Tropical Agroecosystems

These habitats are misunderstood by the temperate zones, mismanaged by the tropics.

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Tropical countries (*1*) have one major problem: how to evolve a social system that is tailored to the carrying capacity of a small resource base and yet have any resources left once the experiments in setting up the system have run their course. This challenge must be met in a very harsh sociobiological environment. Some of the outstanding environmental traits of most tropical countries are (i) past and present harvest of resources by temperate zone countries at prices unrelated to the worth of the resources at their place of origin; (ii) borders established directly or indirectly by temperate zone countries that were partitioning a resource for their own use; (iii) many nearly equal and opposing pressures acting on social structures, pressures generated not so much by the immediate environment as by the hybridization of two or more social structures with radically different goals in resource use; (iv) potential and realized resources per person already lower than in most temperate zone countries; (v) current social aspirations modeled after exploitative social systems that evolved in resource-rich habitats to deal with the harvest of highly pulsed, regionally homogeneous agricultural resources; and (vi) usable productivity per unit of human effort expended that is considerably lower than that in the temperate zones.

Scientists and policy-makers in the temperate zones often express high hopes for the future productivity of tropical agriculture (*2–6*), but constructive criticism of tropical agroecosystems (*2–24*) is in a primitive state. Nearly all research in tropical agriculture is highly reductionist, parochial, and discipline-oriented. This can be quickly observed by perusal of books such as *Farming Systems in the Tropics* (*2*) and *Pests and Diseases of Tropical Crops and Their Control* (*25*), as well as tropical agricultural journals (*26*). Articles with a holistic approach (*21, 27, 28*) are a conspicuous rarity in the trade journals, with the exception of those in recent volumes of *Tropical Science*.

It is widely believed in temperate zone countries that tropical countries disregard the rules of sustained-yield agroecosystems out of ignorance. This condescending evaluation is sometimes correct for certain aspects of the decision-making process. However, there are many more situations in which a key manager is deliberately maximizing short-term returns at the expense of long-term returns. It is not an acceptable defense to point out that technological knowledge, whether that of the culture or of the world at large, is not immediately available to the persons carrying out the act. If the cost of making technological knowledge available were to be charged against the project, even short-term exploitation would often be uneconomical.

Short-term exploitation is conspicuous at all levels of agricultural sophistication in the tropics, except perhaps in those rare "primitive" cultures whose traditions of resource harvest are still intact (*29, 30*). What tropical countries so rarely grasp (*22*) is the fact that agriculture in the temperate zone countries evolved (and is still evolving) from short-term exploitation to sustained-yield agriculture while operating off a much larger natural capital than the tropical countries possess. Furthermore, this natural capital is in part obtained from the tropics (or other "undeveloped" areas) at a cost much less than its value (*31*).

Short-term exploitation is particularly easy in contemporary tropical societies. Government attitudes are generally "frontier exploitative" (*32*), and the "tragedy of the commons" (*33*) is promoted by undefined ownership of resources despite the fact that much of the land has been under stable subsistence agriculture for thousands of years. The temperate zone countries have said to the tropics, "Look at all the nice cash crops you can grow for us to buy," but have neglected to teach the tropics at the same time how to preserve the natural capital and harvest its natural interest.

By assuming that technological ignorance is the sole cause of agricultural problems in the tropics, we allow this ignorance to become the scapegoat for all ills of the agroecosystem (*8, 10, 12*). In fact, the scientific and folklore communities know quite enough to deal with most of the technological problems in tropical agroecosystems, or if not, how to get that information. As Talbot states in his analysis of deterioration of Masai rangeland, "These adverse ecological consequences of the developments were not intentional. They were, however, anticipated, predicted, and documented by some range managers, wildlife ecologists and other biologists who knew the area" (*34*, p. 695). There are many examples of a disastrous tropical agroecosystem existing side by side with a highly successful one—but under a different social system (*35*). This strongly suggests that the social rather than technological environment is at fault in problems of tropical agroecosystems.

