Part II

TOPICAL and DISCIPLINARY PERSPECTIVES
CHAPTER 4

The Tropical Rain Forest as an Ecosystem

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Tropical rain forests are the prevailing natural vegetation in the humid tropics. Rainfall in the humid tropics generally exceeds 2,000 mm per year and is distributed throughout the year, at least eight months of the year having more than 100 mm of rain. This abundance of rainfall allows forest trees to remain green throughout the year and supports a richness of flora and fauna and a level of biological production that is greater than occurs in any other natural ecosystem in the world.

The structure of a tropical rain forest is quite distinctive. Many of the trees have a characteristic smooth bark, pointed “drip-tip” leaves, and a flared “buttress” base. There is an overwhelming impression of greenness, the trees tending to occur in three vertical layers, though the layers are not distinct (Figure 4.1). The main layer is a dense and continuous canopy of trees that are 30 to 60 meters in height. Another layer consists of even taller trees that protrude above the canopy from place to place. The third layer is a discontinuous understory of trees below the canopy. The tallest trees are adapted to full sunlight; the understory trees are adapted to shade. The understory is dense only in spots where one of the taller trees has fallen and left a gap in the canopy, allowing direct sunlight to come through to the trees below. About 1 to 2 percent of the trees fall each year.

A few hectares of tropical rain forest may contain several hundred species of trees and thousands of species of smaller plants. There are many
Figure 4.1. Profile diagram of a tropical rain forest showing some of the movements of nutrients and energy into and out of the ecosystem (Source: UNESCO 1978).
kinds of plants attached to the trees. Some of them, like vines, are rooted in the ground; others, like epiphytes (e.g., orchids), have their roots in the air and obtain part of their water and nutrients from the air while obtaining the rest from the tree surface on which they live. Because the forest has many overlapping trees at various heights, the sun is not visible from most points along the forest floor. In fact, a typical hectare of tropical rain forest has 5 to 10 hectares of leaves on its trees. As the sunlight must pass through so many leaves, only a fraction of the incoming light (less than 1 percent) actually reaches the forest floor. As a consequence, most rain forests have little vegetation at the ground level. Plants less than a half meter in height cover only 10 to 50 percent of the ground. Nonetheless, a variety of tree seedlings are usually found on the forest floor. The seedlings may hardly be growing, waiting for favorable conditions such as an old tree falling and opening up a patch of sunlight above them.

Associated with this diversity of plant life is a corresponding diversity of animals and microorganisms. Few of the animals are conspicuous to the casual observer because the forest supports few animals at ground level. Many animals — thousands of species of insects, hundreds of species of birds, and numerous monkeys and other arboreal mammals — are in the trees where food (e.g., leaves, fruits, seeds) is found in greater abundance. A great variety of tiny animals (e.g., mites and nematodes) and microorganisms (bacteria, fungi, protozoa) also live in the soil where they feed upon decomposing leaves, and much of the forest's biological activity takes place in the soil. Tree roots are also a major source of food for microorganisms and soil animals. Every cubic centimeter of soil contains billions of bacteria and hundreds of soil animals.

Most of the animals in the forest are specialized as to where they live and what they feed upon. Every species of tree has particular species of insects and other animals which feed upon its leaves, other species which eat its bark, and still others that feed upon its wood. Each of these, as well as the numerous species in the soil, has predators, parasites, and disease organisms that feed upon it.

This picture of a tropical rain forest applies best to lowland forests. At a higher altitude, where the lowland forest is replaced by montane forest (often called “cloud forest”), the trees are shorter (canopy 20 to 30 meters in height), the leaves are smaller, and epiphytes, mosses, and ferns are more abundant. The trees do not grow as fast, but as decomposition is slower because of lower temperatures, there is a greater accumulation of litter and humus in the top layers of the soil. The lowland rain forest is also different where the environment is drier. The trees are shorter, the canopy is more patchy (i.e., the cover is not so continuous), and the total area of leaves in the canopy is less. Many species of trees may lose their leaves during the dry season, and there are fewer species of plants and animals.

The flora and fauna of rain forests can vary even over small distances. As topography, microclimate, soil fertility, and soil drainage change from place
to place, the species of plants and animals in the forest change likewise, though the forest may appear superficially the same. The same kinds of plants tend to be found together under the same microenvironmental conditions, each assemblage of plants and associated animals forming a community. Forest communities in the temperate zone are often conspicuously different from each other, with distinct boundaries between them, but tropical rain forest communities tend to grade continuously into one another.

AN ECOSYSTEM PERSPECTIVE

An ecosystem is everything – plants, animals, microorganisms, air, water, minerals – that occurs in a given spatial area. The size of an ecosystem is defined by the observer. At one extreme, a particle of soil or a few drops of water can be regarded as ecosystems; at the other extreme, the entire planet Earth is an ecosystem. However, it is customary to refer to an area of more or less similar vegetation as an ecosystem. A stand of tropical rain forest is an ecosystem.

The numerous plants, animals, and microorganisms in a tropical rain forest interact in a complex fashion that serves to maintain the integrity of the forest. They display a diversity of biological activities, many of them associated with obtaining food and nutrition. The biological activities may be summarized in terms of two major processes (Figure 4.2):

![Figure 4.2. Energy flow and mineral cycling as they occur in the production-consumption cycle.](image-url)
1. **Production** (also called primary production): The growth of green plants that results from photosynthesis. The carbon from carbon dioxide is joined into carbon chains that form the plants' living tissues (i.e., biomass).

2. **Consumption**: The metabolic activities of animals and microorganisms as they feed on plants, animals, or microorganisms and use the carbon chains in their food for their own growth. In the process, many of the carbon chains are broken apart and end up being released to the atmosphere as carbon dioxide.

**Mineral Cycling**

In the course of production and consumption, mineral nutrients move through the forest ecosystem in a cyclic manner (Figure 4.2). The most important mineral elements are those required for photosynthesis (carbon, hydrogen, and oxygen) and for the construction of proteins and other structural and metabolic compounds (nitrogen, sulphur, phosphorus, calcium, magnesium). Potassium and the **minor elements** (iron, copper, boron, zinc, manganese) can also be important. Minerals are transferred from the nonliving part of the ecosystem into the biological part of the cycle in the course of production. They are returned to the nonliving portion of the ecosystem whenever carbon chains are degraded (i.e., broken apart) in the course of consumption. This returns minerals to the soil where they can sustain further plant production.

These transfers of minerals take place through a variety of biological processes (Figure 4.1). Plants take up water through their roots and transpire (i.e., evaporate) water from their leaves. They take up carbon dioxide and release oxygen during the day, doing the opposite at night. Animals take up oxygen and release carbon dioxide. Some microorganisms consume nitrogen gas; others release it. As a consequence of all these activities, there is a net exchange of gases like carbon dioxide, oxygen, and nitrogen between the soil and the air above the soil, and between the forest and the atmosphere above the forest. During the day the net movement of gas may be in one direction, and at night another.

Figure 4.1 shows that mineral nutrients move through the forest not only in a gaseous form but also in tiny particles of dirt or dust and as ions dissolved in water (e.g., NO₃, PO₄, SO₄). Minerals enter the forest in dust and rainfall that fall from the sky above. As rainwater flows over leaves and branches, it leaches minerals from the leaves and carries them to the soil below. Minerals enter the soil solution as they are dissolved out of tiny rock particles in the soil. Streams and underground water flow into and out of the forest, carrying minerals with them. Water percolates downward, carrying minerals below the reach of tree roots.

The key feature of all these biological and physical processes is that they enable the forest to maintain its integrity. For example, trees on poor,
nutrient-depleted soils are able to continue using mineral nutrients for their growth although minerals are only slowly entering the soil system by weathering of the soil parent material. The only way the forest can retain enough minerals is by minimizing loss of minerals from the system.

Tropical rain forests on poor soils have a variety of intricate mechanisms for holding minerals within the system. Their main strategy is to hold nearly all the minerals of the entire forest system in the living organisms themselves, so only a small fraction of the minerals are "loose" in the soil, where they have the possibility of being washed out of the system. When a leaf falls to the forest floor, fungi begin to grow into it, decomposing it and causing it to disappear within a few weeks. The roots of forest trees and other plants grow into the leaf as it decomposes, and special fungi (mycorrhizae) form a living bridge between the decomposing leaf and the roots that are penetrating it. The fungi absorb the leaf's minerals as they decompose it, and minerals such as phosphorus pass directly from the fungi into tree roots. As a consequence, an atom of phosphorus from a decomposing leaf is never loose in the soil for very long before it is taken up by another plant.

**Energy Flow**

Energy enters the forest as sunlight and undergoes numerous physical transformations (Figure 4.1). Soil and plant surfaces absorb sunlight and emit infrared radiation; warm air carries heat energy as it passes to areas of cooler air. Heat passes between the soil and the air above, and between the forest and the atmosphere — in one direction during the day, and the opposite direction at night.

Biological energy flow (Figure 4.3) refers to the transfer of energy into living organisms by photosynthesis (production) and from one organism to another through the food web (consumption). The movement of energy is not cyclic like the movement of minerals. Energy is incorporated into living tissues by photosynthesis, when sunlight energy is bound into the carbon chains that green plants use for their production (i.e., growth). The carbon chains contain potential energy, which the plants can use to drive the metabolic reactions by which they grow and maintain themselves. Internal consumption of energy for metabolic purposes is respiration, and some of this energy is lost as heat. The net energy that goes into the growth of the plant after using energy for respiration (i.e., its net accumulation of potential energy in carbon chains) is net primary production.

Animals and microorganisms are consumers, which have a variety of ecological roles (e.g., herbivore, frugivore, predator, parasite, pathogen, scavenger, decomposer), depending upon the kind of food they eat, whether it is live or dead, and whether or not they eat it whole. Consumers that feed upon plants utilize the carbon chains in their food as building blocks to construct their own tissues, and they degrade a certain percentage of the chains in order to release energy for their metabolic needs (i.e., respiration).
Figure 4.3. Details of energy flow through a food chain.
Minerals that are acquired in surplus of the needs of the animals or microorganisms are excreted along with other metabolic products to the environment. For example, nitrogen is released as ammonia, urea, or phenolic substances such as those passing into the soil from decomposing *Imperata* leaves, described by Sajise in Chapter 8. The rest of the energy and minerals, which are not excreted by animals or microorganisms, are retained for their growth (Figure 4.3).

The same is true for consumers that feed on other consumers. As one consumer eats another, there is a "flow" of biological energy (in carbon chains) along the food chain, and there is a loss of energy (to respiration) at each step in the food chain. The percentage of energy at one step, which passes to the succeeding step, is the food chain efficiency, typically 10 to 50 percent. Because an animal or microorganism may feed upon more than one kind of plant, animal, etc., the chains are interconnected to form a food web.

Figure 4.4 shows the pattern of production and consumption in a typical undisturbed tropical rain forest. Only a minor fraction of the production passes through animals, and only a miniscule fraction passes to humans (assumed to be hunters and gatherers). Most of the plant material falls to the forest floor to become litter, which is decomposed by soil microorganisms. Although the forest contains many kinds of animals, it does not support a large biomass of animals, in part because the plants are effective at making themselves inedible. The woody parts of the plants are indigestable to most animals because of their cellulose and lignin content. Leaves, fruits, and seeds can be more digestable, but they may also contain chemicals that make them poisonous or interfere with the animals' digestive enzymes. To counter this strategy, many animals specialize on particular species of plants, upon which they can feed successfully despite the toxicity or indigestability. Many plants counter with highly synchronized fruiting, which sometimes occurs as infrequently as once every ten years, so that most of the time there is very little food to sustain the animal populations that specialize in feeding upon them. Not all forest trees follow this strategy, however; many bear fruit randomly throughout the year.

**FOREST ECOSYSTEM ORGANIZATION**

An observer of a tropical rain forest is impressed not only by the diversity of living organisms but also by the fact that all of them appear to fit in. Every species is intimately associated with certain other species. Even though every species has its natural enemies (predators, parasites, diseases), none of the natural enemies is able to eliminate it from the forest. By the same token, any organism that is not a natural member of the forest community may have difficulty surviving there.

The functioning of a forest ecosystem is related to its structure by the fact that its living components (each kind of plant, animal, or microorganism) are well adapted to the physical environment and to one another. The plants
Figure 4.4. Typical flow of biomass in a lowland tropical rain forest. The numbers inside boxes represent dry matter standing crops in tons/hectare. The numbers attached to arrows represent flows in tons/hectare/year (shown where figures are available). The thickness of arrows reflects magnitude of flows (Sources: Richards 1952, Whitmore 1975, Leigh 1975).
are highly adapted to growing under the soil and moisture conditions where they are found; and the animals are adapted to obtaining the particular organisms on which they feed, and they are also adapted to avoiding their enemies. In the case of natural ecosystems such as forests, the coadaptation of the ecosystem's living components to one another is the product of a long process of evolution that has generated a highly intricate organization at the level of the ecosystem as a whole.

The organization of a forest ecosystem can be clarified by comparing it to another kind of system, a television set. A television set has some properties in common with a forest ecosystem — properties that are held in common by all systems. There are additional properties that are unique to ecosystems because of their biological organization. One of the most conspicuous characteristics of a television set is its design. It consists of many components, but each component (a particular transistor, resistor, or capacitor) is suited exactly to the components to which it is connected. If there were simply a random connection of components, the television set would blow up as soon as it was plugged in. An ecosystem has a similar design (coadaptation of components), which contributes to its continued persistence.

The television set and the forest ecosystem derive their whole-system behavior from the fact that the behavior of each component in the system is constrained by the actions of other components. Although every resistor in the television set could theoretically output a wide range of voltages, the output of each resistor depends in fact upon inputs from other components. These inputs are limited to those that generate an orderly television picture. Although all the plants, animals, and microorganisms in a forest have the reproductive capacity to multiply to enormous numbers, their populations are in fact held in check by natural enemies and other natural forces. Because uncontrolled populations would exhaust their food supply, possibly destroying themselves and the system, the ecosystem ensures its persistence by evolving feedback mechanisms for regulating the biological populations within it. Details of population regulation are discussed by Marten in Chapter 6.

There are, however, some important differences between ecosystems and television sets. Ecosystems have a higher level of redundancy than television sets, and this gives them a greater reliability. Because television sets are designed to be constructed as economically as possible, there is only one component for every function. (In this regard, many agroecosystems tend to be similar to television sets.) If a component is removed, the television set ceases to function. In the case of ecosystems, there is a considerable overlap of function between different organisms. If a single species is removed from a tropical rain forest, the forest may continue to function almost as though nothing has happened. In addition, the biological components of an ecosystem are adaptive. A resistor in the television set has the same operating characteristics regardless of the rest of the circuit, and once soldered into
place it cannot change the connection it has to the rest of the components. In contrast, some predators in the forest may switch from one kind of prey to another whenever one prey becomes scarce and the other becomes abundant.

We have seen that a tropical forest is organized in space because of vertical stratification of the trees and because the community of mutually adapted plants, animals, and microorganisms can be different according to different environmental conditions at different sites. Forest ecosystems are also organized in time to persist despite periodic environmental disturbances or pertubations (e.g., fires, typhoons, drought), which might otherwise eliminate them. Ecosystems persist by means of change, an orderly progression in the species composition and structure of the ecosystem (i.e., a change in plant and animal communities) known as succession. If a portion of the forest is destroyed by fire, or if a patch of forest is opened up by a falling tree, a different group of plants and animals replace the old forest. Over the years these plants and animals will in turn be replaced by others in a process that eventually leads to the same forest as before. The mature forest and the successional stages leading up to it constitute a total system that is adapted to the fluctuating environmental conditions of the area (Figure 4.5). At any one moment an area may have a patchwork of communities in various successional stages.

Figure 4.5. Stages of community succession in a tropical rain forest ecosystem. Solid arrows indicate natural changes; dashed arrows indicate changes induced by external disturbance.
It is important to avoid unproven generalities and stereotypes concerning tropical ecosystems. A diversity of soil, rainfall, and other environmental conditions are found in the tropics; and there is a similar variation in the plants, animals, and resulting ecosystems that have developed in those environments, as already indicated by Hutterer in Chapter 5. Some tropical forests have soils that are infertile or easily eroded and others do not. Some will support permanent agriculture; others will not. Some will quickly regenerate a forest the same as the one that was cut; others may first experience a succession to some other kind of vegetation (e.g., grassland), as described by Sajise in Chapter 8, and take many years before returning to the original forest (Figure 4.5).

MAN-MADE ECOSYSTEMS ON FOREST LANDS

The complexity outlined in the preceding pages is not unique to tropical rain forests. Although most ecosystems are considerably less complex than a rain forest, even the simplest ecosystem is overwhelmingly complex. All of the processes — the invisible movement of gases, minerals, and energy; the consumption of one organism by another, etc. — are present in all ecosystems, including agricultural ecosystems.

There are some significant differences between agricultural and forest ecosystems, however. Compared to a forest, most agricultural ecosystems are less complex and intricate in design (i.e., coadaptation of components), there is less redundancy, and most agroecosystems are less able to withstand external disturbances unless sustained by external inputs (e.g., fertilizers, pesticides, plowing). An agricultural ecosystem, such as sugarcane, rice paddy, or pasture, may be even more productive than the natural rain forest that once occupied the same land, and it is specifically designed by man to channel a much greater percentage of its production to human consumption than does a forest, but it is not self-sustaining. The soil may be too infertile for continuous crop growth unless it is fortified with fertilizers, or pest may destroy the crop unless they are held in check by pesticides.

Ecologists have used their knowledge of the structure and function of natural ecosystems to suggest how man-made ecosystems might be designed for harmony, rather than conflict, with nature. One of the major points of conflict lies in human efforts to establish and maintain artificial ecosystems that are different from the natural ecosystems they have replaced. Under such conditions there are strong natural forces to revert to the natural ecosystem by means of community succession. An example is the invasion of tropical slash-burn fields by weeds, which are the first stage in a normal succession that occurs when a patch of forest is opened up (Figure 4.5). Allowing the succession to take place (i.e., allowing a fallow that eventually leads to replacement of the field by a weedless, mature forest) is in accord with natural ecological processes like those described by Sajise in Chapter 8. It may only be possible to combat weeds without a fallow by using external
inputs such as herbicides, which are not only costly but may have undesirable side effects on the environment.

A forest fallow can also rebuild soil that has degraded under agricultural use. It may be difficult to maintain the fertility of the soil in a slash-burn field without applying significant quantities of fertilizers; and even with fertilizers, changes in soil pH or loss of soil organic matter may seriously reduce crop yields. During a forest fallow, the trees draw mineral nutrients from deep in the soil and use those minerals for the growth of their leaves. When the leaves fall to the forest floor, they replenish the mineral supply in the topsoil as they decompose. The decomposing leaves also replenish the organic matter in the topsoil - organic matter that is the basis of the soil's capacity to hold mineral nutrients and store water, sustaining crops through dry periods.

An ecological strategy for sustainable agriculture in the humid tropics should keep options open, avoiding soil degradation or other undesirable changes in the environment that may be difficult to reverse. One approach to sustainable agriculture is to structure the farm to be as similar as possible to the forest it replaced. An overstory of trees can produce litter to maintain soil organic matter and protect the soil surface from erosion, and the less bare soil there is, the less erosion there will be. The erosion in an undisturbed forest can be as little as one-hundredth the erosion with a typical field crop. The complex agricultural systems that are sometimes found in traditional human societies may be similar to forests in their structure and function, allowing them to be sustained with fewer external inputs.

An ecological perspective also permits an evaluation of the limits beyond which attempts to improve on nature are counterproductive. This has been demonstrated in North American forest management, where attempts to increase forest production by eliminating fires from "fire-adapted" forests have led to less frequent but more severe fires due to greater accumulation of litter between fires. The same thing has happened when pesticides have been used to prevent natural forest insect attacks. Pesticides have killed predators that naturally regulate insect pests, allowing the pest populations to increase to a point where they do serious damage unless expensive applications of pesticides are continued on a regular basis. Foresters have concluded it is most practical to allow minor fires and pests outbreaks to take place in a natural fashion.

In conclusion, tropical rain forests are complex ecosystems whose intricate design enables them to persist as a system. Ecological prudence suggests this design should be respected when establishing agriculture on tropical forest lands. There is mounting evidence of a trade-off between the amount of an ecosystem's energy that is channeled to human consumption and the sustainability of that ecosystem. If so, it would appear advisable to reassess the widely held view that the principal aim of agricultural development should be to attain the highest possible yields.
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CHAPTER

Ecology and Evolution of Agriculture in Southeast Asia

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Over the past two decades, archaeological work in Southeast Asia and the western Pacific Islands, particularly New Guinea, has generated much excitement among people interested in plant domestication and the beginning of agriculture. A number of tantalizing findings have been reported: archaeological plant remains; indirect evidence of early cultivation; and traces of prehistoric field systems. The fact that these findings were made was not all that surprising in itself. After all, Southeast Asia constitutes one of the important regions of agricultural production in the world today, and it has long been understood that many of the region’s crops and agricultural practices have their roots in prehistory. What was a major surprise, however, was the unexpectedly early date of many of the findings, several of them apparently indicating an early agricultural phase about eight to ten thousand years ago.

