 1979: 22,30). The proposed newsprint mill is expected to produce 290,000 metric tons/year beginning in 1990, which is expected to be worth US$132 million at that time in 1977 dollars (Skillings and Tcheyan, 1979: 22,30). Price estimates are based on the World Bank's annual commodity price forecast review made in April 1979. These production figures are interpreted as meaning that "the project will probably earn only a low return on its total investment, but the incremental return on new investment from now on should be satisfactory." (Skillings and Tcheyan, 1979: 31).

In the case of Jari's *várzea* rice project, which accounts for only about 5% of the company's investment so far, the rate of return on the total investment also appears to be low if development costs for the full area are as high as the cost figures released by Jari's director for the first 2000 ha installed. The development cost figure is US$5000/ha for diking, leveling, and installed equipment (Rocha, 1977, cited by Norgaard, 1979), corrected for inflation to US$6000 in 1978 dollars. Using a variable costs (debt service, maintenance and operation, labor, and seed, fertilizer, and pesticide) figure of US$1750 derived by Norgaard (1979) from a variety of sources for application to smaller-scale *várzea* rice operations, and a period of 11 years for depreciation of the initial development costs (following Norgaard, 1979), one can arrive at a cost estimate of US$2295/ha/year. Using a figure of US$275/metric ton as the international price for high quality long grained unmilled rice, and the average annual yield of 9 metric tons/ha which had been obtained through March 1978 (Jarilino, março 1978), the operation loses money at the rate of US$70/ha/year. If one uses a more optimistic yield figure of 9.5 metric tons/ha/year, which may well be obtainable, the operation makes a profit of US$67/ha/year. If the development cost figure is high, as seems probable, the operation would be making more money accordingly.

2) *Indefinite Sustainability*

The question of whether Jari is indefinitely sustainable at an adequate profit is quite different from the previous question of economic health. It is common to encounter situations, especially in the exploitation of potentially renewable natural resources, where the goal of maximization of profit results in the destruction of the resource with complete economic logic. The best example of this is the whaling industry, where even with an abundance of studies showing that the high fishing pressure would exterminate the whale populations, companies continue to invest in the industry with the intention of simply scrapping their equipment after the resource is destroyed, and reinvesting the profits elsewhere (Clark, 1973, 1976).

The question of sustainability beyond the minimum period for discounting the investments and turning a profit, then, has to be evaluated using somewhat different criteria than those for the evaluation of economic health. If any Jari-type project should fail or close down after passing the economic breakeven point, the costs would be paid by the future generations of Brazilians that would have to live in the degraded area. For this reason the Brazilian government should have a keen interest in the question of indefinite sustainability at an adequate profit.

At present, Jari is heavily dependent on petroleum, both in the rice and in the silviculture operations. Without the expenditures of oil (or a suitable substitute) for mechanized planting and harvesting of the rice, it would not be possible to obtain two harvests per year. In the vast area of the silvicultural plantations, the operation depends on the services of a fleet of vehicles on 4800 km of roads, in addition to machinery used in harvesting, etc. Several features of the present operations at Jari are designed to avoid the need for fossil fuels, such as the 46 km wood-burning railway and the wood-burning 50 megawatt power plant for the present pulp mill; the proposed hydroelectric dam will put future industrial projects on the same footing. Conversion of the vehicle fleet to manioc alcohol has been contemplated, and may eventually occur once justified by continued oil price increases, and once present bureaucratic problems with licensing an alcohol plant are overcome. Jari officials have also speculated about producing methanol and other hydrocarbons from wood in future stages of the project (Pinto, 1979).

Fig. 6: - *Gmelina arborea* plantation with two brazilnut trees (*Bertholetia exelsa*) spared when the original rain forest was cleared, illustrating the difference in biomass between the two systems. This seven-year-old *Gmelina* is beginning to senesce.

The energy problems of undertakings following the Jari model are, of course, the same problems to be faced by mechanized agriculture throughout the world (cf. Pimentel *et al.*, 1973). Projects of this type will have to be evaluated taking into account the inevitable re-ordering of the relative prices of inputs and products as global energy supplies change both in type and availability. Such projects must always be compared with alternatives; for example, less energy-intensive rice production technologies which have long existed may become more attractive as these changes occur.