It is a common argument that technological advance in the tropics will buy time in the war against population increase and deterioration of natural capital (*5*). However, there is little evidence that anything is being done with the time bought. It is of no use to fund a soil or natural resource survey for a major development scheme (*36, 37*) when there is a preordained number of settlers (*38*). I feel that the plea for technological advance gives the scientific community a perfect excuse to continue their reductionist and esoteric approaches (*12, 39*) rather than to put their efforts into the far more frustrating task of generating sustained-yield tropical agroecosystems and ensuring that technological advances are integrated with them. Few basic studies in tropical biology genuinely seek to

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adapt their technology and findings to the agroecosystem (*40*), although many of them could. A few pious sentences in the introduction (*41*), or the use of economically important animals in experiments, does not remove a study from the category of "biological art form." Some argue that a crisis is needed to alter the situation (*42*). However, like other forms of tropical change, approaching tropical crises tend to be inconspicuous and cannot be recovered from as easily as can crises in the temperate zones.

When examining the problems that confront the development of a sustained-yield tropical agroecosystem (SYTA), it is impossible to separate the biological problems of practicing agriculture in the tropics from those of inadequate education, public facilities, administration, and social aspirations. The regions under discussion are both tropical and undeveloped, and it would be a major tactical error to attribute their overall difficulties to either of these traits.

I focus on some of the areas that seem to be generally unappreciated or ignored by those in the temperate zones who influence the development of SYTA's. In most cases, there is a conflict between optimization and maximization. Reductionism is the order of the day in the contemporary forces shaping SYTA's, and descriptions and analyses of SYTA's are influenced by this philosophy. Tropical agroecosystems are characterized by attempts to maximize outcomes of single processes and the glorification of this maximization. The major challenge in the tropics today is to determine which reductionist lines of research and development should be halted or deflected in deference to optimization processes within holistically designed SYTA's.

Productivity

Net annual primary productivity may be higher in the moist, lowland tropics than anywhere else in the world (*43*), but what really matters is the difference between the cost of turning that productivity into human desiderata and the value of the output (*11, 17, 44, 45*). This difference is very poorly understood as it applies to the tropics. There is a strong tendency for tropical administrators to evaluate labor as free input, to value land only for food and fiber production, and to value products in terms of the world market rather than national life-support systems. When people in the temperate zones say (*46*, p. 440):

> The need is universally recognized for drastic increases in production of food and fiber to feed and clothe a rapidly expanding [tropical] population, a large percentage of which is now undernourished and poorly clothed. It is also recognized that much of the increase required must come from the intensification of agricultural production in the developing nations.

and, "A continual guarantee of increasing agricultural productivity is absolutely essential for our tropics" (*27*, p. 1), they forget that tropical people are no more interested in spending all their waking hours picking beetles off bean bushes and transplanting rice by hand than they are. High-yield tropical agriculture requires immense amounts of very accurate hand care (*2, 47–49*) or tremendous amounts of fossil fuel (*50*), or both.

If agricultural production costs were determined equally and fully throughout the world, most of the lowland tropics would be classified as marginal farmland. Some researchers have come to this conclusion on the basis of weather data alone (*9, 19*). As Paddock puts it, "The hungry nations have been and are hungry because they have a poor piece of real estate" (*15*, p. 898). This is well illustrated by the very high cost and slow rate of development of tropical Australia as compared with temperate Australia. Tropical Australia lacks a large, free labor force and its products are in direct competition with those of temperate Australia (*9*). Oddly, the temperate zones accept the concept of nonagricultural use of marginal farmland at the national level, but not at the international level.

In the tropics, "optimum population size and optimal political area are almost irreconcilable: for a state to reach a reasonable size of population it must overstep the optimum-area limits; for it to remain within a reasonable area means more often than not a midget population. . . ." (*51*, p. 435). There is no biological reason that the capacity to support human life should be evenly distributed over the earth's surface, nor why it should be correlated with the primary productivity of natural ecosystems or with the biomass (standing crop) of these ecosystems.

Temperate-tropical comparisons aside, as population density and cash cropping for export increase, the use of marginal land within the tropics increases. In addition to being fragile and having low productivity, marginal farmlands in the tropics have greatly fluctuating productivity. Colonization of such areas may appear justified for several years, and during this time the invading population severs its cultural-economic connection with its homeland (*18*). Then, when drought (*18, 34*), hurricane (*52*), or resistance to pesticides (*8, 53*) occurs, it is termed a "natural disaster." Because one person can be sustained at a minimal standard of living more easily in the tropics than in the temperate zones, the population in the tropics is likely to have been greater before the catastrophe than it would have been in marginal farmland in the temperate zones.