These early dates were all the more interesting as they were being announced at a time when a general reinterpretation of Southeast Asian history and prehistory was going on. Up to about 1950, it had been widely accepted that Southeast Asia was for the most part a culturally passive region

1 A modified and somewhat expanded version of this chapter has been published in the journal *Anthropos* 78(1-2): 169-212, 1983, under the title "The Natural and Cultural History of Southeast Asian Agriculture: Ecological and Evolutionary Considerations." Reprinted by permission of the publisher.
and that its most significant cultural, technological, and political achievements had come about under the influence of the two great and ancient civilizations of the Orient, namely India to the west and China to the north. With the end of the colonial period after World War II, indigenous as well as many foreign scholars started to question this assumption and began to perceive the region as being essentially culturally autonomous, having experienced independent and important historic and prehistoric developments in its own right. The discovery of apparent evidence for extremely early local developments in the domestication of plants and animals came at this time of reorientation and was eagerly accepted as a significant piece of evidence for the independence of developments in Southeast Asia and even the possibility of this region having played a leadership role in world prehistory. Not surprisingly, in the first flush of excitement, there was a tendency to be somewhat uncritical in accepting and interpreting new discoveries. As a consequence, issues and evidence have occasionally become somewhat confused and distorted.

Temper has now cooled down considerably, as the true complexity of the problems has become apparent and as the long and tedious search for solid and unambiguous evidence has continued. This is a good time to pause and consider the question of domestication and early agriculture in Southeast Asia, both from the point of view of the ecological problems involved and by reviewing briefly the actual evidence in hand. This is more than an idle academic exercise. As the Southeast Asian nations struggle to increase the agricultural productivity of their countries, it will be of great value to understand the ecological and evolutionary background of some of their main food crops and, particularly, to understand the context in which indigenous cropping systems and agricultural practices have developed. At the same time, such an understanding will give direction and methodological rigor to the archaeological search for the physical evidence that, we hope, will eventually supply empirical demonstration for the expectations and hypotheses that we now construct on the basis of general ecological principles and theories.

The present chapter does not permit sufficient space to discuss in detail the wide range of environmental, ethnographic, and archaeological issues that have a bearing on the present topic. I will select, therefore, just a few of what I consider to be central points concerning Southeast Asian environments and archaeological evidence and attempt to present them within a broad human ecological framework.

BASIC CONCEPTS

It is good practice in any discussion to define the pivotal concepts at the start. This seems particularly desirable in the present context, as the interest in plant domestication and prehistoric agriculture has a long and venerable history. Over time, the basic concepts have been formulated and reformulated in many different ways and, in the process, have become worn and shapeless.
like an old dress. It is particularly important to reexamine the concepts of "agriculture," "cultivation," and "domestication."

**What is "Agriculture"?**

There has been a tendency to exaggerate the difference between subsistence technologies based on "hunting and gathering" on the one hand, and those based on "food production" on the other. According to a widespread popular notion, hunters simply harvest what grows naturally, while farmers produce food artificially. Although nobody would go so far as to say that farmers make food materialize from ideas or synthesize it from inorganic elements, it is generally assumed that agricultural subsistence is fundamentally and utterly different from a hunting subsistence. Yet, farmers also harvest what nature produces. It is true that agriculturalists manipulate the environments from which they derive their food and other necessities: They concentrate the plants in which they are particularly interested in into dense stands through such methods as artificial seed dispersal (sowing) or other means of propagation (e.g., planting cuttings); they protect these plants against competition and predation by other organisms, both plants and animals; in many cases they supply the concentrated stands with special subsidies of mineral nutrients or water beyond what the natural environment would provide; and so on. All these manipulations may lead to a significant increase in the productivity of the particular plant organisms that are the focus of the farmer's interest, although not necessarily to an increase in the productivity of the ecosystem as a whole.

The central point is, then, that farmers manipulate their environment. However, so do hunters, both deliberately and inadvertently. A survey of ethnographically documented hunting-and-gathering societies will show that virtually all of them interfere with their environments in a variety of ways, many of which result in some increase in the productivity of particular plant and animal species. Human hunters act as dispersal agents for plants; they often look after plants of particular interest to them and suppress their natural enemies and competitors; they set fire to dead or dry vegetation to clear away the detritus and allow fresh growth to develop; they have even been known to dig canals; and they engage in many other acts of environmental modification. (See, in this regard, discussion of Orang Asli environmental modification by Rambo in Chapter 15.) The difference between hunters and farmers is, therefore, not so much one of kind but of degree.

This is not a trivial point because, as others have made clear, successful hunters have to be well attuned to their environments, including the reproductive behavior and life cycles of economically important plants and animals. Thus, the development of agriculture derives not from a "discovery" that plants grow from seeds but represents rather a slow and continuous process of increasing the extent and intensity of the manipulation of natural environments. It is, therefore, quite meaningless to try and fix a point when
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agriculture first occurred, although it may be quite possible to define relatively short periods of time when the process of environmental manipulation intensified very rapidly and when new technological tools appeared in connection with this manipulation (e.g., terracing, irrigation, plow).

Considered from this point of view, the significant question is not when agriculture developed and from where it spread, but rather why humans in various places and at various times felt a need to increase the time and effort spent in wrestling with their environment to coax it to produce a sufficient amount of food. If we approach this question within the framework of human ecology, it will be almost intuitively clear that it is unlikely that we will ever have a simple answer that will be of universal validity.

Types of Agriculture

What has just been said about the difference between hunting and agriculture can also be extended, in some way, to differences between distinct types of agriculture. It need not be pointed out here that there are, in fact, many different forms of agricultural subsistence and technology. Many scholars prefer to use the more general term “cultivation” to refer to all forms of environmental manipulation in which there is a relatively regular, formal, and systematic interference with the natural ecosystem (i.e., deliberate tillage of the soil, sowing, planting, weeding), resulting in a significant increase in the productivity of the cultivated crop(s) beyond what they would have shown under entirely natural conditions. Cultivation, then, is a general term that applies to all forms of agricultural activity.

The term “agriculture” itself in anthropological usage is commonly reserved for highly intensive forms of environmental management that generally involve cultivation in relatively large, and most often permanent, field plots. Frequently, such intensive cultivation systems involve the use of fairly specialized technological methods, such as the use of animal-drawn plows for tillage. Less intensive forms of cultivation are referred to as “horticulture.” In these systems, fields tend to be relatively small, they are often impermanent (shifting cultivation), and tilled with simple technological means (e.g., digging stick, human labor only). Needless to say, there are many forms of agriculture as well as many forms of horticulture. In connection with what has been said above, it also stands to reason that the two types of cultivation systems do not really represent sharply distinct types but rather analytically defined points along a continuum. In practice, it is again often difficult to characterize a given subsistence system as being clearly horticultural or agricultural.

What has been said so far would imply that a particular subsistence system represents not simply a cultural choice but that it is conditioned, even

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2 This formulation is very vague and it is, in fact, quite difficult in some empirical cases (both in archaeology and ethnography) to decide whether a particular human group should be classified as hunters or farmers. This should not be surprising after what has been said in the preceding section.
determined, by the play of a number of ecological variables. The choice between planting hill rice in swidden fields and planting wet rice in pond fields has, therefore, much less to do with whether a community is ethnically Thai or Vietnamese, or Hmong or Karen, than with the ecological conditions of its existence (e.g., climate, topography, soils, drainage, natural vegetation, population size, population density, availability of land). This consideration has important implications for interpreting prehistoric changes in subsistence technology: It means that the appearance of new subsistence techniques does not necessarily imply the presence of new and different populations, or the diffusion of the subsistence techniques from an outside source, but it reflects first and foremost an ecological change. It remains, of course, to investigate the causes of change; the influx of a new population may well figure as such a cause. However, there are also many other possibilities, including conditions of external environmental change (e.g., climatic change, erosion), and internally generated conditions such as population growth or technological innovation. Isolating a single cause will often be difficult, if not impossible, because of the dynamic interaction between the various elements constituting the ecological system.

It should be added here that the diffusion of cultivation techniques does, of course, occur. It is important to recognize, however, that new subsistence techniques are generally not accepted simply because they are available but only if they are seen as desirable and advantageous in a given ecological situation. Once a new technique has been accepted, be it imported or locally developed, it will have its own impact on the ecological system and may, therefore, become an agent of further change.

Cultivation and Domestication

Another concept that is occasionally misunderstood is that of "domestication." Although they often occur in association, the terms cultivation and domestication refer to two very different processes, with neither of them necessarily depending on the other. In other words, it is possible to cultivate nondomesticated plants, while it is also conceivable to have domesticated plants or animals without raising them in a formal cultivation (agricultural) system. The former case is a familiar one; it happens, for instance, when people plant wild flowers in their gardens or when zoos breed lions and giraffes. However, this situation may also occur among hunter-gatherers. Malaysian negritos (Semang), for instance, deliberately or accidentally disperse in the vicinity of their camp sites the seeds of highly valued fruit trees found in the forest. The resulting seedlings and trees almost certainly benefit from a variety of ecological conditions that are peculiar to camp site locations and are related to human activities. In addition, these trees become

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3This explains in part why hunters and gatherers still exist in Southeast Asia although these groups have been in contact with agriculturalists for centuries and perhaps millennia. It also explains why sometimes well-intentioned attempts by development agencies to "improve" indigenous cropping techniques are not being accepted by the local populations.
personal properties of individuals who watch over and protect them. It is possible to say, therefore, that the Semang engage in a simple form of silviculture by raising wild fruit trees. Similarly, Australian aborigines used a species of wild tobacco that is native to Australia (*Nicotiana excelsior*). They collected the plants and often brought them home for consumption in the camp. In this way, the seeds were dispersed in and around caves that were often used for temporary habitation shelters. The nutrient-rich soils and shady location of these sites led to the growth of small but dense and vigorous stands of tobacco plants. Today, the growth of tobacco in rock shelters and in the mouth of caves in interior Australia is usually a good sign that these sites were inhabited prehistorically by aborigines. Again, wild plants of value to human populations grow here under environmental conditions set by humans. Perhaps even more poignant is the case of several species of cultivated plants ("cultivars"), which were widely raised by agricultural groups of North American Indians and which were important in their subsistence systems but were never domesticated.

It is somewhat more difficult to think of examples of the opposite case, the presence of domesticates without cultivation. Although such situations are considerably rarer, they do exist. The most striking instance is perhaps the domestication of the dog during the Upper Palaeolithic, certainly in the context of hunting and gathering.

What, then, is the essence of domestication? Most basically, it represents a process of genetic rather than environmental manipulation. That is, humans interfere with the process of propagation of natural populations of plants and animals by acting as artificial agents of genetic selection. This is done by conferring some sort of reproductive advantage to individuals who have particularly desirable characteristics (e.g., large fruit size, high meat ratio, sweetness, docility, features that make a plant easier to harvest). In principle, the process of domestication is not all that different from genetic change that occurs through natural selection except that the selective agent here is man. The fundamental similarity with natural selection is indicated by the fact that, with sufficient time, artificially selected (domesticated) populations may vary from their ancestral populations to such a degree that they will not be able to interbreed with them successfully and must, therefore, be classified as new species. Most often, domestication and cultivation do go hand in hand. In these cases, domestication may progress to a point where the domesticated species ("domesticate") cannot survive outside the special environmental conditions maintained for its cultivation by man.

**THE ECOLOGY OF DOMESTICATION AND EARLY AGRICULTURE IN SOUTHEAST ASIA**

I have previously stated that the process of cultivation entails human manipulation of natural environments, and that the process of domestication entails human manipulation of the gene pool of natural populations. The genetic makeup of natural populations of plants and animals itself is, of
course, at least partially determined by environmental conditions. It follows, therefore, that an ecological appraisal of native environments, and of potential cultivars and domesticates found in them, is essential to an understanding of prehistoric domestication and the development of agriculture.

The Natural Ecology of the Indo-Pacific Region

Southeast Asia and the islands of the western Pacific fall entirely within a broad environmental zone of the world referred to as "tropics." It is difficult to make generally valid statements about tropical environments since they are extremely diverse as well as complex. In addition, a large portion of the area under consideration here consists of islands of varying size. Islands maintain a range of ecological conditions of their own that depend on island size, topography, distance from a continental land mass, and so forth. Nevertheless, for the purpose on hand, it is defensible to divide tropical environments into two very broad categories: humid tropical environments and seasonally dry tropical environments. It is important, however, to keep in mind that there is in reality a continuous range of variability from one extreme to the other and that there is much variability even within each major division.

Climatically, the humid tropics can be somewhat simplistically characterized as a region where temperatures are consistently high and where the amount of rainfall exceeds evaporation throughout the year or, even more roughly, where average monthly rainfall is not less than 100 mm for any part of the year. The Solomon Islands, the New Hebrides, New Ireland, New Britain, much of New Guinea, much of Celebes, Borneo, western Java, Sumatra, the Malay Peninsula, the eastern part of the Philippines, and Mindanao meet this condition. The major natural vegetation type of the humid tropics is the evergreen rain forest. It typically consists of a tall and extremely lush vegetation, exceedingly rich in species which, however, are often highly dispersed. (See Chapter 4 by Marten for a detailed description of the tropical rain forest ecosystem.)

The very lushness of this vegetation is somewhat deceptive from the point of view of the human forager. Rain forests have generally little vegetation at ground level. Most of the potential plant food occurs high above the ground in the canopy of tall trees and much of it is, in addition, poisonous to humans. Species richness and the high degree of dispersion usually force human foragers to keep track of a large variety of resources that are thinly and unevenly distributed. In the absence of major seasonal environmental stress, rain forest plants also engage in relatively little energy storage in reproductive organs, such as storage of starch and fats in seeds and nuts, or storage of carbohydrates in underground tubers and rhizomes. These environments are, therefore, rather deficient in plant foods for human occupants and have been described as "green deserts." By comparison, animal protein is more easily available, although game animals are also usually not
present in huge numbers and rarely form herd-like groups. Nevertheless, a variety of herbivores are able to utilize plant energy available throughout the tall forest structure (from the forest floor to the top canopy) and to break down specific organic compounds found in plants that are poisonous to humans. These animals, in turn, can then be “harvested” by hunters. Although there are still some questions about this, it appears that it is the scarcity of carbohydrates rather than protein that represents a major limiting factor for low-density human foraging populations in rain forests.

Thus, rain forests do not represent a rich environment for human populations. They have one positive aspect, however, in that the productivity of many of the rain forest plants is relatively easily manipulated. Many of these plants can reproduce vegetatively, that is, they can produce new plants from cuttings and suckers. This makes it relatively easy to interfere with the distribution of these plants by concentrating them in favorable locations and by transferring them to places to which humans have easier and more regular access. At the same time, given the extremely crowded conditions of rain forests, it is not surprising that many of the plants occurring naturally in these environments are limited most strongly by competition from other plant species. They may react, therefore, with a very strong increase in productivity, if this competition is suppressed to some extent through human interference (e.g., reducing the shade by cutting trees, pulling up competitors).

In all, it can be said, then, that minor manipulation of rain forest environments by human occupants is feasible, in fact relatively easy, and has the potential of increasing within limits the productivity of carbohydrate plant foods. Major environmental modifications, on the other hand, are far more difficult to achieve and are possible only with a relatively highly developed technology. While some forest clearance was undoubtedly accomplished prehistorically with stone axes, this must have been a slow and highly labor-intensive process. Since standing rain forests are not amenable to being burned, effective clearing requires the use of metal tools to cut the trees.

*Seasonally dry tropical environments* contrast in many ways with the humid tropics. Climatically, they are characterized by one or two dry seasons per year, that is, periods of varying lengths during which evaporation exceeds the amount of moisture derived from rain. These periods constitute, therefore, seasonally occurring droughts when plant growth is slowed or halted. Yearly average temperature is still high in the seasonal tropics, although daily and seasonal fluctuations tend to be considerably more pronounced than in the humid zone. It is the total amount of rainfall, however, and its distribution throughout the year that constitutes the most important variable distinguishing the two major categories of tropical environments.

The native vegetation of the seasonal tropics varies with the rainfall patterns. In situations where the seasonal drought is short (less than three
months), the typical vegetation consists of forests that are still similar to the evergreen forests of the humid zone. As length and severity of the drought period increase, however, there is a correlated reduction in the height of the forest, in its density, and in its species richness. At the same time, there is an increasing tendency for the various species of trees, shrubs, and herbs to synchronize their reproductive activities in response to the drought conditions. Vegetational communities of the seasonal tropics are not only much less rich in species but tend also to have a great deal more clustering of individuals of the same species. When the drought season exceeds about six to eight weeks in length, the forest breaks up altogether, and is gradually replaced by tree savanna, bush savanna, grass savanna, scrub savanna, and eventually desert.

Excluding conditions of extreme deserts, seasonally dry tropical environments provide as a rule relatively more plant food for human consumption than do rain forests. Most plants go through a burst of rapid production during the rainy period. Toward the end of that season, many of them accumulate energy stores in the form of starches and fats in seeds, nuts, and underground organs. These energy reserves allow the plants to react to the first rains after the dry season with a new spurt of activity. These carbohydrate-rich plant tissues are, of course, a major focus for human collectors. One important point has to be kept in mind, however: Unlike the humid tropics, these plant foods are for the most part available on a highly restricted seasonal basis only. In order to be maximally useful in terms of food supplies throughout the year, they require extensive management in the form of concentrated and coordinated harvest activities during brief periods and subsequent storage. Both are aspects of certain kinds of agriculture and may be considered preadaptations for cultivation.

There is one other element that is of great importance: Most seasonal tropical environments are very easily modified on a large scale through a rather simple tool — fire. This simple device makes it possible not only to clear dry forests and savannas with relative ease but also to clear large areas. Finally, it is also noteworthy that the soils of the seasonal tropics are often highly fertile and can be productive if they are supplied with a sufficient amount of water.

The Ecology of Domestication

By comparison with temperate zones, the tropics are enormously rich in species of plants and animals. This species richness means that tropical environments contain a correspondingly larger number of potential domesticates as well. Indeed, a large variety of plants from all major tropical areas of the world have been domesticated, although relatively few of them are...
widely known by virtue of their having become important staples in our world food economy. Most of these domesticates are, of course, well known to tropical peoples themselves as well as to academic specialists. But there appear to be also a number of domesticated plants that have been replaced during the past few hundred years in local economies by introduced economic plants and have consequently been effectively forgotten. As many as 70 species of useful plants have been reported to occur in active and abandoned swidden fields in Southeast Asia. Many of these are considered weeds or commensals. It is possible, however, that at least some of them actually represent minor indigenous domesticates that have lost their economic importance after the introduction of new cultivars from Africa and particularly the New World beginning primarily in the late fifteenth century. In principle, each tropical region is associated with a suite of plants domesticated in that region, and each suite can be subdivided into at least two sets of plants adapted to humid tropical and seasonally dry conditions respectively.

A tentative and partial list of staple crops domesticated in Southeast Asia and the western Pacific would include the following two groups: (1) plants domesticated in the humid tropics (in alphabetical order): aroid tuber (*Amorphophallus campanulatus*), banana (*Musa* spp.), jow’s tears (*Coix lachrima-jobi*), rice (*Oryza sativa*), sago (*Metroxylon sagu*), taro (*Colocasia* spp., *Alocasia* spp., *Cyrtosperma chamissonis*); (b) plants domesticated in the seasonal tropics: arrowroot (*Tacca leontopetaloides*), millet (*Setaria* sp.), *Pueraria* (*Pueraria lobata*), sugarcane (*Saccharum officinarum*), yam (* Dioscorea alata, D. esculenta*). Besides these species, which may be considered as staples since they supply starches and sugars, there are also many species of vegetables and spices, as well as fruits and nuts. All of these played, and continue to play today, important roles. Among the important effects of genetic changes brought about through domestication are not only morphological changes but also changes in the general ecological adaptation of plants and animals. Such changes may entail development of a tolerance for a

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5 A case in point may be the root crop *Pueraria* (*Pueraria lobata*) that was discovered as a domesticate in Highland New Guinea in the 1960s.