A critical problem for long term viability of the silvicultural operations is the question of whether the production of wood will be sufficient to supply the needs of present and future mills. Production will depend on the rate of growth of the trees, which depends on soil conditions, levels of biological problems (as well as fire in the case of *Pinus*), maintenance of plantations, seed quality, vigor of stump sprouts in the case of *Gmelina*, and age at harvest, among other factors. If the cycle were to be hurried to meet the demands of the mills, the calculations would have to be adjusted accordingly. Altering the cycle due to the physiological demands of the species would also affect the areas required. To a certain extent, slower growth can be compensated for by planting larger areas.

One of the obvious types of data to be examined is changes in the levels of soil nutrients. Jari has a soil sampling program which collects approximately 900 samples annually from observation quadrats both to give warning of possible changes in the soils and to predict growth rates of trees. It appears that there are some pressures within the company to stop or reduce the soils monitoring program due to the high cost of the analyses, even though Jari has its own soils laboratory in Monte Dourado. It is important that the data on soil changes be collected and analyzed.

Although many of the soil data have apparently not yet been analyzed, and none of the results have been published, some general trends were described by the head of Jari's Division of Forest Management during a presentation at a meeting of the Brazilian Society for the Progress of Science in July 1979 (Briscoe, 1979). Many of the residual effects of the initial forest clearing are evident during the first few years, such as elevated pH, calcium, magnesium, phosphorus, and potassium and lowered iron and aluminum ion concentrations. The calcium, magnesium, phosphorus, and potassium concentrations fall steadily in the direction of the virgin forest levels. The pH remains stable at a level higher than that under virgin forest, and the toxic iron and aluminum ion concentrations remain at the lowered levels. Additionally, *Gmelina* apparently accumulates calcium and magnesium in its leaves, and both *Gmelina* and *Pinus* plantations have accumulations of organic matter in the soil.

In interpreting the results of soil monitoring studies it is important to focus attention on those factors which are most directly related to the question of sustainability (cf. Fearnside, 1980). Comparisons of soil nutrient levels under silvicultural plantations, or under any other crop, with levels under virgin forest can be quite misleading for several reasons. Firstly, the tropical rain forests of Amazonia have most of their nutrient stores in the living vegetation rather than in the soil; total nutrient stores in the rain forest ecosystem are far greater than those in the plantation agroecosystems due to the dramatic difference in biomas (see Figure 6). Seccondly, the importance of the level of a nutrient in the soil lies in its sufficiency for crop growth, not whether it is higher or lower than the level prevailing under the virgin forest with its different cycling mechanisms, requirements, growth rates, and associated human expectations.

In addition to the problem of comparing observed nutrient levels with appropriate standards, meaningful interpretations in terms of sustainability of production must focus on the elements which are limiting growth. A high level of calcium, magnesium, or organic matter may not be important if phosphorus should prove to be limiting the growth of the trees, to use a frequently limiting element in Amazonian soils as an example. The relations of nutrient levels to growth rates have apparently not yet been determined; as of the time of our visit the only soil character which had been sucessfully correlated with *Gmelina* growth was the clay content of the soil.

The question of soil nutrients is likely to become more important as the project moves beyond the first cycle of plantation cropping. The removal of large amounts of biomass from the system, first by removal of the original forest and then by the removal of each successive crop, cannot help but result in a decline in total nutrient stores if the nutrients removed are not replaced. Although most of the biomass is derived from the ample supplies of water and atmospheric gasses, the mineral nutrients required for plant growth must be supplied from somewhere if they are to be removed in the crop. The geologically old and highly weathered soils of the Amazon *terra firme* cannot supply these through the weathering of igneous or young rocks, and so they must be supplied by man through fertilization. If nutrients are supplied in the form of fertilizers, the question of sustainability from the point of view of soil nutrients becomes one of economics: as long as the cost of fertilizers is justified, nutrients can be maintained at adequate levels indefinitely. Fertilizers are expensive, and are not presently used in the silvicultural plantations at Jari. In the Amazon *terra firme* fertilizing is more costly than in many areas due to fast leaching with heavy rains (2466 mm/year at Jari), and the relatively high rates at which the nutrients supplied are fixed into unusable compounds in the soil. Since nutrients can only be removed from the system without replacement, or "mined", for a finite and probably short period of time, the cost of replacing the nutrients removed will have to be added to the calculations of the profitability of maintaining such a system on a sustainable basis.