Year-Round Warmth

The year-round warmth of the lowland tropics is a mixed blessing (*11*). High year-round soil temperatures lead to very rapid breakdown of litter, with subsequent leaching of soil nutrients before they can be taken up by plants (*54*). Plant diseases breed year round (*27*), and pests breed freely in stored food that is not chilled by winter cold (*53*). In addition, stored foods degenerate rapidly because of their own metabolic activity at high temperatures. Even in areas with a severe dry season, many insect species are present as active adults; they are concentrated at local moist sites or are breeding on alternate hosts (*55, 56*). Insect pests are therefore available for immediate colonization of newly planted fields, even during the harshest time of year; the same is probably true of plant diseases (*27*). Tropical herbivorous insects are highly adapted for making local migrations (*55, 56*); this makes it difficult to protect crops by introducing heterogeneity of fields in time and space.

One possible remedy is unpleasant for the conservationist. The agricultural potential of many parts of the seasonally dry tropics might well be improved by systematic destruction of the riparian and other vegetation that is often left for livestock shade, erosion control, and conservation. It might be well to replace the spreading banyan tree with a shed. The tremendous number of species of insects (*56*) and diseases (*27*) that characterizes the tropics might be severely reduced through habitat destruction. This conclusion might change the policy problem to a consideration of how much land should be set aside purely for conservation; the remaining land might not even approximate a natural ecosystem (*57*). Some studies even suggest that "overgrazed" pastures may have a higher overall yield than more carefully managed sites (*58*), especially if the real costs of management are charged against the system. If one wishes a high yield from a particular site, year-round warmth necessitates complex fallow systems to deal with the weeds and insects. However, it is possible that, over large areas, a much lower yield per acre in fields under continuous cultivation could produce the same average yield per acre as fallow systems. Social complications, rather than pests, are likely to be the major barrier to experimentation leading to SYTA's based on extensive, rather than intensive, agriculture; tropical countries are conspicuously hostile to schemes requiring tight administrative control over large areas by single sources of power.

It is not only superior nutrient dynamics of the soil that cause the seasonally dry tropics to be more productive agriculturally than the wet tropical lowlands. In the ever-warm tropics, irrigating between subtropical oases (*36, 59*) and between wet seasons is tempting, but it eliminates the only part of the physical environment that is on the farmer's side in his competition with animals and weeds. The less extreme the dry season (or the more thorough the irrigation), the less extreme are the seasonal dips in insect pest population, with which the farmer can synchronize his crop's growth. There are numerous parallel cases between the natural communities of the tropics and those of temperate zones (*60, 61*).

Ecosystem Fragility

Two very different concepts are involved in the "stability" so often attributed to tropical ecosystems. On the one hand, owing to the apparent lack of variation in the weather within each year (*62*) and the apparently small variations in the climate from year to year, temperate zone peoples often regard the tropics as stable. However, much of this stability is illusory (*63*), as any farmer on a large scale will confirm after plowing under his third attempt to grow rice on a site in the seasonal tropics where rice can be grown only in wet years.

On the other hand, the complex biological systems of the tropical lowlands are very easily perturbed and cannot be easily reconstituted from roadside and woodlot plants and animals (*20*), as could many North American habitats. For this reason, the complex processes in SYTA's are likely to be highly unstable. For example, a great variety of horticultural practices and strains of common tropical food plants have accumulated over the centuries (*64*). They are closely adjusted to local farming conditions and coevolved with the other dietary resources of the area. When high-yield hybrids are introduced, the local strains (*65*) and practices (*66*) are quickly abandoned. This later leads to (i) expensive and complex programs to reevolve these strains when adjusting hybrid monocultures to SYTA's (*65*), (ii) increased dependence on pesticides and complex breeding programs to keep abreast of the pest problem in single-strain monocultures, and (iii) increased imbalance in the distribution of wealth among farmers (*6, 15, 16, 22*). The same may be said for the replacement of indigenous floras by foreign grasses (*67*) and pure stands of foreign trees (*14, 68*), the generation of complex irrigation systems susceptible to market perturbations (*69*), and the destruction of adaptive village structures by population pressure (*70*) or cash cropping (*17, 30*). As mentioned earlier with respect to the pest community, one way to remove fragility is to remove complexity. However, monocultures are clearly unstable in certain circumstances (*23, 57, 71*), at least with respect to the demands made on them.