6 It is not possible in the present context to attempt to give a complete list of all these domesticates. Generally, among the vegetables are amaranths (*Amaranthus* spp.), eggplant (*Solanum melongena*), and many pulses (beans). Most of the world’s important spices originated in the Southeast Asian region. Among them are black pepper (*Piper nigrum*), cardamon (*Elettaria cardamomum*), clove (*Syzygium aromaticum*), ginger root (*Zingiber officinale*), nutmeg (*Myristica fragans*), and turmeric (*Curcuma longa*). Tree crops play an important and possibly quite early role among the domesticates of this region. Particularly noteworthy are breadfruit (*Artocarpus communis*), many species of citrus (*Citrus* spp.), coconut palm (*Cocos nucifera*), durian (*Durio zibethinus*), jackfruit (*Artocarpus integrifolia*), mango (*Mangifera indica*), and rambutan (*Nephelium lappaceum*). In addition, there are numerous plants that are domesticated for their narcotic properties, such as the betel nut (*Areca catechu*), the betel leaf (*Piper betle*), and for their fibers, such as cordyline fruticosa and manila hemp (*Musa textilis*). At the present stage of ethnobotanical and palaeobotanical knowledge, it is often difficult to characterize a given plant as a domesticate of the humid or dry tropical zone.
wider range of habitat conditions, and consequently a dispersal of the species beyond its natural range, or (more commonly) a new adaptation to habitat conditions that differ radically from those of the wild ancestor. In most cases, the new adaptations are to habitats with characteristics that can be more easily managed or maintained artificially than those of the plant’s native habitats. This change in habitats, together with a lack of sufficient genetic and palaeobotanical information, makes it often quite difficult to reconstruct whether a given plant was first domesticated in humid or seasonally dry tropical zones.

The Ecology of Cultivation

There are two major cultivation systems in Southeast Asia (and tropical areas in general) involving the use of wet and dry fields respectively. Although there is no empirical proof at this time, ecological considerations indicate that these two systems reflect independent agricultural developments in the two broad environmental categories of the tropics: humid and seasonally dry.

Wet field cultivation represents a system that originated in the humid tropics. It involves the raising of humid tropical crops such as rice and taro in swampy or inundated habitats. It probably has its origin in the manipulation of natural plant communities in swamps and flood plains. Very fundamental ways of manipulating these environments would involve attempts to regulate the water level by draining water, by retaining it through bunds, by heaping soil to raise it above the water level, or by artificially channeling additional water into the field. All these options entail considerable labor investment in the engineering of more or less permanent modifications of the landscape. This in itself would tend to promote repeated use of such fields. In addition, agricultural systems that involve temporary or continuous inundation of the fields generally derive a major portion of their nutrients from minerals and organic materials that are dissolved and suspended in the water that flows into the plots. Wet field systems, therefore, are able to maintain fertility over long periods and are, consequently, in most cases permanent field systems.

Artificial irrigation makes it possible to expand these systems into environmental zones where they would otherwise not be found. In other words, irrigation makes it possible to establish in the seasonal tropics habitats that are typical of the humid tropics. Through this creation of artificial habitats it becomes possible to raise humid tropical crops outside their natural range, in many cases without necessitating major changes in the ecological adaptation of the crops themselves.7

7A word of caution is advised here. While I believe that the argument presented here is correct in its basic outline, it is admittedly highly simplified. Thus, swamps exist also in relatively dry tropical environments, and even deserts, on a seasonal basis. At the same time, there is no assurance that domesticated rice, for instance, derives from an ancestor adapted to the humid tropics. It is conceivable, therefore, although not highly probable, that wet field cultivation developed in dry tropical environments as well and that it went hand in hand with the domestication of rice there. A detailed discussion of this question is not possible in this space.
Cultivation in dry fields represents a system that is originally adapted to the dry tropics and involves the raising of seasonal tropical crops such as yam and millet. Before a plot can be planted, it has to be cleared of its natural vegetation, which is primarily accomplished through burning, although it usually also involves some cutting and felling of larger vegetation elements. The burning not only disposes of unwanted natural vegetation but also releases from it a considerable amount of mineral nutrients that are often essential for the productivity of the field. However, this nutrient supply is soon exhausted both through being taken up by the cultivated crop and through leaching, which occurs at an accelerated rate in the cleared plot.

Since there are very few natural processes that can replenish nutrients in swidden fields at a rate that is even remotely similar to that of the nutrient drain, swidden fields decline rapidly in fertility after the first few crops have been harvested. In addition, competition by noncultivated plants (weeds) is suppressed for a short period through the burning but becomes usually a problem one or two years after initial clearing. Old fields, therefore, are abandoned and new fields are cleared. With time, the abandoned plots will return to a climax vegetation.\(^8\) Thus, the shifting of plots is an important aspect of dry field cultivation in the tropics although it is not entirely synonymous with it. In many parts of Southeast Asia where environmental conditions make the construction and maintenance of wet fields unreasonably costly if not impossible, but where there is insufficient land available for an “integral” shifting cultivation system, dry field cultivation in essentially permanent plots is usually found with short fallow periods. In these cases, however, the fallow fields return only to a grass vegetation, which is still cleared at the end of the fallow period with the help of fire. Such systems are often incorrectly described as “shifting cultivation.”

In principle, dry field cultivation is possible also in the humid tropics. However, as pointed out above, the climax vegetation of the humid tropics, the evergreen rain forest, is a formidable vegetation type that is very difficult to clear with nonindustrial technologies. It is not susceptible to fire unless it is first cut and left to dry. This, I have said, is possible with stone axes but becomes feasible on a larger scale only with the availability of metal tools. Therefore, it must be assumed that the expansion of field cultivation techniques into rain forest areas is a relatively late prehistoric event. Significantly, swidden plots in rain forests in almost all cases tend to be quite small. It should be pointed out, however, that the expansion of dry field cultivation into the rain forest through slash-and-burn technology represents the artificial creation of microhabitats with climatic conditions that resemble those found in the drier tropical zones. This makes it possible to grow seasonal tropical crops in the humid tropics.

\(^8\)Quite commonly, ethnographic swidden cultivators reuse areas before they have completed the full series of natural succession, that is, areas that are covered by secondary rather than primary forest. In many cases, the reason may not so much be insufficient land — and therefore an accelerated swidden cycle — but a human tendency to avoid the larger amount of labor involved in clearing primary forests.
Agricultural ecologists often speak about a third type of cultivation system in Southeast Asia and Oceania: the house garden. It involves the use of small plots adjacent to houses. They are utilized on a relatively permanent basis, that is, continuously at least for the period of time during which the house stands and is inhabited. House gardens differ significantly and in several respects from either dry field or wet field cultivation. In terms of crops, the emphasis in gardens is on supplemental food sources, fruit trees, vegetables, spices, and some industrial materials (fibers), while swidden fields and pond fields are used primarily for the production of staples. The long-range maintenance of fertility in house gardens has to do in part with the complex organization and structure of the cultivated vegetation in these systems, and in part with the fact that these plots usually are supplied with extra nutrients by their cultivators, mostly in the form of organic debris and waste products from the household.

The selection of crops found in house gardens as well as the interactions between these systems and their cultivators make it seem likely that these cultivation systems may have evolved from vegetational complexes (and their interaction with human groups) that were probably found associated with refuse areas surrounding camp sites of foraging populations. As others have pointed out, such rubbish heaps may have been the focal areas for an early domestication of some plants as well the evolution of a number of species of commensals. If this is so, it seems likely that house gardens may represent extremely early forms of cultivation in the tropics.

PREHISTORIC AGRICULTURE IN THE INDO-PACIFIC AREA: THE DATA

Before reviewing the presently available archaeological data bearing on prehistoric domestication and the beginning of agriculture in Southeast Asia and the western Pacific, it is perhaps good to review briefly the main points made earlier. First, it has been said that domestication and cultivation represent two different processes of human manipulation of nature that need not necessarily go hand in hand, although they very often do. Second, both domestication and cultivation are continuous processes. Therefore, it is intrinsically impossible to designate any point as the “first beginning” or “first occurrence” of domestication or agriculture except on an arbitrary basis. It is possible, however, to observe specific events in that process with reasonable archaeological accuracy. Third, there are two groups of domesticates: one deriving from ancestors adapted to the humid tropics, the other deriving from ancestors adapted to the seasonal tropics. Genetic changes accomplished through domestication have made it possible, in part, to grow many of these crops outside their native ranges. Fourth, there are two major systems of cultivation, in wet fields and dry fields, which were developed in the humid and seasonally dry tropics respectively. Certain technological innovations made it possible to transfer these cultivation systems to environmental zones other than those where they were originally developed.
This establishment and maintenance of artificial humid and dry tropical microenvironments generated further possibilities to grow crops outside their natural range. The introduction and spread of such technological innovations may be among the events in the development of cultivation systems that can be observed archaeologically. Finally, house gardens may represent a third and independent cultivation system that is older than the other two.

Unfortunately, it is not possible here to review in great detail all the archaeological evidence bearing on the domestication of Southeast Asian and Pacific crops. It would be particularly desirable to assess the bearing of archaeological evidence on arguments put forward by plant geneticists and plant geographers. Since there is insufficient space to do so here, interested readers are advised to consult the relevant literature in that regard (see the bibliographic notes at the end of this chapter). This chapter is primarily concerned with ecological arguments and I will limit myself, therefore, to evaluating the more important cases of archaeological evidence and interpretations in the framework of these arguments.

Evidence for Domestication

Archaeological evidence for the history of domestication and cultivation of Southeast Asian and Pacific crops is still rare and spotty. There are several reasons for this: the rather small number of archaeological excavations; a largely erroneous but long-held belief that botanical remains do not survive in tropical soils, which has discouraged the application of modern techniques to recover such remains in the process of excavations; and a strong emphasis on the excavation of cave sites, which, for a variety of reasons, are much less likely to contain domesticated, and particularly cultivated, plant materials than most open sites.

Fruits, Vegetables, Condiments, Stimulants, Medicines. Perhaps the most widely known, and most controversial, group of archaeological plant finds is that from the Spirit Cave site in northwestern Thailand. There, Gorman excavated in 1966 evidence of the occupation of this small cave by hunters and collectors, dating from about 9500 to 5500 B.C. This excavation yielded for the first time a significant number of preserved plant remains, evidently left by the prehistoric inhabitants of the site. Among them are a number of tree crops such as candle nut (*Aleurites*), canarium nut (*Canarium*), butter nut (*Madhuca*), almond (*Prunus*), terminalia nut (*Terminalia*), and a chestnut-like nut (*Castanopsis*); several vegetables, among them cucumber (*Cucumis*), bottle gourd (*Lagenaria*), water chestnut (*Trapa*) or gourd (*Luffa*). Excavations at two other caves in the same general region, Banyan...
Valley Cave and Tham Pa Chan, added mango (Mangifera) and rice (Oryza). The occupation of Banyan Valley Cave is tentatively dated from about 3500 B.C. to A.D. 770; that of Tham Pa Chan from about 5500 B.C. to 3500 B.C.

The Spirit Cave finds created at first a good deal of excitement, as there seemed to be reason to believe that some of the remains were of domesticated plants, or at least of plants that were well along the path of domestication. In that case, they would have been among the earliest instances of domestication known at that time. However, the ethnobotanist Yen, who originally identified the archaeological plant material and subsequently carried out extensive field work in northwestern Thailand, has firmly stated that there is at this time no unequivocal evidence for domestication among these finds. Most of the tree crops are still found wild today in primary and secondary forests in the area. The vegetables are today cultivated in swidden plots and house gardens in connection with a variety of other staples. Some of them also have feral or wild forms in the area. It is, of course, possible that some of the species found in the archaeological assemblage reflect plant/man interactions of the sort discussed earlier in this chapter: the dispersal of seeds and cuttings of preferred food plants in the vicinity of camp sites and the eventual development of variants that thrived particularly in the disturbed and enriched habitats typical of such locations. In that case, we would certainly be dealing with plants that cannot simply be classified as wild. Unfortunately, the presently available evidence is insufficient to identify such a situation.

A series of caves in eastern Timor, excavated by Glover in 1966-67, yielded an archaeological plant assemblage that overlaps partially with that from Thailand. The occupation of the sites spans 12,000 years from about 12,000 B.C. to the time of Christ. In the levels predating 3000 B.C., candle nut (Aleurites), hackberry (Celtis), betel nut (Areca), pepper/betel (Piper), and job’s tears (Coix) were recovered. In levels postdating 3000 B.C., there is no hackberry but a number of other plants appear, among them the Polynesian chestnut (Inocarpus), bamboo (Bambusa), bottle gourd (Lagenaria), and possibly foxtail millet (Setaria). Finally several introduced New World crops occur in the top levels of these sites, such as peanuts (Arachis), soursop (Annona), and maize (Zea). With the exception of the introduced species, there is again no satisfactory evidence of the status of domestication of these plants. As Glover points out, the plant assemblages from Thailand and Timor share only a few species, but there is a good deal of similarity between them in terms of the emphasis on fruit trees, stimulants, vegetables, and medicinal or poisonous plants. At the same time, there are virtually no staples in either of the assemblages indicating that they give an incomplete picture of the total subsistence contribution from plants.

More recently, Glover recovered from Ulu Leang Cave in southern Sulawesi a considerable amount of prehistoric plant materials. Occupation of this site dates from about 9000 to 1500 B.C. Only a partial and tentative identification is available at present. The excavator has said that there is less
emphasis on tree fruits and stimulants in the Ulu Leang finds but that there are more grasses, herbs, and shrubs. Perhaps the most interesting and significant find, however, consists of abundant remains of rice (*Oryza sativa*) in layers tentatively dated to about 4000 B.C. The botanical investigation evidently clearly identified the specimens in question as domesticated. This brings us to the question of rice.

**Rice.** Plant geneticists and plant geographers have contributed many and diverse arguments concerning the domestication of rice, the probable wild ancestry of the domesticated species, and the likely geographic region or zone of domestication of this important staple. These cannot be reviewed here. It is important, however, to remind the reader that the major wild form of rice in Asia, *Oryza perennis*, is a perennial adapted to swampy rain forest habitats. Geneticists debate whether the domesticated annual species *O. sativa* evolved directly from *O. perennis*, or whether it derived from an intermediate wild ancestor, possibly an annual that had itself evolved from *O. perennis* with an adaptation to a seasonally dry environment.

Archaeologically, the situation is at this time very difficult to evaluate. Physical remains of prehistoric rice have been found in a number of excavations, among them Ulu Leang Cave in Sulawesi. This find is particularly important, because it is the only one in clearly prehistoric context in Southeast Asia so far where the remains have been unequivocally identified as domesticated. Interestingly enough, although the announced date of ca. 4000 B.C. is still tentative, it might also be the earliest date for domesticated rice in Southeast Asia so far. Of further interest is the fact that southern Sulawesi definitely lies within the humid tropical zone. Rice has also been found in several sites in Thailand, but all of these finds present some problems of identification and dating. Probably the best known finds are from the sites of Non Nok Tha and Ban Chiang in northeastern Thailand. The sites represent a settled agricultural hamlet and a village respectively and have become famous for the apparently early presence of bronze metallurgy. Rice occurs in the basal layers of both sites. Unfortunately, there are some unresolved problems concerning the dating of these sites. Thus, the rice finds could conceivably date to as early as about 4000 B.C. but they could also be between 1,000 to 2,000 years younger. More important is the fact that botanists have characterized the finds as "intermediate between the wild race and the weed race." The already mentioned rice finds from Banyan Valley Cave in northwestern Thailand, dating to somewhere between 3500 B.C. and A.D. 700, have been attributed to a wild form, although botanists have so far been unable to identify the species precisely. At this time, the findings from Thailand could fit into a variety of scenarios concerning the domestication of rice.

Since many specific areas within a large region stretching from India to South China have at some time or other been considered as possible "hearth" for the domestication of rice, we need to touch briefly also on archaeological finds of rice made elsewhere within that zone. Prehistoric
remains of rice have been recovered in a number of Indian sites. They generally date from about 2000 B.C. or later, and at least some of them seem to be confidently identified as domesticated. There has recently also been a preliminary report of finds of domesticated rice dating to before 4500 B.C., but I am not aware of any further confirmation. Physical remains of prehistoric grains of presumably domesticated rice have also been recovered in sites in Viet-Nam with dates ranging between 1000 and 2000 B.C. Since very little specific detail is available on this archaeological work, however, it is difficult to evaluate both dating and botanical identification. Claims by Vietnamese archaeologists of rice cultivation in "early neolithic" context (Bac-sonian) should, at this time, be understood as hypotheses or expectations rather than statements based on positive evidence. Similarly, a number of finds of what is said to be *Oryza sativa* have been reported from sites in both north and south China. Not surprisingly, the oldest dates occur in the south and are said to reach back to about 4000 B.C. Again, there is insufficient information for an independent evaluation of dating and botanical determinations of domestication. The latter appear to be quite secure, while there is some reason to hesitate in accepting the dates at face value at this time.

In all, then, the presently available archaeological information is inadequate to reconstruct the process of domestication of rice, or even to test hypotheses developed by plant geographers and geneticists. One particular school of thought would seem to be best able to account for the evidence on hand at this time. This school holds that the domestication of rice (and that of a number of other tropical crops as well) did not occur in a small and well-defined area but over a broad region and over a very long period of time, involving many separate genetic lineages as well as multiple interactions between wild, domesticated, and feral forms. This view fits well with the concept of domestication presented earlier and implies that the domestication process continues today.  

**Root Crops.** In spite of the fact that a number of root crops are among the important staples domesticated in the Southeast Asia-western Pacific region, and that some of them play an essential role in the subsistence economy of many traditional peoples of that region even today, no archaeological remains of these crops have been found whatsoever. It is not possible, therefore, to comment on the history of domestication and cultivation of these staples from an archaeological point of view and arguments in this regard remain for the time being entirely in the hands of botanists and ecologists.

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9 Modern processes of plant breeding in scientific laboratories and experimental farms are, of course, also a form of domestication. However, I am excluding this approach from consideration here, limiting myself to the interactions of nonindustrialized populations with the plant world.
Evidence of Cultivation

Since domestication and cultivation constitute two different processes of human manipulation of the environment that can occur independently, the finding of domesticated plant remains does not necessarily constitute evidence of agriculture (although such an assumption is often correct), nor does the finding of wild plant remains indicate with certainty the absence of it. This state of affairs complicates considerably the archaeological search for evidence bearing on the development of cultivation. For the most part, the archaeological evidence is of an indirect nature. Even when actual cultivation tools (e.g., hoes, digging sticks) or cultivation features (e.g., irrigation canals) are unearthed, they are often difficult to identify and interpret by themselves. This should not be surprising, since cultivation systems are complex systems that involve the interaction of a large number of physical, biological, and cultural variables. Any one of these elements could, in a similar or identical form, be part of a number of different systems. Reconstruction of prehistoric cultivation systems and cultivation practices usually involves, therefore, multiple lines of evidence.

It was at one time believed that certain technological elements such as polished stone axes and pottery were marks of a "neolithic" phase of cultural development and, by implication, of plant cultivation. It is now known that the archaeological presence of such technologies by itself has little to do with agriculture and that both pottery and axes may be present among hunter-gatherers, while agricultural subsistence systems can exist without either of these elements. This fact, demonstrated well archaeologically, removes from consideration in the present context a large series of finds from Southeast Asia. Nevertheless, there are a few finds that do constitute indirect evidence of cultivation.

Glover believes that the appearance between 3000 and 1500 B.C. of pottery, the introduction of pig, monkey, and civet cat, and a more or less simultaneous increase in the intensity of use of the sites in eastern Timor indicates "the arrival of some form of agriculture." The argument itself is reasonable but, as Glover himself points out, there is no evidence for the particular form of agriculture that may have been present, or the kinds of crops cultivated.

A somewhat similar situation exists in the case of pollen evidence for the removal of native forest vegetation and its replacement with savanna or grassland environments. In certain cases it can be argued that such a change could only have been brought about through human interference with the forest climax, that is, agricultural clearing. This is particularly true when the change in pollen spectra is accompanied by a sudden rise in the amount of small fragments of charcoal in the soil, which presumably derive from use of fire in clearing the forest. While such evidence is extremely important, it is often unable to provide specifics about agricultural system and crop complex. Evidence of this sort exists in the form of a pollen core from Sun-Moon Lake in central Taiwan, which supposedly shows a dramatic increase in charcoal content around 9000 B.C. and a steep increase in the pollen of grasses and
Chenopodiaceae around 2000 B.C. The validity of the 9000 B.C. date, however, has been questioned and has not been further promoted by the original investigators Chang and Tsukada. Pollen cores from Lake Padang, actually a swamp, in central Sumatra, show an appearance and quick increase in grass pollen starting around 2000 B.C. This has, again, been attributed to human destruction of the natural forest environment and its replacement with a cultivated landscape.

The most striking, and most surprising, evidence comes from the Central Highlands of New Guinea from where we have both pollen cores and excavated agricultural features and tools. Several cores indicate forest clearance by about 3000 B.C., followed by more or less periodic fluctuations in forest cover. At the same time, archaeologist Golson and his associates excavated remains of five different systems of drainage ditches, which were constructed and abandoned during alternating periods. The greatest archaeological surprise after discovery of these drainage canals was the extremely early date for their first construction, which goes back to about 7000 B.C.10 Unfortunately, in spite of the multiple evidence, which also includes well-preserved wooden tools such as digging spades, it is unknown what crops were cultivated in these drained swamps, and numerous other important details remain unclear as well.

Some Specific Questions

There are a number of traditional concerns regarding the development of domestication and agriculture in Southeast Asia that need to be briefly addressed in the present context. They have to do with a possible chronological sequence of plants or crops undergoing the process of domestication and cultivation, and their spread from a center into outlying areas. Unfortunately, no solid archaeological evidence bearing on these questions is yet available. Nevertheless, they are best discussed at this point, after the fragmentary data for domestication and cultivation have been reviewed.