It is also important to remember that a reasonable equilibrium in terms of soil nutrients is only one of the criteria which would have to be taken into account for an operation to be sustainable on the long term. If soil degradation should not turn out to be a problem when the data are analyzed, other potential problems such as pests and diseases will still have to be evaluated.

The possibility of pests and/or diseases entering is always a danger with monocultures, especially in the humid tropics where the low density of individuals of the same species serves as a line of defense against these problems for trees in the natural forest (Janzen, 1973). The decimation of the rubber plantations at Fordlândia, in central Pará, by the fungus *Microcylus ulei* between 1926 and 1945 is a classic example of this. The pests and diseases which have already appeared in the plantations of *Gmelina*, in addition to other possible biological threats which have not yet arrived there, have to be considered as risks in developments following the Jari pattern. The probabilities associated with these risks need to be estimated to see if these are compatible with long term sustainability.

In the case of the *várzea* rice plantations at Jari, some of the nutrient requirements are being supplied through fertilization. The soils under rice are also being "mined" for nutrients, since the replenishment of soil fertility in the natural *várzea* from annual flooding has been interrupted by diking. The head researcher in the rice area believes that nitrogen doses will have to be doubled by 1982 for the paddies in production in 1978 (C. H. Wang, personal communication, 1978). Clearly the increased costs of replacing all nutrients removed will have to enter future calculations of profitability for operating the plantation on a sustained basis.

As with the silvicultural plantations, biological problems may also increase with time in the rice plantations. So far the rice has followed the common pattern of introduced monocultures in the tropics of high yields made possible by temporary escape from pests and diseases which would attack the crop in its native area. At Jari the bulk of the production so far has come from the IR22 rice variety, which gives good yields and quality provided it is not attacked by the relatively large number of pests and diseases to which it is susceptible. These include rice blast fungus (*Piricularia oryzae*), planthoppers (Delphacidae), and Hoja Blanca virus, none of which have yet appeared at Jari (IRI Research Institute, 1977: 1). In Colombia and Venezuela, for example, these problems caused IR22 to he replaced by new varieties in 1976, less than three years after it had become the most popular variety (IRI Research Institute, 1977: 1). A continuing program of testing and selecting alternative varieties is maintained at Jari to help assure that appropriate resistant varieties will be on hand for substitution should these pests and diseases appear. Such a substitution would inevitably entail lower production and/or quality than at present. Increased costs for chemical treatments would also be expected if these problems should appear.

Weed problems may also increase significantly in the rice area in the future. For example, wild red rice (*Oryza rufipogon*) is a major problem in many South American countries, and is considered to be the most serious problem affecting paddy in neighboring Guyana (Grist, 1975: 284). This has not yet arrived at Jari (Norgaard, 1979). Barnyard grass (*Echinochloa crusgalli*) has also not yet caused significant problems at Jari, although a small patch of this weed was first observed near the São Raimundo airstrip in 1975 (IRI Research Institute, 1977: 3). *Echinochloa* is a serious problem in many parts of the world; in Italy, for example, it has sometimes caused losses as high as 70 or 80% of the rice crop (Grist, 1975: 280). Low level preventive applications of herbicides being applied at Jari would have to be replaced with a more costly weed control program if these species should spread. Rice yields would probably also be lowered.

3) *Possible Environmental Impacts*

There are a great many present and possible environmental impacts of operations like Jari. The majority of these impacts are not things which would have any effect on the viability of these schemes from the economic point of view (at least from the point of view of the enterprises, if not from the point of view of the other inhabitants of the region). Even if knowledge of these impacts were not of interest to the enterprises themselves, it would be important for the Brazilian government to be aware of them in considering the merits of promoting other Jaris.