Crops and Spacing

Long distances in space and time between conspecific plants in the lowland tropics are a major element in their escape from their host-specific herbivores (*11, 13, 60, 61, 72–74*). The monocultures or moderately mixed stands that characterize modern agriculture are thus a much greater departure from normal in the tropics than they are in the temperate zones. In this sense, modern agriculture removes a much greater proportion of the plant's defense in the tropics than in the temperate zones. However, as has been correctly emphasized (*45, 57, 71, 72, 75*), crop heterogeneity is a mixed bag.

First, there is heterogeneity among monoculture fields in time and space. Here, the benefits of heterogeneity depend on whether the vegetation that is interspersed with the crop field sustains a pest community of less risk than the benefit of the entomophagus parasites and predators it also contains. The outcome has to be determined individually for each site, and in the tropics, it may well go either way (*72, 76*). The efficacy of letting a field lie fallow depends also on the proximity of seed sources for wild plants (*30, 77*) and the value of these wild plants for other uses (*78*). We cannot even infer that a reduction in yield after a shortened fallow period is the result of less effective pest control (*79*).

Second, there is heterogeneity within the field. Often viewed as *the* answer for the tropics, this practice has two major problems: harvesting a mixed crop requires greatly increased labor and skill, and different crops may well require mutually incompatible treatments (*48, 68, 80*). Furthermore, crop plants have had much of their chemical and mechanical defense system bred out of them. For many pests, a field of four or five crops may be a monoculture (*13, 74*).

While some of the most complex mixed cropping is in the tropics (*2*), the tropics also have some very successful monoculture agriculture, if human labor is not included in the cost calculation (*47*). Finally, in some cases in the tropics, a monoculture may have a greater productivity than mixed crops (*81*).

Chemical Defenses against Pests

Secondary compounds are a tropical plant's other major form of defense. However, tropical crops, perhaps even more than those in the temperate zones, have had many of their internal defenses bred out of them in man's quest for less toxic or offensive food. It is almost impossible to grow vegetables in pure stands in the lowland tropics without heavy use of pesticides (*11, 82*). Furthermore, when there is intense selection for higher yields and other energy- and nutrient-consuming traits, the plant probably reduces its defense outlay in order to balance its internal resource budget. "Miracle grains" may be especially susceptible to insects and disease for internal reasons, as well as their genetic and horticultural uniformity.

In the tropics, as in the temperate zones, plants' internal defenses are often replaced with pesticides. However, tropical insects should develop resistance to pesticides as fast as or faster than insects in the temperate zones. One of the classic stories of mismanagement of a tropical agroecosystem is the losing battle between large-scale cotton production with the aid of pesticides and the evolution of insects' resistance (*53, 82, 83*). The modern tropics are dotted with doomed pesticide disclimaxes requiring ever-increasing amounts of chemicals for their maintenance. Only now are the side effects being monitored for a few major crops (*84*).

There are several reasons to expect a more rapid evolution of a pesticide-resistant pest community in tropical agroecosystems than in temperate agroecosystems: (i) the coevolution of herbivores and plant chemistry has always been a major aspect of tropical community structure—if there is a biochemical defense genome in insects, this is probably where it is most highly developed (*11*); (ii) the larger the proportion of the insect community that is hit by the pesticide, the more rapidly resistance may be expected to appear (*85*), and in tropical communities it is commonplace for an insect that is rare in nature to be very common in adjacent fields—even the use of systemic pesticides against vampire bats (*86*) has this problem; (iii) if tropical insects are as localized in their geographic distributions as they appear to be, there will be less chance for dilution of resistant genotypes by susceptible genotypes from unsprayed neighboring regions (*82*); and (iv) in species-rich tropical communities (*27, 56, 87*), the pool from which resistant species may be drawn is much larger than in a temperate zone community.

Tree crops, particularly prominent in discussions of tropical agroecosystem potential (*73, 88, 89*), deserve special mention here. In contrast to annual plants, it is impossible to breed resistant tree strains each year in order to keep ahead of pests that are resistant to natural and artificial pesticides. Not only are the breeding times of pest and host disproportionate, but farming tree crops is a long-term investment, and the loss of a tree crop to a newly resistant pest is a much greater loss to the agroecosystem than is the loss of an annual crop.