Traditional views of Southeast Asian prehistory have held that root crops represent the earliest domesticates and that they were cultivated in swidden fields. It was also widely believed that the domestication and cultivation of

10 The New Guinea evidence is particularly intriguing from the viewpoint of science history. Before European exploration of the Highlands in the early 1930s, it was generally assumed that these forbidding mountains were essentially uninhabited. When Europeans finally penetrated these areas, however, they found that some of the highland valleys and plateaus maintained extremely high population densities, in many cases far above those of coastal plains. In the 1950s and 1960s, it was thought that this high population density was a relatively recent phenomenon, having come about in the wake of the introduction of the sweet potato in historic times. This New World crop, it was believed, quickly became the basis of highly productive horticultural systems that would have been impossible with native crops only. The new evidence now indicates that highly intensive cultivation systems were present periodically long before the sweet potato could possibly have been present, even if it was introduced prehistorically, and that these systems were probably associated with substantial populations.
rice occurred first in the context of swidden fields and that this cereal was later reintroduced to an aquatic environment and then raised in flooded fields. In essence, this view rests on a misinterpretation of the natural and human ecology of Southeast Asia. It is based on the assumption that the subsistence technology and the sociopolitical organization of living populations are unchanged survivals of prehistoric phases or stages of development. This is, however, in most cases an unwarranted and even illogical assumption. As alluded to earlier, the fact that one population engages in swidden cultivation while another raises rice in flooded fields reflects adaptations to different environmental conditions. Even if it could be demonstrated that a specific case of contemporary swidden cultivation represents a survival of some early prehistoric subsistence system, it would still have to be explained why the population of swidden cultivators never switched to the supposedly superior and more productive system of wet-rice cultivation. Such a situation certainly cannot simply be ascribed to cultural conservatism, since virtually all swidden systems in Southeast Asia have incorporated New World plants into their crop complexes, and such introduced crops constitute often the dominant staple. That the explanation has to be sought on an ecological level is further indicated by the fact that many contemporary populations in Southeast Asia combine several different cultivation practices in their subsistence economies. Particulars about the use of these practices are invariably related to variation in several important environmental parameters within the habitats of these societies.

In the face of ecological arguments, it is unreasonable to postulate a root crop – cereal crop sequence and to correlate it with a shifting (dry field) to permanent (wet field) sequence of cultivation systems. Such sequences may well exist in specific local cases in the Southeast Asian-Pacific region but cannot be assumed to have universal validity within that part of the world. It must be remembered that different sets of domesticates and cultivars are typical of the humid and dry tropics respectively and the same is true of basic cultivation systems. As far as domestication is concerned, therefore, root crops, cereal crops, vegetables, or fruit trees may be among the earliest domesticates in a given geographical area, either individually or in combinations involving representatives of any of these groups. It is at present virtually impossible to predict particulars without knowing more about palaeoenvironments and the human ecology of prehistoric periods. Only one thing is certain at this time: that the process of domestication has little to do with “discovering” that certain plants can be raised deliberately by man from either cuttings or seeds. Similar considerations apply with regard to historical or developmental sequences of cultivation systems. If the ecological outline I presented is correct, one would have to expect that swidden systems would develop first in the dry tropics, while wet field systems would develop first in the humid tropics.

The historical reconstruction and the search for empirical evidence are considerably complicated, however, by the fact that both genetic and
environmental manipulations involved in domestication and cultivation make it possible to transfer crops and cultivation systems into different environments. This can, in fact, happen relatively early in the process. Thus, seasonal floods or permanent streams in dry tropical areas can become the basis for the establishment of wet field systems (artificial humid tropical habitats), while slash-and-burn techniques can establish artificial dry tropical habitats in the humid tropics. It is possible, and even to be expected, that major elaborations and modifications of cultivation techniques occur in connection with such habitat transfers. At the same time, it must also be kept in mind that specific environmental, technological, and sociological conditions may set limits to habitat transfers, and it is here that the explanation has to be sought for the diversity of cultivation practices found in Southeast Asia today, and probably also in prehistory.¹¹

The transfer of crops from one environmental zone into another, the independent evolution in different environments of feral and weedy species from the varieties undergoing domestication, backcrossing with these weedy and feral forms, and repeated exchange of domesticated forms between areas and environments can lead to an exceedingly complex and complicated history of these crops. It is unlikely, therefore, that we will be able to pinpoint for most crops a narrow geographical locus as "the hearth" of their domestication, or that we will be able to reconstruct a simple unilineal history of their development.

One specific argument raised traditionally in favor of a sequential development of a root crop phase followed by a phase of cereal (rice) cultivation must be briefly mentioned. It has to do with the total absence of rice cultivation in the premodern subsistence systems of the Pacific Islands, including New Guinea, and a reliance there on root crop staples. This would indicate, so the argument goes, that the expansion of Austronesian settlers from Southeast Asia into the Oceanic region occurred at a time when these pioneers were familiar with root crop horticulture but not with cereal agriculture. Thus Southeast Asian root crops and other economic plants diffused with them, but not rice. A number of voices have been raised against this argument, but it is most seriously weakened by strong linguistic evidence that the ancestral population of the Pacific Austronesians already had rice cultivation in their subsistence repertoire. An ecological explanation is probably most compelling in explaining the absence of rice in the Pacific, although we lack at present sufficient information (archaeological, palaeoenvironmental, etc.) to construct a specific argument of that sort with confidence. According to my own view of the human ecology of the

¹¹To be somewhat more concrete, the maintenance of a swidden system in a given area may have to do, among other things, with soils or topographical conditions that essentially rule out the establishment of wet fields, the fact that locational conditions would necessitate such enormous investments in tillage and irrigation technology that they would exceed the benefits derived in increased production, insufficient population size and density to provide the necessary labor to maintain intensively cultivated permanent field systems, or a combination of several such variables.
region, expounded in this chapter, which assumes that the earliest phase of
the domestication and cultivation of rice occurred in the humid tropics, it
seems reasonable to propose that the Austronesian expansion took place at a
time when rice cultivation had not yet been adapted to dry tropical
environments. As the Austronesians expanded into the relatively arid zone of
eastern Indonesia, therefore, it was ecologically advantageous for them to
abandon the cultivation of rice and rely on tubers and other crops instead.
Consequently, the population directly ancestral to the settlers of the Pacific
had neither seeds nor cultivation methods of that cereal to take with them,
although they did retain a linguistic memory of it.

CONCLUSIONS

Before concluding this chapter, it must be stressed once more that the
statements made here present both a sketchy and highly simplified view of
problems and data concerning the history of domestication and cultivation in
Southeast Asia and the western Pacific. This has to do with space
constraints in the context of the present publication as well as with lack of
specific information in some crucial areas. Nevertheless, I feel confident that
the general approach advocated here is at least in principle sound and fruitful.
The most basic premise is that human populations articulate and interact
with their environments most directly through their subsistence economies.
The form and configuration of subsistence systems, therefore, is very strongly
constrained by ecological conditions. As a consequence, it is relatively
meaningless to consider the cultivation of root crops or the building of
elaborately terraced and irrigated field systems simply as cultural
preferences. Such ecological considerations apply also to the prehistoric study of
domestication and agriculture. Any investigation of the evolution of
domesticated plants and of subsistence economies must begin with a
consideration of the ecological variables involved. Any other approach, any
purely empirical search for prehistoric evidence for the development of such
systems, for instance, will constitute little more than haphazard groping.

Naturally, ecological models are at first constructed on the basis of an
understanding of contemporary ecological relationships and systems. On the
other hand, our view of contemporary ecological relationships is incomplete
and untested until it has been held up against, and complemented with, a
knowledge of long-range interactions and developments. More concretely, an
understanding of the development of Southeast Asian crops and agricultural
systems will elude us, unless our study is guided by ecological insights derived
from contemporary agricultural systems. By the same token, however, our
understanding of contemporary agricultural systems in Southeast Asia, and
their potential for further development, can and must derive essential
contributions from a study of their prehistoric development. While this may
at first seem like a paradoxical situation, it is in reality a reflection of the
dynamic nature of all ecological systems. No ecological system can be
completely understood outside its historical context.
SOME BIBLIOGRAPHIC NOTES

Although I am ultimately responsible for the overall content of this paper and for the way in which various ideas have been presented, most of the ideas themselves are not my own but have been taken from the literature or from conversations with friends and colleagues. However, in order to make the present chapter less cumbersome and more readable, I have dispensed with bibliographic citations in the text. To compensate at least partially for this lapse, the following bibliographic notes are intended as a preliminary guide for readers who would like to pursue some of the issues in more detail. The bibliographic items provided below constitute by no means a complete list of references for this paper but only a first gateway to the relevant literature. Much more extensive materials will be found in the bibliographies of the books and papers cited here.

Two relatively recent collections of papers contain a broad range of both theoretical and empirical studies relating to the origin of domestication and agriculture. They are 
Origins of Agriculture, edited by Charles A. Reed (The Hague: Mouton, 1977); and


Population ecology is a science that explains the distribution and abundance of living organisms (Begon and Mortimer 1981, Berryman 1981, Harper 1977, Krebs 1978, Ricklefs 1979, Watt 1968). Why does a particular species of plant, animal, or microorganism occur in some places and not others? Why does it occur at a particular abundance instead of a higher abundance or a lower abundance? These are the central questions of population ecology.

Population ecology is also important for agroecosystem research. Agroecosystems contain crops and livestock and many other species of living organisms. The occurrence of particular species of plants, animals and microorganisms in an agricultural field and the abundance of each of those species can have a decisive impact on how the agroecosystem functions from a human perspective. In addition to interactions among the cultivated plants themselves, some organisms have a direct impact on crops as pests that compete with the crops for light, water, or mineral nutrients or feed upon the crops as herbivores, parasites, or pathogens. Other organisms are essential to sustaining crop production on a long-term basis because of their roles in ecosystem processes. For example, soil animals, fungi, and bacteria are essential to the maintenance of soil fertility because of their role in biological decomposition which releases mineral nutrients into the soil for utilization by crops. Other animals and microorganisms are natural enemies of crop pests, preventing the pests from becoming abundant enough to cause serious crop damage.
DISTRIBUTION

The distribution of a given species depends upon two factors: (1) the distribution of suitable habitat for that species; and (2) areas of suitable habitat, which the species actually reaches.

The habitat of a species is the kind of ecosystem in which it normally lives. A habitat is suitable if (1) it contains the resources necessary to sustain the species, (2) its physical properties do not exceed the tolerance of the species, and (3) it contains no other living organisms that threaten the survival or well-being of the species. The features of a habitat, which provide a place for a particular species in that habitat, are encapsulated by the concept of ecological niche. An ecological niche reflects the functional role of a particular species in the ecosystem, how it relates to the physical environment and to other living organisms in the ecosystem. The niche is defined by the temporal and spatial pattern of resources such as food and shelter, physical factors such as microclimate (temperature and humidity), and all living organisms that impact upon the given species. Temporal patterns include both diurnal and seasonal fluctuations through time, whereas spatial patterns include horizontal and vertical distribution in space. An ecological niche is a dynamic concept not only because of fluctuations in the physical environment but also because the niche for one species includes fluctuating populations of other species of living organisms with which it interacts.

An agricultural field is a habitat. However, even though a field may be a suitable habitat for many kinds of organisms (because it contains suitable ecological niches for those organisms), many of the species may be absent because they have not had an opportunity to colonize the habitat. An agricultural landscape is a patchwork of diverse habitats, every point in the patchwork constantly changing from one month to the next. A particular field may not provide a suitable habitat for a given species during one month but may become suitable the following month, as a new crop is planted or a crop reaches a new stage of growth. Whether a particular species actually colonizes a newly suitable habitat depends upon whether that species is already present in nearby habitats and its ability to traverse unfavorable habitats to reach the new habitat.

ABUNDANCE

Population Growth Curve

Abundance is the number of individuals of a particular species per unit area of land. It is possible to gain insight into the processes that determine population abundance by contemplating the growth of a population that colonizes a new habitat (Figure 6.1). If a female aphid settles in a bean field that is free of aphids, the aphid produces offspring quite rapidly because of the abundance of food. Within a few weeks there are dozens of aphids, and in a few more weeks there are hundreds. The aphid population doubles several
times a week; population growth is exponential. At first, despite this high rate of increase, the aphids are hardly noticeable, but after a few weeks there are enough aphids so their population becomes evident. This rapid growth phase is short-lived, however, because the quality of the beans on which the aphids are feeding begins to deteriorate as the aphids become more numerous and feed on them more heavily. The aphids are now competing with one another for food. Because of their impact on the beans, the aphids are no longer so well nourished; they produce fewer offspring; they are more susceptible to predators, parasites, and diseases; and the population grows more slowly. The population finally levels off when the production of new offspring no longer exceeds the deaths of aphids from natural causes. The final abundance is the bean field’s *carrying capacity* for aphids. The food resources for aphids in the field will not support a larger population.

This is an idealized picture of population growth in a constant environment. The growth of real populations is not exactly as pictured because their environment, including their food resource, is not constant. Moreover, a growing population may temporarily overshoot the carrying capacity of its environment before leveling off (the dashed part of the curve in Figure 6.1) because of lags in the impact of environmental conditions on birth and death rates. In some cases, for example, the rabbits that were introduced to Laysan Island in the Hawaiian chain, the population overshoot
was so pronounced that the rabbits effectively destroyed their food source and then starved to death.

However, the idealized growth curve serves to illustrate some important features of population growth: (1) exponential (i.e., geometric) growth of a population when it is small, and (2) the leveling off of a population when it has reached the capacity of its environment to support it. The carrying capacity of a habitat depends upon the ecological niche of the species involved. The carrying capacity is high if there is a large quantity of resources (e.g., beans) in the species' ecological niche.

If two species have similar ecological niches, particularly if they utilize the same resources, then an increase in the abundance of one species can decrease the carrying capacity of the habitat for the other species. This competition between species can lead in extreme cases to the exclusion of one species by another if one species is more efficient at utilizing the resources, particularly when competition reduces resources to a level where one of the species cannot achieve sufficient reproduction to offset its natural mortality. The numerous species that coexist in natural ecosystems are able to do so because they have coevolved subtle but significant differences in the way they utilize resources (i.e., they have different ecological niches). In man-made ecosystems (e.g., agricultural fields) some of the organisms (e.g., crops and weeds) may not avoid competition in this way, and weeds may have a devastating effect on crops as a consequence. However, the competitive impact of weeds may be relatively mild in traditional agricultural systems that are a product of centuries of coevolution between weeds and crops.

Different species of plants and animals can be classified according to how they fall on a spectrum from r to K in their pattern of population growth. r refers to the capacity for increase when the population is small (part A of Figure 6.1), and species with "r-strategies" have an especially high capacity for population growth when their abundance is low. These are typically "opportunistic species" with high powers of dispersal and an ability to establish themselves rapidly in a fluctuating environment whenever or wherever conditions become favorable. K refers to carrying capacity (part C of Figure 6.1). Species with "K-strategies" are well adapted to living in a well-established ecological community in which their population and the population of other species are more or less at carrying capacity. Species with a K-strategy are effective competitors, able to hold their own in an environment that is "crowded" with their own and other species.

Annual field crops are r-strategy plants that grow rapidly in a disturbed environment (e.g., a newly plowed field) and place a large percentage of their production into reproduction (i.e., seeds or fruits) for rapid population growth. Humans have exploited this property of field crops by consuming the seeds or fruits and breeding the crops to emphasize even further this aspect of their r-strategy. Because most agricultural fields change so much in the course
of a crop cycle, the majority of weeds, insects, diseases, and other agricultural pests are species that, like the crops, follow an r-strategy as also indicated by Sajise in Chapter 8. Perennial crops (e.g., fruit trees) follow more of a K-strategy than field crops, and although some pests of perennial crops follow an r-strategy, perennial crops often have many pests that follow more of a K-strategy. Whereas, r-strategy pests can increase rapidly in numbers and devastate the crop, K-strategy pests tend to be around all the time in numbers that never cause serious crop damage.

Population Regulation

The question of why particular species of plants and animals have the abundance they do can be expressed as a question concerning population regulation. Given the high reproductive capacity of living organisms, why don't their populations continue to increase indefinitely? The explanation lies in negative feedback, the fact that the balance of births and deaths in a population depends upon the population's abundance in such a way that, whenever the abundance of the population is significantly greater or less than its equilibrium abundance, the balance of births and deaths tends to bring the population closer to the equilibrium. As a rule, when a population becomes more abundant, its birth rate declines and its death rate increases (Figure 6.2).

Figure 6.2. Population equilibrium due to a balance between births and deaths.
When population abundance is greater than the equilibrium level (the abundance at which births and deaths are in balance), then deaths exceed births and the population declines. When population abundance is less than the equilibrium level, births exceed deaths and the population increases. This is called density dependent population regulation.

The carrying capacity of a habitat is the most significant determinant of the equilibrium level for population abundance, but carrying capacity is not the sole determinant of population abundance. Animal and plant populations may be regulated below their carrying capacity by natural enemies such as predators, parasites, or pathogens. Again, the regulation is by negative feedback. The population is more vulnerable to natural enemies when it is more abundant, because diseases and parasites are passed more readily from one individual to another. Moreover, the population may exceed the availability of suitable places to hide from predators. As a consequence, deaths exceed births and the population declines. If the population is less abundant, the death rate due to natural enemies is lower, allowing the population to increase.

It also appears that many kinds of plants and animals have a capacity for internal population regulation, the ability to regulate their own population abundance below the carrying capacity of the environment. Some plants do this by allelopathy, releasing a chemical into the soil that does not allow other plants to grow within a certain distance, as in the case of Imperata discussed by Sajise in Chapter 8. This spaces out the plants. Many kinds of animals regulate their populations by means of territoriality, where an individual or a breeding pair will not allow any other members of the same species within its territory. This assures exclusive access to sufficient resources to satisfy needs for successful reproduction, and it spaces out the population, placing a ceiling on the total number of animals that can live in a given area.

Because population regulation can be a consequence of resource limitation, natural enemies, or internal factors, a particular species of plant or animal may have two or more levels of abundance at which population regulation can occur. Figure 6.3 shows that a population can be regulated by the availability of its food supply (i.e., at the carrying capacity of the ecosystem) on some occasions, but on other occasions predation could regulate the same population at an abundance below carrying capacity. In other words, there are multiple equilibria for population abundance, each of these points of equilibrium falling within its own domain of attraction (Figure 6.4). A population may fall within one domain and be regulated at one level of abundance at one time, but it may fall within another domain and be regulated at a different level of abundance at other times. The change can be precipitated by a shift in the boundaries between domains as a consequence of environmental fluctuations or human activities.
Figure 6.3. Population regulation by carrying capacity or predation.

Figure 6.4. Domains of attraction for population regulation.
Domains of attraction are important from a practical point of view because agroecosystems may cross the abstract boundary between two domains of attraction and (as a result) experience sudden, unexpected, and far-reaching changes. Populations of plants, animals, or microorganisms in the agroecosystem may change suddenly in abundance, with no prior indications that such changes will occur. Although a word like regulation suggests constancy, the abundance of a real population is far from constant. This aspect of population dynamics is called *density independence* and is due in large measure to environmental fluctuation. As weather and other aspects of the physical environment change from day to day, season to season, and year to year, food resources (i.e., the carrying capacity of the environment) fluctuate as well. The population birthrate may then fluctuate in response to fluctuating nutrition, and the death rate may fluctuate in response to nutrition and fluctuating natural hazards in the environment.

As a consequence, the abundance of a real population tends to fluctuate around a fluctuating carrying capacity (Figure 6.5). For example, an agricultural pest may only find the food resources it needs during a particular stage of crop growth. The carrying capacity of a field for the pest (and the abundance of the pest in the field) may be zero until the crop reaches that stage, as shown at the left-most extreme of the curves in Figure 6.5. As the crop begins to enter a suitable stage for the pest, the carrying capacity increases, the pest begins to colonize the field, and there is exponential population growth, as shown in part A of Figure 6.5 (exactly as in part A of Figure 6.1). However, population growth is cut off when the carrying capacity drops because the crop has passed the suitable stage (illustrated by dips in the curves in Figure 6.5). An effective means of agricultural pest

![Figure 6.5](https://example.com/figure6.5)

Figure 6.5. Typical time pattern of abundance for a population in a single agricultural field. Carrying capacity is fluctuating, and population abundance tracks carrying capacity with a lag.
control is to manage the crops so the carrying capacity of the field for particular pests is fluctuating rather than constant. For example, with crop rotations or fallows, the carrying capacity for particular pests associated with particular crops may never be high for long enough to allow the pests to reach an abundance where they can do serious damage.

The extent of these fluctuations depends upon the fineness of the observer's perspective in space and time, the fluctuations being less when they are averaged over a broader temporal or spatial perspective. Month-to-month fluctuations in a single field may be extreme, but the average over many months may be more constant. Month-to-month fluctuations in the total pest population over the entire agricultural landscape, consisting of a patchwork of fields, may be much less because different fields have their peak pest populations at different times.