The permanent destruction of vast areas of natural forest, with the elimination of unique species and ecosystems, is an obvious effect of development of the Jari type. This is a characteristic of many (but not all) of the possible types of economic development in the Amazon (See Rankin, 1979). This is not a type of effect which could be undone at some future date (cf. Gomez-Pompa *et al.*, 1972). The loss of genetic and ecological resources, in addition to the loss of the possibility of future renewable exploitation of forest products, applies both to areas deforested for plantations and to areas such as the site of the proposed hydroelectric dam.

When the silvicultural plantations are harvested, the existence or not of erosion and silting problems, as well as information on any additional soil compaction from the use of heavy machinery, will be known. Retarded growth due to soil compaction from heavy machinery used in land clearing has been a problem in the past in some parts of the *Gmelina* plantations. This has contributed to the decision to discontinue using heavy machinery in the initial forest clearing operations.

No information is available regarding potential water pollution caused by the pulp mill since the mill began to function. As of the time of our visit the present mill lacked various safeguards against pollution, such as tertiary treatment of wastes and emergency holding ponds capable of holding the contents of the digestors should they need to be drained at one time. Alleged lack of attention to pollution controls has caused concern in the Brazilian press (Borin, 1978), although company representatives insist that the mill complies with government standards (A Crítica, Manaus, 19 de maio de 1978: 12). The water pollution potential of the proposed second pulp and paper mill will, of course, only be known in the future.

Water pollution due to pesticides and other chemicals used in the rice operation is also unknown. Any possible pollution from this source could also change with future changes in choices of chemicals and dosages. The IRI Research Institute staff in the rice project area expect per hectare requirements of chemicals to increase in future years.

The possibility of converting large areas of *várzea* to rice may also have an untoward effect on breeding sites for many riverine fish species (Goulding, forthcoming). Since fish are a principal source of protein for the human population in the Amazon Basin, any such effects should be closely watched.

The fact that risks to the environment such as these are accepted in many types of development in the Amazon and in other places does not mean that these risks should not be taken into account in considering the appropriateness of Jari as a model for other projects in the Amazon. These effects, especially those resulting from deforestation, become even more important when considered with the very important question of long term sustainability of these operations.

Recommendations for Future Research

The questions approached here suggest various lines of future research to arrive at a better evaluation of the applicability of the Jari Project as a model for other developments in the Amazon. In the first place, a study of energy use, especially energy derived from fossil fuels, should be done. The expansion of this type of development in other areas could then be better understood with relation to the projections of the future availability of fuels and in relation to government policies for energy conservation.

Another essential study is the analysis of economic information necessary to judge the profitability of Jari in economic terms. The enormous demands of the operation for capital are evident, but the quantification of these is necessary to allow examination of the feasibility of proposals to follow the path of Jari in other places. The estimates of savings derived from economies of scale and other aspects of the project require a detailed study, and would allow a better evaluation of the applicability of Jari's methods to other development projects. The time for the operation to reach the breakeven point is essential for these calculations. Since other possible projects would always have conditions somewhat different from Jari, this information would be necessary in order to interpret the applicability of the results obtained at Jari to each new project proposed.

A priority project should be the analysis of the data on soil changes. In addition to this, it would be worthwhile to collect much more data on soils both in monitoring programs and in the experimental plantations. The soil results should be published in the public domain, not only as summary statistics, but as data sufficiently detailed to allow interpretation by the scientific community at large.

The data on silvicultural and agricultural experiments should be analyzed and published soon. Scientific debate over data such as these should help both planners thinking of promoting other projects like Jari, and Jari's managers themselves. Jari also would be well advised to intensify its efforts in pursuing experiments with alternative tree species.

Studies should be undertaken to shed light on the identities, population dynamics, and life histories of the pests and diseases which have appeared in the plantations. Such studies would aid greatly both in evaluating the possibility of more serious attacks and in evaluating the possibilities of controlling them.

Basic research is needed to allow determination of the amount of *várzea* which can be safely converted to rice without undue damage to fish breeding populations.

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