Soils

Soils in the tropical lowlands are often a nutrient reservoir of very low capacity (*54, 90, 91*). Plant ash from burning, ions from the very rapid litter breakdown, and chemical fertilizers are rapidly leached from the soil if not taken up by plants. There is generally a deep layer of nutrient-poor material over unweathered rock. Chemical fertilizers are a far more complex solution than they would appear to be. Because of the high rate of leaching from the soil, fertilizers must be added in far greater amounts than are actually taken up by the plant, and this creates a pollution problem. This overdose also raises the real cost of the crop. If fertilizers are added frequently, but in small amounts, the amount of work put into the crop is greatly increased. Even less appreciated is the fact that, since the soil nutrient pool is very small, a careful balance of chemical fertilizers must be added to avoid toxicity; sulfate of ammonia, the standard nitrogenous fertilizer in much of the tropics, may be doing more harm than good in that it acidifies an already acid soil (*91*).

In shifting agriculture, fields are commonly left fallow after 2 to 5 years of farming. The standard explanation for this is exhaustion of the nutrients in the soil. However, the real cause is lowered yield, and pest insects and competing weeds probably contribute as much as or more than soil depletion does to lowered yield (*11, 30, 92*). Magnificent stands of native weeds grow in the abandoned fields—and often in fields before they are abandoned. It is a very great mistake to analyze the adaptive significance of subsistence cultivation patterns in the tropics solely in terms of soil nutrient depletion. Ruthenberg's detailed description of tropical agriculture (*2*) contains not one sentence analyzing pest problems. The literature of tropical agriculture is replete with fertilizer trials, and there is almost no information on the dynamics of field colonization by insect and weed faunas (*93*).

Heterogeneity of Pest Distribution

There are at least five major kinds of pest communities that may be encountered as background to a tropical agroecosystem. As mentioned earlier, the insect community of the lowland seasonal tropics differs strikingly from that of the lowland aseasonal tropics, primarily because of the difference in intensity of the dry season in the two habitats.

The third major pest community is that of upper elevations. Cooler soils and the lower humus decomposition rates associated with them are undoubtedly partly responsible for the higher yields per acre of fixed-field agriculture at upper elevations in the tropics [and the focus of major societies on them (*94*)]. However, one cannot ignore the effect of cool weather in slowing the growth rates of insect and weed populations. The elevation at which this effect is maximal is a complicated function of the decline of plant photosynthesis with increasing elevation, the amount of photosynthate metabolized at night, and the growth rates of insect and weed populations. I have recently found that there are more species and a greater biomass in natural insect communities at elevations of 500 to 1000 meters than in the lowland tropics (*56*). This suggests that man may be able to harvest more there if he is clever about it. Ironically, it is the intermediate to high elevations that are often ignored in overall investigations of tropical productivity (*95*, figure 1, p. 47).

The fourth major pest community is that of tropical islands. In addition to having very few species, native insect populations on tropical islands have an amazingly low biomass (*56*). Aside from the obvious potential effects on natural plant community structure and decomposition (*60, 96*), this means that crops on islands should have fewer challenges from native pests than those on the mainland. Further, when a pest is introduced, it is unlikely to be fed on by a native entomophage. These observations speak poorly for the extrapolation of results from tropical island agroecosystem studies (*97*) to mainland circumstances.

The fifth major type of pest community is that produced by plants growing on very poor soils. I have recently found that animal communities in Borneo are drastically reduced when supported by tropical rain forest growing on nutrient-poor white sand soils. The conspicuous success of lowland rice monoculture in Southeast Asia may be due, in part, to a generally depauperate insect community, as compared to that of other parts of the lowland tropics.

Finally, and to put it bluntly, next to nothing is known about the losses caused by insects and weeds in tropical agroecosystems. The evaluation systems so badly needed (*98*) are not only difficult to develop in areas with a poorly educated population, but they may cost more in cash and complexity than the value of the crop.

Cash Cropping

One of the largest stumbling blocks to the development of SYTA's is the philosophy that cash crops, usually for export, are the best use of the land, and that subsistence agriculture [including nomadism (*99*)] is a nuisance that must be tolerated to feed the farmer. For example (*100*, p. 569):

> The basic idea behind argicultural development in East Africa has been that it must increase the cash income from the land. Development has usually meant the introduction of a cash crop, such as cotton, pyrethrum, milk, coffee or tea into a subsistence economy, and the new system is expected to increase the farmer's incomes fivefold or more.