So far populations have been discussed as though their birth rates and death rates always respond to the physical and biological environment in the same way. In fact, the operating characteristics of living organisms (and populations) are continually changing, because their capacity to adapt (i.e., change) in response to changing environmental conditions is a fundamental strategy for survival. This adaptive capacity spans a hierarchy of time scales ranging from seconds to centuries. Included are a great variety of mechanisms for physiological and behavioral adaptation within the lifetime of individual organisms and a host of genetic mechanisms for changing the operating characteristics of a population over generations.

**APPLICATION TO HUMAN DEMOGRAPHY**

The concept of carrying capacity applies as much to human beings as to other kinds of organisms. The human carrying capacity of an area depends upon land and water resources for agricultural production, as well as resources such as energy and minerals that are required for industrial activities. There is an important difference between human carrying capacity and the carrying capacity for other animals, because the carrying capacity of man's environment depends upon levels of consumption and the technology at his disposal. A higher level of consumption means a lower human carrying capacity, but a more efficient technology means a higher carrying capacity.

As humans have achieved higher levels of technological capabilities over the millennia, their ecological niche has expanded so as to successively increase the carrying capacity of the globe for their population. At each successive stage of technological advance, the human population has experienced sigmoid growth (as in Figure 6.1), subsequently fluctuating about a new and higher carrying capacity. However, as Pirie describes at greater length in Chapter 7, many human societies have used internal regulation to maintain their populations below environmental carrying capacity, thereby reducing the roles of limited food supplies and high death
rates in their population regulation. Territoriality at the level of family, village, and nation has been one mechanism for internal population regulation. Other mechanisms have included infanticide and restrictions on birthrates by traditional means of family spacing. Numerous cultural changes that have occurred so rapidly in recent years have disrupted traditional mechanisms of internal population regulation in many areas. Territoriality and traditional methods of birth control have often broken down and communicable diseases have been reduced, allowing the human population to increase and sometimes overshoot the carrying capacity of its environment. The consequence can be environmental degradation and human hardship, when ecological forces eventually act to reduce the population to carrying capacity.

The age structure of a population is important to how it functions with regard to growth, overpopulation, and population stabilization. A rapidly growing population has a relatively high proportion of young individuals, a declining population has a high proportion of older individuals, and a population in equilibrium is intermediate in its age structure. As a consequence, the extent and nature of the burden of "dependent" (i.e., children and elderly) people compared with people of intermediate age in a human population can change as it increases, declines, or levels off.

Age structure also has serious implications for efforts to curb the human population explosion, because the age structure of a population can generate lags in the response of the population to a birth control program. Even if family size is reduced to the point where each person is producing on average only one child to replace himself, a growing population will continue to grow for one or more generations before it reaches equilibrium. The population continues to grow (i.e., births exceed deaths) because the youthful age distribution of a growing population has a large percentage of people who are highly reproductive and not prone to mortality. It is only possible for equilibrium to be reached after the population has adjusted its age distribution from a relatively youthful one to the older age distribution of a population in equilibrium.

APPLICATION TO AGROECOSYSTEMS

Productivity, Stability, and Sustainability

A major objective of agricultural science is the design of improved agricultural systems. Three major characteristics mentioned by Conway in Chapter 2 are of particular importance for agroecosystem design: (1) productivity, (2) stability, and (3) sustainability.

Productivity is the yield of goods and services from an agricultural system; stability is the reliability or constancy of the yield; and sustainability is the viability of the system, its capacity to continue producing on a long-term basis. These three characteristics are a consequence of complex population processes in the agroecosystem, as well as interactions of the agroecosystem with the outer world. The productivity of an agricultural
system is usually evaluated in terms of the tonnage yield of agricultural products per unit time or the monetary value of that yield. However, productivity can be interpreted more broadly to include other goods and services such as human nutrition (e.g., calories, vitamins, minerals, and amino acids) and the soil conservation and watershed functions of an agricultural field.

**Stability** is important because people depend upon a certain level of production year after year. Nonetheless, agricultural production often fluctuates from year to year as droughts, pest infestations, or a variety of other natural disasters reduce yields. Although risks of partial or complete crop failure are an unavoidable part of farming, poor farmers, with few resources to fall back on, place a particularly high priority on minimizing those risks. Local crop varieties can be important to these farmers because local varieties are often resistant to pests, droughts, soil nutrient deficiencies, and other environmental stresses of the area. Small-scale farmers also feel more secure when they can employ cropping systems based on a technology they understand, knowing they can provide necessary inputs and use or sell the resulting products.

**Sustainability** is a problem when an agricultural technology generates changes in the agroecosystem that undermine the continuing productivity of the system. Soil degradation is the most common problem, but weeds, diseases, and animal pests can also build up to a point where the crop is no longer functioning as the farmer needs. Sustainability may also be in jeopardy if the agricultural system lacks resilience, the ability to withstand severe and unexpected perturbations such as prolonged drought, the introduction of a new agricultural pest or disease, a significant change in markets, or an increase in the cost of inputs.

Although it is desirable for an agricultural system to be high in all three qualities — productivity, stability, and sustainability — the three are often in conflict with one another. Highly productive agricultural systems often entail high risks that reduce their stability. For example, highly productive crop varieties may fail if nutrient inputs, water supplies, or protection of the crop from pests are not adequate. Highly productive systems may also place a drain on ecosystem resources, jeopardizing the continued sustainability of the system. For example, highly productive crops may remove large quantities of nutrients from the soil, nutrients that are permanently removed from the field when the crop is harvested and therefore not available for future crop production. Furthermore, a system that is stable may not be resilient to unexpected disturbances because it does not “exercise” its capacity for dealing with such disturbances. For example, the extension of irrigation to new areas increases the stability of agricultural production in those areas because yields will not be depressed by a period of low rainfall. However, farmers may develop a dependence on the irrigation that could lead to disastrous crop failure if the irrigation system should temporarily break down.
Pest Management

The concept of alternative domains of attraction for population abundance (i.e., multiple equilibria) is particularly important for managing agricultural pests. A pest that is regulated by food availability at the carrying capacity of an agricultural habitat is not only reducing the amount of food for itself but may also be causing severe crop damage in the process. In contrast, if the pest is regulated at a lower abundance by its natural enemies, crop damage may not be of economic significance. Looking at the same picture from the perspective of the crop, when the pest is regulated by resource availability, the crop is "predator regulated" by the pest. This may put the crop at a lower level of abundance (Figure 6.4) than desired by the farmer. In contrast, if the pest is regulated by natural enemies, the crop has the opportunity to be regulated by the carrying capacity of its environment (i.e., by the availability of light, water, and mineral nutrients), allowing the crop to achieve a higher abundance, more in accord with the farmer's desires.

The heavy dependence of improved crop varieties on pesticides has led to pesticide pollution problems that have destroyed the fish in rice paddies (an important source of protein) or reduced the diversity and abundance of soil organisms important to decomposition processes for maintaining soil fertility. The use of pesticides has also led to the "pesticide trap," where natural enemies of pests are exterminated. The natural enemies have served an important function of keeping many potential pests — weeds, insects, and other animals — below the level of abundance where they cause serious damage. If natural enemies are eliminated, the result can be secondary pest problems, where previously obscure insects become serious pests because their population regulation has shifted from a lower to a higher domain of attraction. The result can be a dependence on larger and larger pesticide applications to prevent pest damage to the crops. It is instructive to note that on average the levels of pest damage in traditional Third World agriculture, without the use of pesticides, is not much higher than in modern agriculture with heavy, repeated use of pesticides. The big difference is that modern agriculture is dependent on pesticides. Pest damage in modern agriculture can be almost total when pesticides are not used, because pesticides have eliminated the pest control due to natural enemies of the pests.

Because agroecosystems are so complex, it is difficult to predict how a new agricultural system will function in the long term. Adaptive resource management is an approach to agricultural system design that takes account of the realities of agroecosystem functioning, including limitations in our ability to predict what will happen in complex ecosystems (Holling 1978). This approach emphasizes strategies that are above all resilience, keeping options open so the system can be modified to respond to unpleasant "surprises." Application of adaptive resource management to agricultural pest control takes the form of integrated pest management, which emphasizes full utilization of the agroecosystem's natural capacity for pest control (Apple
and Smith 1976, Knipling 1979). Integrated pest management discourages the application of pesticides on a routine, "just-in-case" basis. It encourages monitoring the fields so pesticides are applied only when necessary to prevent economic damage, and then in the smallest amounts possible. Applying pesticides with a full knowledge of the population ecology of target pests allows the pesticides to be applied in small amounts with maximum effectiveness.

In conclusion, population ecology can help to explain why the populations of living organisms in agroecosystems change the way they do. The key concepts are population regulation and multiple equilibria of population abundance. Population regulation means there are strong forces tending to maintain the various kinds of plants, animals, and microorganisms in an agroecosystem at particular levels of abundance independently of what people might desire. Because it can sometimes be ineffective and costly to oppose these forces, it is ecologically prudent to structure agroecosystems so population regulation is reinforcing rather than opposing what the farmer wants. Because of multiple equilibria, the direction of population regulation can suddenly switch, resulting in unexpected and sometimes undesirable changes in an agroecosystem (e.g., a serious pest attack). An appreciation for multiple equilibria and how they function can help to anticipate such changes and to design agroecosystems for equilibria that farmers desire.

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curiosity concerning the interaction between human populations and the agroecosystems that sustain them is of long standing, if not easily recognized from this modern terminology. A concern for the adequacy and durability of subsistence showed itself 24 centuries ago in the pioneering work of Yu Kung, whose work addressed the questions of a real variation in resources, population, and environment in China. Unfortunately, this early and auspicious beginning did not set the tone for what followed and the present condition of this investigation scarcely reflects its lengthy history or its contemporary importance. We remain uncertain, and often maladroit, in our abilities to manipulate the relationships between agricultural systems and population dynamics to the best advantage.

There are several reasons for the relative backwardness of the study of human populations in their environmental context. To begin, we must observe that the area has a history of being used as a playground by the unscientific. Since both demographic and environmental processes are constantly subject to the tyranny of contingency and hazard, literally matters of life and death, it has been customary for most peoples to resort to magico-religious or supernatural assistance in their attempts to come to terms with them. The persistence of this essentially irrational approach in most
HUMAN POPULATIONS AND AGROECOSYSTEMS

traditional, and many not so traditional, societies is symptomatic of the pervasive disinclination to examine these processes and their interrelationships objectively.

A further problem has been that interest in the prospects of the two components, more particularly the demographic, has not been consistent. The most recent swing in the level of public and official concern has been downward. From a high point toward the end of the 1960s, apprehension over the malign effect of excessive population numbers on the future of mankind has diminished steadily. The reasons for this nonchalance are due probably to a variety of causes — not the least a reaction to the overenthusiasm of some of the more journalistically inclined researchers into this topic. Extravagant predictions were made, for instance, of imminent widespread starvation by 1975 (P. Paddock and W. Paddock 1967). Works with colorful titles such as Born to Starve (Tydings 1970) and The Population Bomb (Ehrlich 1968) sold well. The “headline-making report on the imminent global disaster” as the publication for the Club of Rome of The Limits to Growth (Meadows et al. 1972) billed itself in later editions, confidently predicted inevitable doom. But the public quickly wearied of this message and, as time overcame some of the prophesies, they appeared manifestly overwrought. As McNicoll and Nag have remarked recently,

A population “explosion,” for example, fairly describes the phenomena of contemporary growth seen against past millennia of near stationality, but is a poor depiction of the shorter-term reality — year-by-year increases of 2 percent or so... (McNicoll and Nag 1982, 121).

Many concerned people, aware of the threat that continued excessive population growth offered, sank into a chronic low-grade depression, as the faddish moved on to something more catchy.

Few of the writers included in the hyperintense group cited earlier have been in fact much in error about population growth. The mathematics of population projection are relatively simple and the baselines are now well established for most countries. In most cases numbers similar to those given have arrived on schedule. Only in China, with the forceful imposition of the “one-child family” policy, has a large population begun an unforeseen trend toward fewer than projected. More frequently censuses have indicated that underestimation has been characteristic of many projections of Third World populations. The major errors in prediction have occurred in the degree to which the population increases have been accommodated in the process of resource development and intensification.

THE POPULATION TRANSITIONS

While the absolute growth of population numbers and unprecedented rates of increase have been the major source of popular concern, fundamental changes in demographic structures have also been playing a major part in the
accommodation of the growing numbers to the extent that the crises predicted so far, for the most part, have been averted. These changes are usually included in a theoretical construct termed by demographers the "demographic transition" (Caldwell 1976, Notestein 1952, Robinson 1964). It may be portrayed visually as a diagram of two curves: the first portraying the progress of mortality from premedical conditions through to the highly controlled levels characteristic of developed economies, and the second of fertility, lagging a decade or two, descending from the high levels usually found in traditional societies through to the low and highly controlled levels of modernized societies. While there is some validity in this model, it has been criticized because of later observations that fertility decline sometimes preceded that of mortality and that experience in the developing countries has not followed the pattern, first observed in the developed countries, very closely, showing both much more extreme rates and also accelerated processes.

While this theory retains considerable validity, for the purposes here it is preferable to disaggregate the whole transition into its parts. We may look at the "mortality transition" and the "fertility transition" separately and recognize there are several other transitions that are just as demographic as these two and perhaps as important, particularly as they apply to agricultural populations, but that they are not necessarily closely related to each other or to the others through a similarity in preconditions, causes, or processes. Although these transitions are usually examined on a national basis, it is also important to recognize that in reality they proceed at different rates and for different reasons in different regions of most countries and that different social classes, different cultures, and different occupational groups, notably agriculturalists, may react differently to similar stimuli, or may in fact be receiving entirely different stimuli than those applying to other groups within the same country.

In general almost all countries have had some contact with modern medical and sanitary intervention and have seen the life spans of their people prolonged, and an increasing proportion of the children born survive through the dangerous times of early childhood. What this adds up to is that more people are surviving for longer periods and thus are spending more person-years in the population, which in turn translates in demographic terms into an increased expectation of life at birth ($e_0$). This measure, when it can be derived, is the most satisfactory measure of the status a population has within the mortality transition.

There is no doubt whatever that, on balance, this transition is welcomed in most societies as a distinct improvement of what went on before. There is usually low cultural opposition to the innovations involved, although there always is some, and governments usually feel that at least modest investment in the prolongation of life is worthwhile when compared to the alternative opportunities for expending the national wealth. It was a particular favorite of colonial regimes combining high visibility, often spectacular improvement,
particularly if related to a low baseline, and the appearance of humane benevolence with low administrative effort, modest expenditure, and ready statistical demonstration to the metropolitan ministries to which they reported.

The result was often that newly independent countries were immediately faced with a population of much larger size than it had recently been — an astonishing growth rate, 3.0 percent to 3.5 percent annually being quite common — and a population given to expect a high level of medical activity provided at little or no cost. The new governments would often have preferred to have invested some of the precious resources committed in this way into spheres that had been previously neglected — economic development projects, infrastructure and education, not to mention items that seemed to offer more tangible national prestige than a high expectation of life figure. Over the years, however, most countries in this position have stabilized or reduced the proportion of the national budget they spend on health.

Associated with this mortality transition is another that is closely related to it, and this is the "morbidity transition," by which the prevalence of various diseases, and the role they play in being a cause of death, changes. In populations with high mortality, it is always true that diseases associated with the environment prevail. These diseases are usually communicable and are bacterial or viral in origin. People acquire them from the water, food, air, and soil with which they come into contact, not to mention from each other. They affect particularly the young so that infant and toddler mortality is proportionately high. The group within the population who survive these risks into old age is relatively small. Environmentally related diseases are almost invariably preventable these days, although only one, smallpox, has actually been eliminated. Formerly, the dispersed settlement patterns or small settlement groups characteristic of rural agricultural areas gave them an edge when compared to the larger noxious cities in being harboring grounds for infection, but these days cities are cleaner and rural areas usually are more dangerous for environmental diseases. Some are specific to rural agricultural populations or to particular agroecosystems.

Since, if one survives the risk of premature death from environmental causes, one still has to die of something eventually, the major causes of death necessarily change, and the so-called degenerative or chronic noncommunicable diseases, more characteristic of older age, become proportionately more important. By this we mean heart and circulatory diseases and other diseases that crop up as the body begins to wear out. Another group associated with the more modern, urban, and affluent lifestyle (violent deaths, motor vehicle accidents, for instance; and diseases related to excesses - substance abuse, liver diseases related to alcohol abuse, diabetes, and those aggravated by obesity) may also become more important. These problems aside, the alteration in the chances of survival are dramatic, from an average of <40 years, for instance, to e_75> being general in countries such as Japan. These changes, on the whole, have been immensely popular and desired, reflecting self-preservation as an important basic human concern.
The question that must be asked, however, is whether in accepting the innovations involved, and consequently upsetting an established balance, it is then possible to avoid, eventually, adopting a train of other changes, which are a good deal more controversial.

While the control of fertility and family size in the end must be the inevitable response to results foreseeable from the control of mortality, in the event the trend has been initiated in many populations long before the effects of mortality control, such as frequent famine or excessive rural overcrowding, become discernible. This has been the basis for the third transition, the "fertility transition." The reasons for the desire to have a smaller number of children in a family are not as clear as they might be but do seem to be related to the diffusion of secular and rational attitudes among women who enjoyed a relatively high and improving status. Departures from "natural" fertility were first observed among married women with a commonly shared language in some communities in Europe, apparently beginning in a few cases — notably in France — late in the eighteenth century, although most of the movement in other countries did not occur until after 1870 (Coale 1975, 1979). Methods of avoiding conception, for one reason or another, had been available in crude forms long before this. Fertility levels and proportions of women who married had varied considerably in different parts of western Europe, but the decline was related to fertility levels being consciously reduced and brought under better control. The advantages of having fewer children gradually became more and more obvious, and the idea diffused throughout western Europe, North America, and lately to a wide variety of peoples, particularly in Asia — lead by the Japanese and lately by the Chinese, wherever they occur.

With some interesting exceptions, fertility control tends to be more popular among the affluent; than the poor, the educated rather than the less literate, the urban rather than the rural. Along with the fertility transition, we have been able to observe another closely related to it, and this we term the "transition in the value of children." This matter has been the subject of a large cross-national survey coordinated by the East-West Population Institute (EWPI). It is reported here based on the work of the sociologist Bulatao (1979, 1982). This transition may be expressed in three major value changes.

1. A decline in the perceived economic benefits of children: In pretransitional societies the obvious contributions of children to the family economic unit, commonly observed as being substantially from ages as low as seven years, are highly valued and expected to continue through to old-age support for parents. In transitional populations there is an increase in the concern expressed for the monetary cost of children, particularly relating to their health and education, and less expectation of economic return.

2. An increase in the restrictions that parents perceive resulting from having children: Progeny come to be perceived as a barrier to the attainment of greater levels of consumption of goods and services, the aspirations for which rise with development.
3. An increase in the value parents place on socio-emotional benefits of raising children: Examples include companionship in the context of an increasing prevalence of the tighter and more exclusive conjugal family in modernized societies. These satisfactions are adequately provided by a small number of children on whom, with the decline in child mortality, it is emotionally rewarding to expend considerable effort and investment.

For those of us who have been able to observe the joy that mothers and other members of the family in peasant societies show in their young children, this change in value may seem to be paradoxical, or even spurious, but the data from these studies showed clearly in several separate countries that large families in traditional societies are more related to the economic than to the emotional rewards involved, the latter being effectively satisfied by much smaller family sizes than are normal in societies rooted in peasant agriculture.

There is also in progress a “nuptiality transition,” whereby marriage contracts are ceasing to be negotiated by the parents of couples with the mutual benefits to the families uppermost in their minds, the marriages commonly taking place when the bride is in her teens. Increasingly the need for completing education and often some employment experience is postponing female marriage to older ages and increasingly it is becoming a matter of mutual choice among the couples themselves. Nonmarriage, previously very rare in traditional societies, is increasingly a possible alternative for females.

Parallel with these transitions is another that we know as the “education transition.” In more and more populations, illiteracy is becoming unacceptable and it is expected increasingly that some years will be spent in school. Censuses in most parts of the world show that increasing proportions in the young age groups are completing ever higher levels in the educational systems. The financial sacrifice made to achieve this in many families is very considerable, a measure of how powerfully this transition is being propelled. But in the Third World, much more than in the better developed countries, the economic benefits of education are commonly direct and obvious.

A somewhat different transition, relating to the third leg of the demographic tripod, migration, is also occurring (Zelinsky 1979). The “migration transition” occurs in many different forms although some forms are actually much less available now, when so many more people could take advantage of it than they were 50 or 100 years ago when the means of travel, its cost, danger, and difficulty were so much greater but the national barriers so much less. The permanent exodus of Europeans to everywhere else has now largely ceased, and the same is largely true of the Chinese who spread out in quite large numbers in the late nineteenth and early twentieth centuries.