In his 1971 text *Introduction to Tropical Agriculture*, designed for junior high school students in the tropics, Sutherland states, "What is wrong with subsistence agriculture is that everything that is produced is used up by the people. The people only grow what they need" (*4*, p. 5). Such reductionist economics leads easily into very distorted analyses. In his detailed description of tropical farming methods in 1971, Ruthenberg provides an example (*2*, pp. 108–109):

> Although [alternative] practices are traditionally known, they are rarely employed in farming systems where cash cropping has been introduced and where land shortage is a recent phenomenon. In many of these situations, particularly in the drier savanas, gullies increase rapidly in number and size, soil conservation usually being neglected as cash cropping and incomes per head increase, mainly because of the unfavorable short-term input-output relationship of the labor invested. The way out of this undesirable situation probably does not lie in a return to traditional agricultural methods, but in additional cash cropping which, by changing the economic setting, can make soil conservation economically worthwhile.

It is repeatedly stated that tropical staples are ignored in research programs (*101*), while export crops are studied extensively. Some cash cropping is necessary for a country's SYTA, but when the crop is grown for export there is often a large social cost that is not charged against the product. When crops are grown in plantation-size stands, often to generate the crop uniformity desired by temperate zone markets, it disrupts the local agroecosystem. Farming peoples are lured from small holdings by wages and then are unable to return to their land when prices drop or disease eliminates the crop from the area. They cannot return because others have taken over their land, closely adapted seeds and stocks have been lost, sites have degenerated for lack of close care, details of farming the site have been forgotten, and the people are psychologically habituated to the things money can buy. Families on wages set the size of their families by the amount of cash coming in, rather than by the amount of land (homesteads) available and the multitude of other natural systems regulating population. This removes one of the main feedback loops in population control; large tropical families are often the result of planning rather than ignorance of birth control mechanisms.

Subsistence farming of steep slopes and other marginal farmlands is commonly the result when large commercial establishments own or control the best land (*18*). For example: "Whereas smallholders usually have to operate where they are settled, and adapt to the natural habitat, and are thus compelled to diversify production, the firm [engaged in cash farming] can select the most favorable economic and natural location, which is chiefly on land suitable for monoculture" (*2*, p. 194).

As cash cropping becomes a larger proportion of the total production of an area, there is generally a decrease in the variety of crops the farmer can grow and still mesh with the community's or world's plans for development (*15, 102*). The sensitivity of tropical crop monocultures to economic perturbations is well known (*2, 23, 73*). Demand for labor and machinery becomes highly pulsed, and production may be limited by the cost of maintaining people and draft animals between periods of maximum need (*2*). The more pulsed the labor demand, the less possible it is to execute the complex crop timing required to generate high yields. (Experiment stations can produce high yields by virtue of large labor, fossil fuel, and pesticide supplies for their small plots.) As the agroecosystem turns entirely to cash crop production, there is no upper limit to the security desired by the farmer, and the tendency to mine the soil and then move elsewhere becomes overpowering (*103*). Ultimately, the country may find itself in the position of having very little idea of the real value of its farmland in supporting its people on a sustained-yield basis, as their incomes are set by the taste and biochemical whims of the temperate zone countries. One of the major reasons that species-rich neotropical rain forests are not harvested for export as a mixed-species sustained yield, as is done by the African Timber and Plywood Company in Nigeria, is that the North American markets are not willing to accept the large variety of wood types that European markets will accept.

Political Expedience

Although seldom openly acknowledged, much of the motive for governmental manipulation of tropical agroecosystems is political. Occupancy implies ownership; an argument for development of the Australian tropics appears to be the irrational notion that occupancy will decrease the likelihood of its being invaded (*9*)—and this is not an uncommon sentiment with respect to the agricultural development of the Amazon basin. Farming is a job that many administrators assume can be done well by anybody (*18*); agrarian resettlement programs in the tropics commonly have as a driving force the need to quiet restive slum dwellers or starving farmers on marginal land during droughts (*38*). Fragmentation of large landholdings after revolutions need not be the best use of that land, even for a highly nationalized agroecosystem. Experiment stations tend to be political footballs, with the maximum life of an experiment limited to the amount of time between major elections (*18, 104*).