Much more important now than these long-term, long-distance, international movements is a kind of revolution in employment migration, mainly
internal, but with some international examples, such as the movement to the labor-short Middle Eastern countries, which is now characteristic of more and more populations. Much of this is a movement between rural areas and urban areas, but there have been many observed cases of circular mobility involving only rural areas.

While the proportion to be counted in urban areas in most populations rises from census to census, these migrations are less to be thought of as one-time, one-direction movements than as circular or reciprocal flows within populations, which, if each mapped, would show a pattern around the home node resembling a bird's nest (Chapman and Prothero 1983). This massive increase in mobility, utilizing the immensely greater facilities offered by the proliferation of roads, wheels, and airline seats throughout the world, has materialized mainly since World War II. These systems permit people who were entirely rural until very recently to seek employment, education, or whatever else is on their minds in the urban areas without necessarily cutting their ties with the sending rural community, or even reducing their roles in the family to any great extent. Commuters, weekend villagers, and family providers through the mail—all these categories of people have multiplied vastly over the past few decades. Technological advances already making their appearance and beginning their dispersal may change, but will scarcely reduce, these possibilities. The energy crises gave the trend pause but only for a breathing space.

This brings us to our final transition, the "employment transition," the one that all the others have made possible or, in some cases, forced. In this transition the predominantly rural populations of traditional societies are moving toward diversification, usually as fast as they can manage. This trend was initiated earliest in England and the Low Countries that had almost half of their populations in nonagricultural employment by the seventeenth century. It has spread beyond those shores in an ever-widening ripple so that now, while scarcely half of the world's people remain on the farm, the trend shows no signs of abating.

This transition has almost never meant that farming ceases, becomes an unimportant part of the economy, or even that production drops; it means rather that farm incomes per capita rise and that investment and modernization can proceed more rapidly. The proportions in farming occupations in countries usually thought of as agricultural—such as Denmark and New Zealand, about 6 percent and 10 percent respectively—might suggest to us that most countries in the Third World should actively and by policy be promoting a reduction in the proportion of their populations involved in agriculture as rapidly as they can manage.

This entails, of course, finding reasonably attractive employment for the rural exodus in secondary and tertiary industries. This is easier talked about than achieved, and we do not wish to imply that this will be a smooth
transition. Next to reducing population growth rates to manageable levels, employment is probably the most intractable problem Third World governments face. The difficulty is not lessened by the dubious future, related to the prospects for robotization and other labor-reducing possibilities, that secondary industrial development faces in terms of providing vast employment opportunities in places where few exist at present; nor is the transition to be perceived as an unalloyed good. However, the transition does seem to be inevitable and, on balance, beneficial both individually and nationally. Governments of the populations affected would do well to direct their planning accordingly.

It is likely that many populations, perhaps because of sheer size, a prevalence of extreme poverty, or for specific cultural reasons, will be unable or unwilling to restructure their labor force within the foreseeable future but may be induced to evolve differently in ways that have not yet been tested. It is likely the proportions that continue in agriculture could persist at much higher levels than in presently developed countries without necessarily perpetuating the low productivity peasant systems as they presently are or without jeopardizing a rising quality of life for these rural people.

The assumption that the migrant fleeing the countryside will make for the primate city is probably unjustified. The thought of Jakarta housing a population of 40 million or Bangkok 20 million must be one of the nightmares that keep policymakers and academics from accepting easily the prospect of the migration transition. The fact is that farmers of the type that can emerge when the traditional forms fade away require a great deal more attention and service than their predecessors and can better afford to pay for it. A large proportion of the displaced population is likely to be absorbed in smaller regional settlements where they spend their lives in occupations related to the needs of the surrounding farmers.

Omitted deliberately from this list of transitions is one which might have been called the "urban transition." While this has been a characteristic component of the large transitions achieved so far, there are no compelling reasons, as there are for the other transitions, why this should continue to be inevitable. The development of huge, urban agglomerations to absorb the majority of enormous populations such as those of Indonesia or Pakistan, for instance, seems to be a poor alternative to the existing pattern and therefore will not necessarily come to pass, at least not in the form characteristic of western Europe or Japan. The employment transition does entail settlement redistribution but the forms this may take could well vary and be rather different from those we can perceive at present.

One matter connected with these transitions needs to be laid to rest—the notion that this movement is "westernization." Technological and societal changes have been characteristic of human history, and many have diffused the world around without being labeled for any particular culture. We do not think of towns as Syrian or explosives as Chinese. The difference
with this spasm of change is that it is more compressed in time and more intense than any previously seen, but it is not qualitatively different from transitions that have gone before.

These transitions are rather loosely related one to the other but are probably inevitable once the first set of innovations, usually the set related to mortality, is accepted. While it is true that the signs of this transition were perceptible first in western Europe, centered on the English Channel region, this is an historical accident. The transition spread out from there to the rest of Europe, including the Soviet Union, diffusing to North America and the other culturally European countries and, since World War II, it has become of major importance in culturally non-European countries. Only one, Japan, has made a complete transition, if any are actually complete, but it does not seem appropriate to regard Japan as having become "westernized." It resembles its former self quite as much as European countries resemble their former selves. The Japanese are not less Japanese than they once were, and this would be their own perception. The prospect is for peoples to make culturally specific adjustments to. this new set of opportunities, limited admittedly by some constraints related to the nature of the adjustments themselves but still quite distinct and potentially satisfying.

THE EFFECTS OF THE TRANSITION ON AGROECOSYSTEMS

Some characteristics of these transitions have profound implications for the well-being not only for rural populations but also for the agroecosystems they presently operate. A pervasive quality has been the need, before significant movement occurs, for individuals or groups to modify or abandon deeply rooted traditional concepts about what is appropriate behavior within a society. Although initially related to vital events, the tendency has been demonstrated for this re-evaluation of societal norms to spill over into other social and economic areas including attitudes to livelihood. Usually the individuals or groups who pioneer these traditions cannot now be identified, but their influence in shaping the history of mankind is no less great than some of our most famous thinkers and innovators. The process is usually a relatively slow one and the diffusion is usually well advanced before it is recognized as a set of ideas for which the time has come.

The ideas that propel the transitions contain several elements that are almost universally seductive and are now spread around the world, often inadvertently, by the mass media to the extent few communities are unaffected. Technological innovation is also of great importance but it is not clear in many cases which of the two is the primary moving force. Implicit in this perception of the forces behind the transitions is that while government may accelerate or retard movement by education, example, policies, or law, for instance, initiation, direction, and rate are primarily related to combined individual actions. It has been repeatedly demonstrated that family limitation, to take the clearest example, is not adopted as a result of government programs if the target population is unready, while governments (and other
institutions) have been unable to prevent a fall in fertility if the need to reduce family size pervades community thought. Even the present, apparently successful, program in China, with all the coercive power of an authoritarian government behind it, is working only because, for most Chinese, the program meets a perceived and urgent need.

The demographic prospect for the next few decades has grown scarcely less ominous as a result of some leveling off in the rates of population growth observed in widely dispersed populations in recent years. For every apparent success such as China, there are persistent problems such as India. All too frequently the successes apply to small populations such as Singapore, the failures to large populations such as Pakistan. The yearly absolute increase in population is continuing to rise and is likely to do so until about A.D. 2000 when the annual increase will probably be about 90 million per year. This figure is actually less significant in terms of its effect on society than is the number in this annual crop who later present themselves, as teenagers or young adults, at the gates leading to employment.

Paradoxically, one of the emerging problems in some of the developing countries further along in the transition, Malaysia being a good example, is an apparent shortage of agricultural labor. In the past few years commercial estate managers have begun to complain that "plantation workers" are difficult to recruit and retain, while the rice farmers on the irrigated paddy areas of northern Malaysia lament a shortage of extra seasonal labor, particularly females. Far from recognizing this development as evidence for the success of government economic policies in place since the early 1970s, some agriculturalists have been calling for the abolition of the family planning authority. More to blame for their predicament than the relatively feeble effect of official family planning programs two or three decades ago are the relatively archaic working conditions and low wage levels of most agricultural employment compared to the more prestigious urban employment that has expanded dramatically in recent years. Similar problems will develop in other countries as they move along the transition. Agricultural employment will need to be used more economically as it increases in price and is competed for by other sectors. This modification should be anticipated and, as a matter of policy, encouraged.

**THE MAN-LAND RELATIONSHIP**

There are several other situations in which demographic dynamics infringe directly on agriculture. In its simplest form, the essential man-land relationship, expressed as various forms of density, crude, agricultural, or habitation, for instance, expresses this connection. Although this measurement is the most commonly used, it is primarily a macrolevel indicator and, to express the relationship more exactly, we have to examine the elements more deeply; both may be usefully broken down and refined. For land, the method most frequently used is to express the population densities in relation
to areas of various classes or qualities. Surveys of land capability or soil, for instance, are a prerequisite for this. From the viewpoint of individuals, households, or other small socioeconomic groups, density, in the sense of population pressure on available resources, will first be felt through the working of another human institution — the land-tenure system. For most societies, the method by which land is subdivided and assigned reflects deep and sensitive values and is one of the institutions most resistant to change. All but the simplest utilize fairly rigid frameworks, which, if anything, have become more rigid in recent decades as techniques of survey and recording have become more sophisticated and as increasing demographic and commercial pressure has become evident.

Existing land-tenure systems were usually developed under conditions of lower fertility, higher mortality, and simpler systems of intergenerational replacement than is now the rule. With higher levels of fertility and better chances of child survival, thus resulting in larger completed families, the intergenerational transfers have become more complex and difficult and the systems often come under a strain that they are ill equipped to bear. The lengthening expectation of life applying to most populations will extend the average period between transfers, but this effect has been small compared with the flood of heirs that has been engulfing many land-tenure systems in recent times.

The results of these processes include:

- The development of a range of actual densities and demographic pressures on resources around the average, as expressed by overall population densities. Even in areas of relatively low average densities, there are likely to be individuals or groups who suffer extreme deprivation because of excessive numbers crowded on to uneconomically sized holdings.

- A tendency toward subdivision, smaller holdings, uneconomic units, "agricultural involution" in the terminology of Geertz (1963), and, eventually, landlessness for growing proportion of the population.

- Decrease in flexibility and greater exclusivity as the pressure on land and usually its relative value rises, creating economic and social strata or aggravating class differences. This in turn aggravates political and social instability.

- A rise in litigation relating to land, putting additional pressure on the legal systems relating to land disputes, and an increase in intrafamily tensions, rivalries and, in some instances, violence.

Although most of these effects are negative, there are some which may be positive. In systems where some individuals do not inherit, or become surplus to the labor needs of the agricultural unit in which they have an interest, they are encouraged to seek other means of livelihood. Migration, the opening up of uncultivated lands or agricultural expansion as referred to by Rambo in Chapter 3, and economic diversification into secondary or
tertiary occupations may be promoted. While often wrenching for individuals at the time, the results to society may be beneficial. Most developed countries have been through such a process and have successfully weathered the transition. Populations entering this phase more recently have not had the wider opportunities of the earlier pioneers and usually lack adequate capital and technology to provide for and absorb this rural surplus stream as successfully.

HUMAN FERTILITY AND LAND RESOURCES

Other demographically related processes affected by access to land include those associated with fertility. A number of instances have been examined in which pressures related to land shortages have resulted in postponement of marriage and lower fertility within marriage. For example, Demeny (1968) in the case of Hungary. Conversely, a number of studies have cited availability of newly accessible land, in North America for instance, as contributing to higher fertility (Stokes et al. 1979). These relationships have been incorporated into a “bequest model” by Easterlin (1976, 66). The phenomenon of readily available land, either in the form of new development or in the persistence of large holdings being positively correlated with higher fertility and the converse, pressure on land resources, or increasingly subdivided holdings being associated with lower fertility seems to be well established.

It is seen as applying also to the populations of less developed countries in the works of Beaver (1975), applying to 24 Latin American cases, and of Hicks (1974), who sampled 155 small areas in Brazil. Other studies of this effect include Driver (1963) and Kleinman (1973) in India, Prasithrathsin (1971) and Chalumwong et al. (1979) in Thailand, and Hawley (1955) in the Philippines.

Under conditions of technological innovation, the relationship may break down. If new crops, for instance, or new varieties or wider markets are utilized, they may alter the effective pressure on land (Stokes et al. 1979, 16). In these cases the pressure to limit fertility may be released. The effect of land reform on fertility has been the subject of conflicting evidence and consequently of debate. In agricultural societies the distribution of land is most often the primary determinant of the distribution of agricultural incomes and consequently of other goods and services, including education and health levels. These in turn have an effect upon fertility, but the direction of this effect is not necessarily the same in all societies. For instance, two studies — by Kleinman (1973) and Rosenweig and Evenson (1977) — concluded that land reform, to the extent that land would be more equitably distributed, would have a positive effect on fertility. Contradicting this conclusion are the findings of Ratcliffe (1978) in Kerala where he cited land reform and greatly reduced wealth and income inequalities (although combined with overall poverty worse than the average for India as a whole),
together with improvements in income security, as having been the major elements in the process of fertility decline. In this case, however, land reform and redistribution were combined with other public policies, which increased the levels of social justice and economic equity throughout society beginning in the 1950s and continued by later governments at the state level to the present.

A reconciliation between these apparently contradictory findings could lie in the possibility that access to new resources, through land distribution may initially affect fertility primarily by permitting a previously thwarted desire for additional children to be realized, through improved incomes, health, and nutrition, for instance. Improved education levels, greater equity, and security may take longer to have their effect on fertility, but their eventual influence would be more permanent and toward reduction.

The ways in which land is held also have observable effects upon fertility, but the patterns are often complex. The system of land control is an important factor in the perception agricultural populations have about the value of children. Several instances have been observed in which families with many children, particularly sons, have a more powerful claim to a larger share of communally held land (e.g., Ware [1978] for Africa; DeVaney and Sanchez [1977] for Mexico). Even in cases where land is individually owned, a farmer with many sons or brothers can dispense with hired labor and perhaps afford to acquire the use of additional land. The problem of later subdivision is recognized, but the need to make a living may be more immediate and therefore takes precedence (Mamdani 1972, 73).

The literature on human fertility relative to land access strongly suggests that ownership, hereditary rights, conditions on use of land, and the distribution of rights are all important in understanding the relationships involved. But consistent patterns are elusive. Agricultural technology may often modify the relationship between fertility and the physical and institutional availability of land. Additional research and detailed consideration of individual cases are needed in order to clarify the processes and forces involved.

THE EFFECT OF THE AGRICULTURAL ENVIRONMENT

The relationship between mortality levels and agroecosystems is mainly environmental, with some specific types related to typical causes of illness and death. Systems involving irrigation, for instance, seem to provide environmental conditions favoring several insect and waterborne diseases, notably malaria, while simultaneously promoting high population densities, which maximizes their effect.

In recent decades, dramatic improvements in the control of environmental and other health conditions in most populations were realized. Where this has not applied, or applies to a lesser extent, the inhibiting problems are usually social, political, or economic rather than technological. Mortality
among infants and the young particularly has been lowered in most agricultural societies over the past 50 years, upsetting the traditionally close balance between fertility and mortality that applied to these populations in previous centuries. Efforts to re-establish these balances by lowering fertility have had varied, although steadily accumulating, success. The resulting alterations in the structures of most agricultural populations have been destabilizing in many instances, altering the consumption demand of the communities, as well as the provision of labor to operate their agricultural systems. Redistribution of population and technological innovation have the potential to ameliorate these problems and have often been used effectively but, in many other instances, have instead aggravated them.

**EARLY APPROACHES TO MAN-ENVIRONMENT RELATIONSHIPS**

Our knowledge of the relationships between agricultural systems and population dynamics and our abilities to manipulate them are still relatively primitive and uncertain. Considering the importance of these relationships to human well-being, this is surprising and would seem to have causes related to historical development. The preoccupation in environmental studies with "determinism," that is, a search for the environmental causes of cultural variation, is the major example. This approach dominated thinking in geography, for instance, during the first decades of this century and proved to be extremely destructive to the development of soundly constructed scientific theory relating to population and its environmental context. Without sound theory, the development of method was pointless.

The German geographer Friedrich Ratzel was the most influential proponent of this approach in European scientific circles in the late nineteenth century but his disciple, Ellen Churchill Semple, was mainly responsible for its dissemination in English during its early days. She began her famous book, *The Influences of Geographic Environment*, with the following arresting and vivid paragraph:

> Man is a product of the earth's surface. This means not merely that he is a child of the earth, dust of her dust; but that the earth has mothered him, fed him, set him tasks, directed his thoughts, confronted him with difficulties that have strengthened his body and sharpened his wits, given him problems of navigation or irrigation, and at the same time whispered hints for their solution. She has entered into his bone and tissue, into his mind and soul. On the mountains she has given him leg muscles of iron to climb the slope; along the coast she has left these weak and flabby, but given him instead vigorous development of chest and arm to handle his paddle on oar (Semple 1911, 1).

This colorful claptrap seems to be based on the most casual observation, if any at all; her words are for literary effect rather than scientific enlightenment. But this paradigm pervaded subsequent geographical writing
for many decades in the educational institutions of the English-speaking world and persisted in some academic recesses until well after World War II, and possibly still does.

In other disciplines similar controversies occurred. In philosophy, for instance, Herbert Spencer extended Darwin’s evolutionary theories into a social doctrine, “social Darwinism” – an extremely deterministic and conservative view of social processes that saw the poor as unfit and social reform as not only ill advised but fruitless since it tended to extend the lives of the unfit and was an attempt to thwart “the inexorable law of nature.”

The philosophical impediments that have retarded the development of a validated scientific approach to populations and their environmental context have been only part of the problem. The whole field has been politicized, and this also has had a baneful effect on the development of rational thought and appropriately directed work about these matters. The politicization of the field began almost at its birth. Thomas Malthus published “An Essay on the Principle of Population as it Affects the Future Improvement of Society with Remarks on the Speculations of Mr. Godwin, M. Condorcet and Other Writers” in 1798. Then termed an essay in “political economy” and since hailed as the first attempt at demographic analysis, Malthus’s essay was in fact a political document with strong deterministic overtones and a flavor of social Darwinism. It was also the first salvo in a battle that rages on today undiminished, over the policies to be applied to those aspects of societal improvement involving demographic issues, subsistence, the environment, income redistribution, and the problems of resources allocation.

In considering Malthus’s work it is important to note the full title of his essay, the period in which he wrote it, and the fact that at this time agriculture was relatively a much more important component of the economies of the western European countries or North America, which were Malthus’s concern, than it is now. Malthus in the very title, since his remarks on the speculations were not complimentary, expresses his intention to attack individuals who were associated with a particular point of view. His hostility was directed toward the “Perfectabilians,” of whom Godwin and Condorcet were among the best known. His immediate concern was the possibility that their ideas, giving support to sentiments then associated with the success of the French Revolution and the establishment of a republic in the former American colonies, would spread to the English population. By the time Malthus wrote his essay, the French Revolution had spawned the Terror and Napoleon, and was perceived, especially by the English upper middle class, as a grave threat to the stability of British institutions and the continuation of the monarchy. Godwin’s ideas included, for instance, the notion that man was infinitely perfectible, and the ills of society could be traced directly to the malevolent influence of evil social institutions. In general his ideas could be perceived as optimistic and, by the standards of the time, dangerously radical. In 1793, referring to population and the world environment, Godwin wrote:
Three-fourths of the habitable globe is now uncultivated. The parts already cultivated are capable of immeasurable improvement. Myriads of centuries of still increasing population may pass away, and the earth be still found sufficient for the subsistence of its inhabitants (Godwin 1793, 510).

Underlying this opinion, for the statement was no more than that since precise data on this matter was not then available, was the assumption that the natural environment would be able to absorb the increasing population and the impact of their economic activities so far into the future as could be imagined.

Malthus was on the other side of the philosophical fence in almost every respect. His comment on the French Revolution and the dangerous lines of thought that underlay it and which it inspired in its admirers, expresses his distaste with vigor.

To see the human mind in one of the most enlightened nations in the world, after a lapse of some thousand years, debased by such a fermentation of disgusting passion, of fear, cruelty, malice, revenge, ambition, madness and folly, as would have disgraced the most savage nation in the most barbarous age must have been such a tremendous shock to [Godwin's] ideas of the necessary and inevitable progress of the human mind that nothing but the firmest conviction of the truth of his principles, in spite of all appearances, could have withstood (Malthus 1798, 54).

The thesis, which Malthus put forward, may be expressed in three propositions:

1. That the increase of population is necessarily limited by the means of subsistence,
2. That population will invariably increase when the means of subsistence increases, and
3. That this superior power of population is repressed, and the actual population kept equal to the means of subsistence by "checks," "preventative" (moral restraint, mainly late marriage and various vices in which he included contraception), and "positive" (wars, epidemics, and as a last resort, famine).

Population, when unchecked, was seen to increase in a "geometrical ratio" (i.e., exponentially) while the means of subsistence, mainly food production, could increase only in an "arithmetical ratio." This implies in economic terms that per capita production diminishes as the size of the population increases, or that the marginal increase in productivity is zero.