When farming populations are displaced even short distances, their age-old farming traditions often do not function well, and the reeducation programs generated by governments are notorious for technological and psychological insensitivity (*18*). The displaced smallholders are poor farmers, and it is often concluded that the smallholder is incapable of farming the tropics. For example, to make census-taking easier, the government of Sarawak forced the Iban upland rice farmers to live in village (longhouse) units of ten or more families, which increased rates of land degradation near the village and decreased crop protection at greater distances from the village (*30*). The people displaced by hydroelectric impoundments are usually relocated in areas where their age-old riparian farming traditions are of little use; the people downstream are of even less concern (*8*, *18*). The following is a representative story (*105*, p. 597):

> As part of an attempt to introduce cash-cropping to the district, the Zande Scheme opened in the 1940's with the commissioner resettling five thousand homesteads in the Yambio area. The theory was that the cotton-producing scheme would be more successful if the supervision were easier. Ultimately 40 thousand families were resettled, almost the entire population. The cotton crop was a success for the first few years and the yields were high, but after three years of operation the production dropped off markedly. Force was then applied to attain the desired production levels and the Azande became plantation "peons" instead of the prime actors in a great drama of the advance of the stone age.

This would appear to be only quaint history today, but in fact it would probably be impossible to fit this population back into the tightly integrated local ecosystem they once occupied, and such settlement programs are currently in progress elsewhere (*89*).

Interference by the Temperate Zone

Can SYTA's really be developed if new traditions are constantly being bombarded by innovations from other social systems? Well-meaning persons are constantly injecting fragments of temperate zone agricultural technology into the tropics without realizing that much of the value of these fragments is intrinsic not to the technology, but rather to the society in which that technology evolved. Temperate zone countries tend to give "aid" in forms of which they have an excess, or in forms that will benefit their foreign trade (*24*). The Peace Corps, military bases, tractors, miracle grains, grain surpluses, hydroelectric dams, and antibiotics without birth control are a few examples. More often than not, these acts are simply modern versions of buying Manhattan for a few trinkets. That the tropical country "cannot resist" these gratuities is hardly justification for giving them. There appears to be no moral code for the injection of temperate zone technology into the tropics (*106*). Although DDT is banned in the United States, it is freely exported to the tropics. American cigarettes are sold in Central and South America without cancer warning labels. By eradicating tsetse flies, we encourage the raising of cattle in preference to wild game animals, the harvest of which may have been conducive to an SYTA. In the long run, modern drugs without concomitant birth control will take more lives than they save and will lead to a long-range lowering of health and standard of living.

A major force in tropical agroecosystems is "international development," as exported by the temperate zones. It is "a nebulous term, and its meaning seems to reflect the opinion, interest and profession of the beholder" (*107*). An important aspect of international development is illustrated by the following comments on irrigation, which apply equally to other areas (*107*):

> Many development projects, whether in Australia, Massiland, Saudi Arabia, or Rhodesia, fail because they do not take this question of carrying capacity into consideration. Water is provided perhaps, and the land is thus enabled to support more animals and people. But seldom is provision made to hold populations at the new levels that land can support. *In consequence, the land deteriorates, deserts spread or become more barren, and a greater number of people end up worse off than they were before development of the area took place* [italics added]. One can question whether international development agencies should continue to play this losing game.

Conclusion

I have listed some of the ways in which the lowland tropics are not such a warm and wonderful place for the farmer, some of the reasons why it may be unreasonable to expect him to cope with the problems, and some of the ways in which the temperate zones make his task more difficult. The tropics are very close to being a tragedy of the commons on a global scale (*69*, *103*), and it is the temperate zone's shepherds and sheep who are among the greatest offenders (*31*). Given that the temperate zones have some limited amount of resources with which they are willing to repay the tropics, how can these resources best be spent? The first answer, without doubt, is education, and the incorporation of what is already known about the tropics into that education. Second should be the generation of secure psychological and physical resources for governments that show they are enthusiastic about the development of an SYTA. Third should be support of intensive research needed to generate the set of site-specific rules for specific, clearly identified SYTA's.

The subject matter of youths' cultural programming is presumably determined by what they will need during the rest of their lives. A major component of this programming should be the teaching of the socioeconomic rules of a sustained-yield, nonexpanding economy, tuned to the concept of living within the carrying capacity of the country's or region's resources. Incorporating such a process into tropical school systems will cause a major upheaval, if for no other reason than that it will involve an evaluation of the country's resources, what standard of living is to be accepted by those living on them, and who is presently harvesting them. Of even greater impact, it will have to evaluate resources in terms of their ability to raise the standard of living by Y amount for X proportion of the people in the region, rather than in terms of their cash value on the world market.

For such a change to be technologically successful, it will require a great deal of pantropical information exchange. This information exchange will cost a great deal of resource, not only in travel funds and support of on-site study, but in insurance policies for the countries that are willing to take the risk of trying to change from an exploitative agroecosystem to an SYTA. For such an experiment to be sociologically successful, it will require a complete change in tropical educational systems, from emphasizing descriptions of events as they now stand, to emphasizing analysis of why things happen the way they do. This will also be very expensive, not only in retreading the technology and mind-sets of current teaching programs, but in gathering the facts on why the tropics have met their current fate.