This natural inequality of the two powers of population and of production in the earth and that great law of our nature which most constantly keep their effects equal form the great difficulty
that to me appears insurmountable in the way to the perfectibility of society (Malthus 1798, 8-10).

Malthus also felt that man’s nature was inclined to irresponsible procreation and laziness, and that it was only the necessity of supporting self and family that drove the species to work or to consider limiting the size of their families, and that this would only be achieved if self interest were further involved in the system of private property. Believing that the lower classes were feckless, irresponsible, and prone to have more children than they could support, he had no sympathy whatever for the optimism and idealism that the French Revolution encouraged in many English intellectuals. Malthus has usually been classed as having a pessimistic view of human nature: he saw himself as well intentioned and humane, but realistic.

These ideas were not new or unique to Malthus; the notion that any improvement in living conditions among the poor would inevitably cause an acceleration in population growth and the numbers looking for employment had been familiar in England for some time before Malthus’s statement. Hobbes (1651) and Adam Smith (1776) both explained the persistence of poverty in this way. Hobbes also developed the idea that because of the niggardliness of the environment, the resources available to a population were always limited and that one man’s accumulation must be another’s loss. To this “zero-sum game” theory of resources, Malthus added his view of man as essentially dismal future of want and misery for the majority of mankind; but his essay was welcomed by the literate higher classes in England as expressing a set of ideas whose time had come.

The alternative view, which we first observed with Godwin but which preceded his work, was never abandoned but persisted and along the way gained some powerful support. The idea that the resources of the planet were for all practical purposes infinite, that agricultural production increased in proportion to the number of hands engaged in it, and that a growing, large and happy population was the basis of national strength has retained considerable appeal. During the nineteenth century an increasingly humane view of the importance of the well-being of the individual and a greater level of social concern was apparent in the writings on demographic and social problems.

The analytical and empirical bases for criticism of Malthus’s views has in the event been far less important than the ideological. Here the major protagonist is Karl Marx whose hostility to Malthus’s views aggravated the political bias, which has been characteristic of this controversy from its beginning. The dissent registered by Marx and his later followers is important less for what Marx actually said about population, which was brief indeed, than the context, which became the basis for the worldwide Communist movement, in which he said it. Marx, in his major work, Das Kapital (Capital), maintained that,

... every special historic mode of production has its own special laws of population, historically valid within its limits alone. An
abstract law of population [such as Malthus's] exists for plants and animals only, and only insofar as man has not interfered with them (Marx 1867, 580).

Marx saw the Malthusian explanation of "over-population" as being a result of the external laws of nature, rather than as an inevitable result of the capitalist system as a reactionary plot to justify the perpetuation of poverty. Marxists have continued to maintain that the pressure of population on resources is a myth; the pressure is instead on the means of employment. Poverty is the result of population outstripping the rate of economic development. Population change by this reasoning is related to changes in economic institutions rather than the reverse. Appropriately reformed institutions would be able to absorb whatever-sized population occurred under their auspices. Both Malthus and Marx have essentially deterministic views of the connections between population dynamics and resources; they differ on which determines what.

POST-WORLD WAR II POSITIONS

Since World War II, the two factions, persisting and dumbfounding as it may seem in retrospect and little advanced in sophistication, have had to absorb and, in many cases, rationalize as best they may, vast quantities of new information about population. Soon after the war concluded, information on the extremely rapid growth rates applying to many colonial, developing, or newly independent countries began to accumulate. The Economic and Social Council of the United Nations commissioned the Statistical Office and the Population Division of the Department of Social Affairs to begin publishing a demographic yearbook, the first of which appeared in 1949.

While in the well-developed countries it was recognized that the Malthusian prediction — that increases in production would induce proportionate increases in population — had not come to pass, in those areas later became known as "the Third World," the Malthusian view seemed to be more justified. A school of development thought, which fastened upon excessive population growth, along with stagnant technology and insufficient capital investment as the major reasons for slow or even slipping rates of increase of per capita Gross National Product (GNP), emerged. The group, promptly dubbed "the neo-Malthusians," became the dominant philosophical force in the councils that allocated development aid. The title would have surprised and annoyed Malthus since one of their central themes was the propagation of contraception as a means of having the rapidly growing populations regain a reasonable balance between fertility and mortality.

In addition to their preoccupation with population growth and the GNP, the neo-Malthusian economic establishment also showed great concern over the deficiencies and erratic shortfalls in the food supply in developing
countries. Populations trapped in this combination of rapid population growth, poverty, and recurring food shortages were labeled as being in "a low-level equilibrium." This view of Third World problems became the established perception that persisted, little challenged, until the 1970s.

In the countries that emerged from World War II with Communist governments, or have since acquired them, Marxist dogma has been somewhat erratically applied. In a truly socialist state the problems of excessive population growth and a propensity to permanently high unemployment are expected to cure themselves as a result of societal reorganization. In the 120 years since this idea was put forward, it has never been disproved nor has it been validated. The Russian population has followed the western model, depending on privately arrange family planning to achieve a marked decline in population growth rates, and their east European satellites have also followed this track. The interesting case is China. After wavering under the all too obvious weight of high densities, the Chinese finally gave up waiting for Marx's nostrum to work and have come down on the side of neo-Malthusianism in a particularly draconian form.

The Marxist view of population, thinly developed as it was, had a great effect on the approach to population theory in centers of learning outside the Communist world and aggravated the degree of politicization that has characterized the field since the time of Malthus and Godwin. Extreme positions; Malthus and the neo-Malthusians labeled as reactionary, right-wing, pessimistic, and misanthropic on the one hand, while the Godwin-Marx line claimed the revolutionary, left-wing, optimistic, and comradely posture, became more politically lithified than the namesakes of each group would probably have approved.

Philosophical differences over attitudes to population also made for some strange bedfellows. Major objections to Malthus's views, and particularly the contraceptive activism of the neo-Malthusians, have come from religious authorities, many of whom were not notably radical in other areas. The most prominent among these has been the Roman Catholic Church, which has forcefully opposed several methods commonly advocated by various antinatalist organizations to reduce fertility, notably the use of artificial contraception and induced abortion.

In the process of justifying their position, the church authorities have resisted the idea that the planetary environment will be seriously stressed by population growth of the magnitude already inevitable over the next several decades in many countries of the world, not to mention the longer term prospect. Some support for this position has been forthcoming from academic writers, notably Clark whose work *Population Growth and Land Use* (1967) takes this line, and Conroy (1976) who reviewed the evidence relating to family planning as a major development strategy and found it seriously deficient in several ways. Among the non-Christian religions, Islam has been notable in its hostility to the control of family size by artificial means.
More pervasive is the hostility to the call for smaller families in societies engaged primarily in subsistence or peasant agriculture. Since these predominate in the world of developing countries, the attitude is the one most formidable barrier to further decline in fertility. It has been repeatedly observed that in agrarian societies the contribution of offspring to the family economic unit, commonly seen to be substantial, from ages as low as six or seven in some instances is highly valued and expected to continue through to old-age support for parents. This expectation of economic benefit, which may increase with each additional child, combines with the virtually universal desire of couples to become parents, and is reinforced by family and social approval. Religious and even political institutions, which are supported and validated by habit and tradition, often extending over unknown hundreds of years, add external support. Additional reinforcement undoubtedly arose from the virtually certain expectation that only an unknown proportion of children born to any one couple would survive to adulthood. These attitudes toward fertility, childbearing, and family size, being concerned with some of the most instinctive and basic emotions involving the continuation of the species and the perpetuation of the group, are among the most durable and tenacious in the human psyche.

**THE BOSERUP POSITION**

The philosophical position of the pro-natalist, anti-Malthusian faction appeared to be strengthened by the Danish economist Boserup whose book *The Condition of Agricultural Growth: the Economics of Agrarian Change Under Population Pressure* (1965) seemed to provide some intellectual underpinning for this argument.

The thesis of this work is that population density, or at least the pressure of population on local resources, is the independent variable upon which agricultural change, that is, the intensification of land use, is dependent. The response, "unwilling," Boserup suggests, is to increase the frequency of cropping, first reducing fallow periods and then increasing the cropping frequency per year, portrayed as a continuum with 20- to 25-year forest fallow at one extreme and intense multicropping with heavy applications of labor, fertilizer, and water control at the other. As intensity is increased, greater application of labor is required, but this increase is seen as not giving a proportionate increase in output so that each unit of labor suffers a diminished return. Instead of population numbers being limited by agricultural resources or food supply and showing a relentless tendency to rise up to the level when pressure begins to inhibit its further growth, as Malthus believed, Boserup sees population as the main engine of agricultural development, improvement in land use, and agricultural technology. Changes in land tenure systems and settlement forms may also be inaugurated under this pressure.

Stated in this form Boserup's theory appears to undercut the notion that population increase is a negative influence on economic development. It can
also be interpreted as support for the allegation that the pre-eminence of western countries, not only industrially but agriculturally, is a function of their rising and increasingly dense populations, occurring particularly in the nineteenth century and that their present efforts to persuade the less developed countries to slow their population growth rates is yet another neo-colonialist device to keep the Third World in perpetual bondage. Interpretations of this nature are triply attractive to many governments of developing countries in that they not only reflect the traditional prejudices of their predominantly agricultural populations but appear to be endowed with intellectual respectability from an apparently unbiased and eminent source, and they allow them to rationalize a situation that many of them feel is difficult to alter successfully.

One of the points of this paper is that Boserup's notions do not, as she states them, apply to most of the populations of the contemporary Third World and that her theories, even kindly interpreted, are so flawed that their utility for explaining development situations or population and environmental relationships is extremely limited.

Several aspects of Boserup's theories, both explicit and implicit, are of dubious value; some have been reviewed critically already, notably by Grigg (1979) and Cowgill (1975). Among these are Boserup's assumption that population growth is a natural condition and inherent in the species. To the extent that homo sapiens may be presumed to have been once of extremely small numbers and now is over six billion and growing fast, this is true. In any but this gross situation, however, the assumption that this tendency is general and will ordinarily apply to populations of disparate sizes, in varying situations, at different scales and unlike locations, is not warranted by the evidence. For most of human history the balance between mortality and fertility has been a fine and precarious one, easily upset by a variety of forces, often over long periods, so that for most surviving population groups in many different environments, stagnation or decline have been almost, if not quite, as prevalent as increase.

Another problem, from the point of view of the contemporary usefulness of the theory, is that Boserup seems to confine it to agricultural types that are fast disappearing. The basis for Boserup's theory is that increased inputs of labor do not yield proportional increases in the crops so that per capita returns will decline. This is one of the few ideas she shares with Malthus; it is an unfortunate choice because time has proved Malthus spectacularly wrong on this point. Yields per agricultural man-hour have risen amazingly in Europe as total output increases and the number engaged in agriculture continues to decline.¹ In modern day developing countries, where the numbers engaged in agriculture may still be rising, even if the proportions involved are declining, the incorporation of modern technologies continues to

¹As Rambo describes in Chapter 9, this rise is dependent upon the ability to substitute cheap fossil fuel energy for human labor.
increase the return per man-hour. Boserup circumvents the problem of including this conflicting evidence into her scheme by excluding situations where it occurs — instances in which labor-saving machinery, artificial fertilizers, or industrial products augment the systems are discarded, leaving her theory applicable only to traditional agriculture.

More serious is the exclusion of farmers who are "profit maximizers," that is, those who produce for the rural markets, the urban centers, or certainly for export. The restriction to premodern or preindustrial agriculture should, in fact, reduce the applicability of the theory, limiting it largely to historical applications. In practice, the majority of the agriculturalists in the world are transitional between purely traditional, noncommercial, and predominantly subsistence forms of agriculture, and those that are intended to be commercially profitable and in which subsistence is a minor component if present at all; what we have is considerable confusion over which agricultural systems remain influenced significantly by the processes Boserup has in mind.

To a geographer, Boserup's environment-free approach is the most difficult aspect of her theory to accept. Boserup's perception is that the physical environment, which includes factors such as climates (including microclimates), slope, rock, soils, and natural vegetation have little or no influence on the spatial differences in land-use intensity; these are accounted for in her scheme by differences in population pressure. Millions of the world's farmers, battling their intractable plots, may wish Boserup's perception were true, but it is one that few practical geographers, or in fact anyone who takes sufficient interest in the world to look about, can take at all seriously. This must be armchair economics at its most naive form.

Disquieting as these objections to the theory are, we must return to the discussion earlier in the paper for the basic reason why the Boserup thesis should be discarded as being, in the end, irrelevant. It will be possible to find examples where the spur of population pressure has induced agriculturalists to intensify their methods or switch to a new system entirely, and Boserup's work has been useful in pointing up the alternative to the Malthusian model. But both share the flaw, fatal in our view, of being essentially unicausal, oversimplifying, deterministic models that are totally unable to accommodate the complexity of most of the real situations that they are attempting to describe. Boserup's approach allows her, for instance, to ignore the option that many farming communities have traditionally had, of extending their present system over a wider area (the expansion of area referred to by Rambo in Chapter 3), rather than intensifying in situ.

Other familiar agricultural stratagems for avoiding the forms of intensification that Boserup sees to be inevitable are the adoption of higher yielding crops, root crops such as the potato for cereals, for instance, and the adoption of new methods that were seen to be manifestly superior, knowledge of which diffused outward from an innovating source. Such
alteration does not have to wait for population pressure to force its adoption. There are cases where this has occurred during periods of static or declining population (Grigg 1979, 75).

Also obvious is that surplus labor has been absorbed on many occasions by diversion into nonagricultural activities, such as handicrafts, or to fishing, hunting, or forestry. The options of migration or reducing family size are omitted as alternatives to intensification. Boserup seems to neglect the possibility that some communities merely accept lower standards, such as poorer diets or increasing frequency of landlessness, as a response to growing pressure of population on local resources.

In most agricultural systems, there is a much greater degree of elasticity than Boserup seems to admit. There is considerable extra effort expended on activities beyond just subsistence. Avoidance of risk is one of the major activities of many farmers, and fluctuations of yields due to seasonal and weather variations must always be allowed for, or stratagems adopted to minimize the damage or to store or dispose of unexpected surpluses. In many cultures the highest levels of effort and skill applied to agriculture are expended on items that are only incidentally related to subsistence, if at all, but are used instead for ceremonial, social, or political purposes (Brookfield 1972, 278).

Within each community the levels of individual performance vary in ways that must affect the pressure to change to higher systems. Field observations of agricultural activities will always turn up the fact that the best farmers outproduce the worst, often by very substantial margins. Neither labor, capital, nor subsistence can always be counted on. States can suddenly levy taxes, militarily conscript agricultural labor, or fail to protect the citizenry from marauding bandits and the like, so that pressures other than population, and often more unpredictable, were felt by agricultural communities. The possibility of decimation by epidemic disease was always a possibility in traditional agricultural communities so that population pressure perceived one year might have evaporated by the next. It is apparent that the whole matter of population, environmental, and agricultural interaction is too complex to be handled by a theoretical construct as simple as Boserup's — or that by any of her predecessors, including Malthus and Marx.

A VIEW FROM THE FIELD

One other example, derived from the Indonesian experience, does need to be examined briefly. This is the Geertz study Agricultural Involution: The Processes of Ecological Change in Indonesia (1963). In this examination of agrarian evolution in relation to population pressure, Geertz portrays two of the agroecosystems most typical of Indonesia: the fragile swidden system found principally on the thin, lateritic soils of the Outer Islands and the wet rice system typical of the volcanic ash-showered lowlands of Java (the type of system described by O. Soemarwoto and I. Soemarwoto in Chapter 16). These two agroecosystems provide a dramatic contrast in that the former is
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capable of limited intensification before environmental degradation renders further labor input unrewarding, whereas the latter in Brookfield's words is:

...characterized by an extraordinary elasticity of response to additional inputs of labor combined with further inputs of skill. The elasticity of response permits marginal productivity to remain above zero long after average productivity has ceased to grow with additional inputs, and thus facilitates the ingrowing process of "agricultural involution" in which smaller and smaller pieces are ever more closely fitted together in a squeezed-down shared poverty. The wet-rice ecosystem is at once capital- labor- and skill-intensive, while involution represents intensification of organization carried to an extreme degree (Brookfield 1972, 274).

This description of the wet rice system in its most developed form represents an example of the final stage of the Malthusian model whereby the population is at or about maximum density relative to the productivity of the system it operates. Although Geertz uses the Java case as his only example, the concept has wider implications, and "involution" is an expected response in other cases developing in other areas. It would seem in this case that Malthusian "checks" are, or are about to begin, operating. In the event this has not occurred as the surplus population in the rice-growing ecosystems of Java is being siphoned off into nonagricultural and usually urban activities.

A development of Geertz's work has been suggested by Brookfield (1972) who somewhat ingeniously suggests that, in spite of appearing to be directly opposed to each other, the theories of Malthus and Geertz on the one hand and Boserup on the other can actually be reconciled by taking into account the variables that each disregards. Although I feel that, in the end, this laudable attempt is scarcely worth the trouble, Brookfield makes some interesting and worthwhile points, the result of his very considerable field experience in a variety of settings. He writes:

Any given area, with a given resource endowment can be considered to have a hierarchy of feasible agricultural ecosystems. The hierarchy is ranked by the complex of skills and technology involved, from least to greatest. If we assume that the level of inputs into the system per head of population is fixed, each system has a range of population capacities. The minimum capacity is defined as the population whose inputs are just sufficient to sustain the system in viable condition; the maximum is the population at which the marginal per capita return reaches zero. Between the two is a theoretical optimum for the system at which average productivity per capita is at a maximum, and beyond which average productivity will decline (Brookfield 1972, 275).

Assuming populations will adopt the system that offers maximum advantage consistent with least effort as the population increases and maximum productivity per capita is passed, pressure from population will be
felt with ever increasing force. Change may be delayed, however, by
resistance and because of rigidities related to existing capital investment in
the present system. At higher technological levels the delays are likely to be
more pronounced, so that systems will be retained until marginal returns
approach zero. Geertz’s involuttonary wet rice system is an example of this.
When the marginal return finally reaches bottom, there will be either a forced
shift to a higher system or a Malthusian level will have been reached. When
the point is reached when there is no further technological innovation known
or available to the population, an ultimate Malthusian situation will have
arrived.

The aims of the Geertz study are limited but are relevant to our purposes
here. One does not have to agree with Geertz’s interpretation of the causes of
population growth in Java (he blames Dutch colonial policies) or fail to
observe that the Javanese wet rice systems are now evolving in the direction
of increased commercialization, and that their role as a sink into which
endless amounts of labor can be poured for the benefit of the group is
altering as the landowners become more profit conscious to appreciate the
basic usefulness of his work.

The major omission in Geertz’s work is his failure to see the Javanese
situation in the transitional context, which would have allowed him to see the
trends he observed in better perspective. The lack of this quality is seen
frequently in discussions of population particularly in relation to agricultural
resource systems. One unfortunate result of this has been a preoccupation
with food supply as the major problem relative to future populations. In fact
there is very little evidence to suggest that world agriculture is unable to
provide the existing population with an adequate diet. The recurring failure
to do so, rising to famine levels in a few recent instances in Bangladesh and
the Sahel, lies much more with human incompetence, that is, with social,
political, and administrative deficiencies than with excessive population
pressure as such.

How much longer will it be true to say this is a matter of conjecture?
There is, however, considerable room for intensification and flexibility even
in the most congested situations. Field contact with agricultural systems will
usually turn up the fact that the better farmers, using the same set of natural
and cultural resources, will out-produce the worse, often by factors of three
to four times. Producing more food than can be soon consumed or readily
sold is a futile, and often expensive, activity as farmers in most developed
countries have long known. Increases in food production, which are
substantially faster than natural population growth rates, plus some al­
lowances for improvement in diet, are not in the interest of anyone except
those in the business of storage.

Efforts in the direction of improving diet should be directed at improving
the ability of persons to purchase food at distributional systems and at
improving political and administrative structures rather than at the relatively
simple matter of growing greater quantities. Recent developments in agricultural technology have permitted more and more populations to become self-sufficient in their staple foods and for production totals to increase at rates higher than those of population growth. So far this has been highly beneficial, but it could easily become too much of a good thing if the cultural and institutional impediments to improving diets are not given greater priority.

Another matter to which insufficient attention has been paid is the matter of energy application relative to natural resources. Population numbers are an incomplete basis for assessing the pressure put on local resources, notably land. The concept of "power density" is one that deserves greater notice. Smil makes the point nicely:

Some conclusions from research on power densities are not only unexpected but are in direct contrast to the nearly universal perception of reality. Foremost among these are the findings that the power densities for energy consumption in many large urban areas in developing countries are already comparable to those found in cities in warmer regions of the highly industrialized nations, and that the power density of food production in heavily populated and intensively cultivated parts of Asia, Africa and Latin America is often similar to or even higher than for regions of the temperate zone where farming is more technologically advanced (Smil 1984, 15).

Apart from suggesting that the problem of food supply in some developing countries is likely to be replaced in the popular forums by shortages of other resources, notably energy (with water another inevitable candidate), Smil is implying that future increases in productivity in the agricultural systems of developing countries may be much less than presently surmised.