There is a surfeit of biological and agricultural reports dealing with ecological experiments and generalities which suggest that such and such will be the outcome if such and such form of resource harvest is attempted. It is clear that human desiderata regarding a particular site are often radically different from the needs of the "average" wild animals and plants that formed the basis for such experiments and generalities. A finely tuned SYTA will come close to providing a unique solution for each region. The generalities that will rule it are highly stochastic. The more tropical the region, the more evenly weighted the suboutcomes will be, and thus the more likely each region will be to have a unique overall outcome. For example, it is easy to imagine four different parts of the tropics, each with the same kind of soil and the same climate, with four different, successful SYTA's, one based on paddy rice, one on shelterwood forestry, one on tourism, and one on shifting maize culture.

A regional experiment station working holistically toward an SYTA is potentially one of the best solutions available. As currently structured, however, almost all tropical experiment stations are inadequate for such a mission. Most commonly they are structured around a single export crop such as coffee, sugar, rubber, cotton, cacao, or tea. A major portion of their budgets comes directly or indirectly from the industry concerned. This industry can hardly be expected to wish to see its production integrated with a sustained-yield system that charges real costs for its materials. When an experiment station is centered around a major food crop, such as rice or maize, the goal becomes one of maximizing production per acre rather than per unit of resource spent; this goal may often be translated into one of generating more people. More general experiment stations tend to be established in the most productive regions of the country and, therefore, receive the most funding. Such regions (islands, intermediate elevations, areas with severe dry seasons) need experiment stations the least because they can often be successfully farmed with only slightly modified temperate zone technologies and philosophies. The administrators of tropical experiment stations often regard their job as a hardship post and tend to orient their research toward the hand that feeds them, which is certainly not the farming communities in which they have been placed.

The tropics do not need more hard cash for tractors; they need a program that will show when, where, and how hand care should be replaced with draft animals, and draft animals with tractors. The tropics do not need more randomly gathered, esoteric or applied agricultural research; they need a means to integrate what is already known into the process of developing SYTA's. The tropics do not need more food as much as a means of evaluating the resources they have and generating social systems that will maximize the standard of living possible with those resources, whatever the size. The tropics need a realistic set of expectations.

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The Colossi of Memnon Revisited

Recent research has established the source of the stone of the two 720-ton statues at Thebes.

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The two colossal statues usually referred to as the "Colossi of Memnon" are prominent features on the western plain of Thebes in Upper Egypt (Fig. 1). The impressive dimensions of the colossi, the quality of the stone, the technology involved in moving them to their present location, and the desire to determine the exact sources of the stone have been the primary reasons for continued interest in the statues. However, the location of the quarry sources, the weights of the statues, and even their dimensions have been matters of disagreement for a long time. In this article we describe the results of field and laboratory investigations that we undertook in an attempt to resolve these questions. To determine the provenience (place of origin) of the rock, which to us was the most important problem, we used neutron activation analysis to obtain elemental composition patterns of samples from the colossi which could be compared with the composition patterns of samples from different quarries (*1*).

The colossi are seated representations of King Amenhotep III (14th century B.C.), with smaller figures of members of his family forming part of the monument. Originally each of the colossi were monolithic, and they stood in front of a sumptuous mortuary temple of the monarch. The temple was destroyed soon after it was built. The statues are made of ferruginous quartzite, probably the hardest stone used for large sculpture in antiquity, and they rest on pedestals of similar material. The quartzite is distinguished not only by its hardness—greater than that of diorite—but also by its beauty and its ability to take on a high polish. There are about six quartzite quarries known in Egypt from which the stone might have been derived; the nearest of these is about 60 kilometers upriver from Thebes. Some of the quarries, however, may not have been able to produce blocks of the size and quality considered suitable for making the statues by the ancient Egyptians.

In antiquity, the colossi acquired fame by a curious development. In 27 B.C. an earthquake toppled the upper half of the northern colossus to the ground (*2*); thereafter in the early morning, strange sounds began to issue from the truncated statue. In contemporary reports these sounds are variously described as sounding like human voices, wind instruments, breaking harp or lyre strings, trumpets, and the sound of clashing cymbals. At this time

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