Some of the implications for the future relationships between demographic change and agricultural systems are clear enough, but many remain mired in controversy. Perhaps the greatest remaining impediment to our understanding of these implications, and therefore the ability to act constructively, is the persistence of the philosophical debate with which the study of population began.

It would be pleasant to report that this debate was moving toward some resolution; instead it has become more complex and acrimonious. The descendants of the two wings of opinion are no longer boxed neatly into right or left, conservative or radical. Rather they must now be classed as belonging either to a group that feels, on the one hand, that the population problem is nonexistent or greatly overblown; or to the other group that persists in the belief that the population resource systems resemble time bombs, programmed to explode in the near future. The third and somewhat more credible alternative is that the problem is a subtle one, creeping up on us.
disguised often in ways that lead us to overlook indications that the root causes of negative trends already working are often demographic and that inevitably they will get more powerful, pervasive, and irreversible. This view of our demographic future is presently neglected.

To add to the confusion the approaches to economic and social development are still fixed along the traditional anti-Communist, pro-Communist split that distorts, when it does not paralyze, the assistance that the developed countries, capitalist and Communist, might render to their less developed cousins. Perhaps our most urgent need is to divest ourselves of these tattered intellectual and philosophical straight jackets and get on with assisting, as best we can, in the provision of adequate accommodation for the inevitable numbers to come.

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INTRODUCTION

If you look at an intact forest in the tropics of the kind described by Marten in Chapter 4, there seems to be little change in species composition with time. If you cut the trees, however, there is an immediate and even dramatic transformation so that new species of vines, trees, and ferns flourish. With time, barring continuing human intervention, the ecosystem will slowly revert back to its original species composition depending on the magnitude of disturbance and climatic conditions in the area.

In other instances, a forest will be cut and subjected to shifting cultivation (slash and burn) as described in Chapter 5 by Hutterer. During the first year, few weeds can be observed and the soil is fertile and so the farmer gets a good harvest. In hilly areas subjected to cultivation in successive years, however, the relatively exposed conditions and rapid soil erosion (on the average 10 to 30 tons/ha/yr or more) allows the growth of cogon or lalang or alang-alang grass (*Imperata cylindrica* [L.] Beauv.) and other weeds. This indicates that the area now has a low productivity, the farmer will need more labor for weeding as described by Rambo in Chapter 9 and the farmer must abandon the plot and open a new one in the secondary forest. If the abandoned plot is not burned or overgrazed, shrubs and vines will gradually
take over and shade out the grasses. Eventually, forest tree seedlings will become established and the area will revert back to a forest stand. This is the normal pattern of plant succession in the humid tropics. If burning is allowed in the abandoned plot, however, the regeneration of trees is prevented and the stand of *Imperata* and other grasses are maintained.

In high elevation areas (greater than 1,500 meters), the species successional sequence will still follow the general pattern of grass → shrub → trees, but the species composition of each stage will differ from that of lowland areas. For example, in the highland areas of Northern Luzon, Philippines, the dominant grass stage of an abandoned shifting cultivation area will be *Paspalum* spp. followed by *Miscanthus* spp. instead of *Imperata* grass.

**SOME BASIC CONCEPTS**

This orderly process of community changes, which is directional and often predictable, is called ecological succession. If it is described in terms of plant community changes, then it is referred to as plant succession. However, it is usually described in terms of total community changes, not just plants.

Succession initially developed as a botanical concept. This was apparent in the early writings of plant geographers and taxonomists such as Von Humboldt and de Candolle. Much of the earlier work, which showed the universality of this phenomenon, were done by plant ecologists such as Cowles in 1899 who described the development of sand dunes in Lake Michigan and Clements who studied the prairie ecosystem in Nebraska. It was Clements (1916) who first developed a comprehensive theory on plant succession, which involved the recognition of successional stages and their associated habitat factors. Since then, succession has been defined in many different ways showing varied emphasis of different workers, that is, (1) changes in the vegetation composition in a particular habitat in the course of time (Tansley 1920, Mueller-Dombois and Ellenberg 1974), (2) changes in plant community composition due to disturbances (Horn 1974; Pickett, pers. com.), and success as an expression of reciprocity between the plant community and its environment (Margalef 1968).

There are two basic assumptions regarding the process of succession, namely, (1) species replacement during succession occurs because populations tend to modify the environment, making conditions less favorable for their own persistence and leading to progressive substitutions, and (2) climax is the end point consisting of plant community that is self-perpetuating and in equilibrium.

There are two types of succession: When changes are internally generated or self-propelled, it is known as *autogenic* succession; and when change is brought about by external factors, it is known as *allogenic* succession. For example, during the eruption of the volcano Krakatoa in Indonesia in the 1880s, several nearby islands were inundated by tidal waves.
and covered with volcanic ash. The original communities were destroyed and new, very different communities later developed.

The distinct and recognizable stages of plant communities are known as seral stages, and the final steady state as the climax. The climax is generally believed to be a function of the prevailing climate and edaphic or soil condition and is termed either as an edaphic or climatic climax. In certain instances, however, the climax is not reached because of the occurrence of a dominant factor such as regular burning. In such instances a particular plant community will persist, which is quite different from the climatic climax, and this is referred to as a disclimax community; if it is due to the regular occurrence of fire, it is a fire disclimax community. If burning is prevented, then the normal course of succession will take place leading to the formation of a climatic climax. The entire gradient of communities that is characteristic of a given site is called a sere. Succession that begins on a sterile area where conditions of existence are not favorable at first, such as from a bare rock, is known as primary succession, while succession that occurs after disruption of previously well-developed plant communities is known as secondary succession.

Succession as an ecological concept has dominated the thinking of ecologists for many years. However, it has also been subjected to severe criticisms on two points, namely, (1) implications within the concept of a purposive or directed change, which reminds one of some teleological concept, and (2) the debate on whether there is really such a thing as a climax. Nevertheless, a common and readily accepted notion is that plant succession is initiated and sustained by some disturbance that creates change and destabilization in the systems (Farnworth and Golley 1973, Grime 1979). Therefore, it is important that conditions where a particular successional process takes place is described and related to community changes.

GENERAL PATTERN AND CHARACTERISTICS OF SERAL STAGES

The general pattern of plant succession is the replacement of annuals by perennials as dominant species. The replacement of dominants can be recognized and is considered as the indication of succession. Reproductive patterns of different seral stages present contrasting patterns of adaptation as described by Bazzaz and Pickett (1980). Pioneer species, for example, can be described as generally opportunist species following the “r” reproductive strategy. This is exemplified by Imperata that produces numerous seeds (more than 200 seeds per panicle), which require light for germination (the reason why it cannot establish itself in shaded areas) and are easily dispersed by wind, water, and animal vectors. Furthermore, its abundant underground rhizomes promote its dominance in habitats affected by regular occurrence of fire and livestock grazing. Pioneer tree species, on the other hand, are generally fast growing in the early stages, but their growing ability degenerates after establishment. They have wide areas of distribution and their small, long-lived propagules are readily dispersed by birds and bats.
Examples in the tropics are *Trema orientalis*, *Macaranga* spp., *Ficus* spp., and *Leucaena leucocephala*.

In contrast, climax tree species are generally limited in distribution, slow in growth, long in life span, and mostly shade tolerant at the seedling stage. The dispersal of their propagules is short range, caused by gravity or carried by mammals and rodents. The propagules are also short-lived. An example of this in the tropics is the *Shorea* or dipterocarp tree species.

**SOME FACTORS AFFECTING SUCCESSION IN AGROECOSYSTEMS**

The understanding of the forces or disturbances that drives plant succession or the causal relationships between plant communities and the environment has an important bearing on agroecosystem management. Two examples will be given in this chapter: (1) weed succession in intensive agriculture, and (2) grassland succession.

**Weed Succession and Intensive Agriculture**

The particular importance of a weed community in an agroecosystem is its effect on crop yield. Patterns of weed succession in agroecosystems have been shown to be affected by some biotic reactions and cultural practices. The following are some examples:

**Fertilizer Application.** Studies at the International Rice Research Institute (IRRI) (1975) have shown that some weeds growing in rainfed rice areas are intolerant of shading by taller crops. These weed species usually have high, dry matter production under open conditions such as *Portulaca oleracea*, *Ipomea triloba*, *Digitaria sanguinalis*, *Eleusine indica*, and *Cyperus rotundus*. Other upland weed species growing with rice are more tolerant to shade such as *Echinocloa colonum* and *Rottboellia exaltata*. This response of weed species to shading is tied up to their physiological response to light. For example, *R. exaltata* has a low, light saturation level and can maintain optimum levels of net carbon dioxide exchange rate under a wide range of light intensity conditions, which enables this species to tolerate shade. By utilizing crops or specifically crop varieties that are efficient in using fertilizer for rapid development of their canopy, shade intolerant weed species can be controlled by the right timing in the application of fertilizer. This same study at IRRI has shown that the yield advantage of intercropping mung bean with corn increased to 60 percent even at low weed control levels if it is grown under high nitrogen levels. This was explained in terms of rate of crop canopy development, which was slow at low nitrogen levels of fertilization resulting in greater weed competition.

**Allelopathy.** Allelopathy is a type of chemical interaction where one plant exudes a secondary chemical substance that inhibits the growth and development of other species. This kind of interaction has been shown to occur with some weed species such as *Imperata cylindrica* (Sajise 1972).
phenolic substance found in the roots and leaves of *Imperata* has been shown to inhibit the seed germination and growth of lettuce and mung bean (Eussen, pers. com.). Fresh and up to two weeks old leaf litter of *Leucaena leucochphala* has also been reported to inhibit seed germination and seedling growth of upland rice but which can be removed by the leaching effect of rain (Cuevas and Samulde 1983).

**Tillage Practice.** This practice can affect weed succession in terms of its effect on weed propagule germination. Some weed species are favored by tillage because their seed germination requires light. Mechanical cultivation was also shown to increase the number of local points of infestation in *Cyperus rotundus* when cut into several small pieces or sections because it stimulates dormant tubers to sprout (De Datta et al. 1973). In other instances, however, tillage operation will expose rhizomes to dessication, which will prevent their regrowth. Rhizomatous weed species such as *Imperata* are susceptible to dessication.

**Irrigation Practice.** This practice can promote dispersal of weed seeds and other propagules, dilutes water soluble allelopathic substances, and enhances or retards growth and infestation of some pests and diseases. Irrigation and tillage are believed to have enhanced the dominance of *Scirpus maritimus*, a problem weed species, in Central Luzon, Philippines.

**Chemical Application.** The continuous application of some herbicides can promote the dominance of some weed species. For example, Vega et al. (1971) have shown that continuous application of propanil favored the population of *Monochoria vaginalis*. Numata (1971) also observed that successful control of annual weeds in paddy rice elicited a shift in weeds from annuals to perennials, from less competitive to more competitive forms, from shallow emergeable species to deep emergeable ones such as *Scirpus maritimus*. This effect is similar to regular cutting, which shifts dominant weed population from Therophytes or species with growing points above the ground surface to Geophytes or species with growing points below the ground level.

**Grassland Succession**

**Grassland Succession Influenced by Fire.** Grassland succession as influenced by fire and grazing in the tropics is an interesting and important phenomenon to observe. Sajise et al. (1976) conducted a phytosociological analysis of Philippine grasslands, and a model of grassland community succession is shown in Figure 8.1. *Imperata cylindrica*, *Themeda triandra*, and *Capillipedium parviflorum* grassland community types represent fire disclimax communities. As long as there is a regular annual occurrence of fire, these grassland community types will persist. Plant competition experiments conducted in the laboratory and field conditions have also shown that the *Themeda* grassland community type is favored by relatively higher levels of soil nitrogen compared with the *Imperata* grassland community type. The
Figure 8.1. General pattern of plant succession in the Philippine grassland ecosystem (from Sajise et al. 1976).
Capillipedium grassland community type, on the other hand, is favored by relatively higher soil pH. The grassland community type that predominates with overgrazing is Chrysopogon aciculatus, which is replaced by Imperata or the other grassland community types if the area is released from overgrazing.

Overgrazing can lead to the continuous deterioration of the grassland or pasture area. An indicator of this condition is the gradual replacement of the native grass species with unpalatable broad leaf species such as Chromolaena odorata (formerly Eupatorium odoratum), Lantana camara, Hyptis suaveolens, Sida acuta, Pseudoelephantopus spicatus, and Amaranthus sp. Compacted grassland soils resulting from overgrazing also tend to favor species that can survive poorly drained and eroded soil conditions such as Aristida cunningiana, Eragrostis zeylanica, Panicum walense, Chrysopogon aciculatus, and Brachiaria quadrirpara. In this context, specific stages of grassland succession are associated or can be considered as indicators of specific environmental conditions such as the dominant influence of fire, grazing, or the physical characteristics of the soil.

The carrying capacity of native grasslands in the tropics can be considerably reduced by the invasion of unpalatable and toxic weed species. A well-known example in Southeast Asia is Chromolaena odorata. It plays an important role not only in the grasslands but also in swidden agriculture (Dove 1984). During the relatively short day months of November to February it produces numerous seeds, which are easily dispersed by wind. Starting from partly shaded and moist gullies, the seedlings spread uphill into plowed and overstocked pasture areas. It can be controlled by the application of 2,4-D and 2,4,5-T, but the cost of chemical control is prohibitive and uneconomical. Resting the pasture for three to six months and burning Imperata has been observed to control Chromolaena. However, after Chromolaena has been allowed to form dense cover, fire is no longer effective in controlling the weed. In the Philippines, improving the pasture areas by planting napier grass (Pennisetum purpureum) and regulating grazing led to the eventual control and replacement of Chromolaena (Javier 1974).

Grassland Succession in the Absence of Fire. In relatively wet areas in the Philippines, Sajise and Orildo (1973) observed that Imperata-dominated grasslands is replaced by a shrub community of Mikania-Melastoma-Solanum association after three to five years. Gradual replacement of Imperata follows as a result of shading. Sajise (1972) has demonstrated that 50-percent shading of Imperata reduces its net photosynthesis and consequently its rhizome production. This effect of shading is important because 60 percent of total dry matter produced by this grass species is stored below the ground in the form of rhizomes, which are the main source of energy for rapid regeneration after burning or cutting. The shrub community may persist for four to six years after which it will be gradually replaced by softwood tree species such as Ficus spp., Mallotus spp., Trema orientalis, and Homolanthus populneus. In fact, these tree species are used by some swidden farmers as an indicator
for the appropriate time to open a fallow area for cultivation. For example, the Ikalahans of Imugan, Nueva Vizcaya in the Philippines use *Ficus* spp., attaining the size of a man's biceps (usually attained within 10 to 15 years), as an indicator that the fallow area is again ready for cropping with sweet potato.

In Indonesia, *Gliricidia maculata*, *Macadamia hildebrandii*, and *Schima walichii* are the more common tree species that take over after the *Imperata* seral stage (K. Kartawinata, pers. com.), while in the dry parts of Thailand, it is the tree species *Cassia siamea* (Likitramanit, pers. com.).

**Grassland Succession and Reforestation.** A successful reforestation program in grassland areas should consider plant succession and the particular characteristic of each seral stage. Reforestation of *Imperata* grassland, for example, must consider the characteristics of this seral stage such as its allelopathic influence, tolerance or low tolerance for shade, and its ability to persist after a fire. Tree species such as *Casuarina* spp. can be established in *Imperata* grasslands because it can tolerate its allelopathy and the acid soil conditions of the grassland area. *Piliostigma malabaricum* and *Antidesma* spp. are two tree species found growing in *Imperata* grasslands because these trees possess thick, fleshy bark and deep root systems that enable them to tolerate the effects of fire.

As an ecological concept, plant succession can be useful in the management of weeds in different cropping systems, grassland management, reforestation, and forestry or silviculture. It can draw in the human ecological perspective, especially in describing the influence of human activities and its effect on plant communities. Such a perspective has been used in the analysis of successional patterns in swidden agriculture (Brosius 1982).

**IMPLICATIONS IN AGROECOSYSTEM MANAGEMENT**

The examples given in this chapter show that present-day agricultural practices, especially of annual crop-based systems, deliberately aim to maintain a seral stage of plant succession characterized by the dominance of one or a few selected species of crops (E. P. Odum 1966, Rambo et al. 1984). This is deliberate because advanced seral stages in the tropics consist of plant communities that are relatively diverse and stable. From these plant communities, people have selected or introduced only certain species as sources of food, materials, and other needs. All other species that they think they do not need for the moment, they categorize as unwanted and strive to eliminate. In their attempt to provide a "suitable environment" for these specialized crops, people have to continually contend with certain unwanted species, unaware that this is nature's way of filling up the "void"; that this is the normal course of ecological succession. To control the unwanted species or to prevent the normal course of ecological succession, people have to continually apply external sources of energy such as fossil-based energy, chemicals (e.g., herbicides, insecticides, nematicides), and nutrients to their
agricultural system. These have been of major concern in modern-day agroecosystem management because of declining fossil fuel supplies and deleterious ecological impacts such as generating new pests and diseases, pollution, and general biotic disruptions, which has raised serious doubt as to the stability and sustainability of intensively managed agroecosystems.

E.P. Odum (1966) described ecological succession as a development process of the ecosystem marked by the following changes: (1) from high net primary productivity (photosynthesis: respiration ratio greater than 1) in the early seral stages to a shift in energy use for biomass, maintenance, information content, and symbiotic functions between organisms in the more advanced seral stages, (2) simple and linear food chain in the early seral stages to more complex food webs in the advanced seral stages, and (3) from an “open” nutrient cycling pattern in early seral stages to a highly nutrient conserving, closed nutrient cycling pattern in the later seral stages. In these terms, annual cropping systems are clearly at an early successional stage. H. T. Odum (1962) further added that “a successional stage which is developing towards a climax steady state is also characterized by a certain pattern of accumulation or build-up or removal of materials and energy such as nutrients and organic matter.”

Man’s agricultural practices, therefore, have always been geared toward arresting the advance of ecological succession to maintain high net productivity, which is a characteristic of early seral stages. In the process, natural homeostatic mechanisms inherent in advanced seral stages have to be artificially supplied to the agroecosystem. For example, sewage algal populations can be maintained only by artificially controlling the nutrient flux in the ponds. This is done by the spraying of waste that changes the flux of organic matter and water. Such intervention can maintain a herbaceous system characteristic of a moist habitat instead of a forest (H. T. Odum 1962). Regular burning in grasslands that maintain Imperata is also an example of human use of force (in this case, fire) to control nutrient and energy flux within the ecosystem.

Taking the ecological succession principle into account, what are some possible tropical agroecosystem management strategies that can be utilized to promote productivity and sustainability? There are four possible areas that can be explored.

Directed Agroecosystem Diversification

This strategy would involve allowing ecological succession of weed communities and crops to proceed to a certain level so one can obtain the benefits of both high net primary productivity (of usable products) and a certain degree of homeostasis. In fact, this is the strategy being pursued in multiple cropping. The requirement of this strategy would be a knowledge of what comprises this advanced seral stage in terms of the right combinations not only of crops but also of weed communities. For example, Altieri (1980) demonstrated that damage to corn by army worms (Spodoptera frugiperda)
was reduced by interplanting mung beans or by allowing corn to grow with selected weed communities such as *Amaranthus* sp., *Heterotheca subaxillaris*, *Chenopodium ambrosioides*, *Solidago altissima*, and *Bidens pilosa*. In an earlier study, Altieri and Whitcomb (1979) also showed that a leaf hopper (*Emposca kraemeri* Ross and Moore) was repelled from beans by weed species such as *Eleusine indica* and *Leptochloa fliliformis*. Feeny (1976) hypothesized that diversification of cropping systems would reduce plant “apparency” and would lead to greater pest protection.

**Regulation of Material Fluxes by Natural Agents**

The greatest constraint in maintaining an agricultural system or in preventing its natural tendency to develop into “less desirable” seral stage is the availability of external energy sources or material inputs necessary to maintain this “desirable” seral stage. There are, however, natural agents that can be utilized to regulate these material/energy fluxes. For example, water, in the form of irrigation water, or fire can be utilized as a regulatory force. The world famous Bontoc rice paddy system in the Cordilleras, Northern Luzon, Philippines, has been maintained over thousands of years because of the regulation of nutrient fluxes through the irrigation system and the natural recycling process effected by animals, pigs in this particular case (Omengan and Sajise 1981). Rambo, in Chapter 9, describes how swidden farmers use fire to set back the successional stage of their plots.

**Coupling of Complementary Ecosystems at Different Seral Stages**

This is a least explored agroecosystem strategy. What may accrue from this strategy is the benefit of high productivity (or desirable products) of the early seral stages and the homeostatic mechanisms for stability of the more advanced seral stages. An example is the coupling of an upland rice agroecosystem with a secondary forest at Mount Makiling, Philippines. A positive effect was the control of rodent damage to upland rice because of the presence of civet cat in the secondary forest, which preys on the rodents. However, there are also possible negative effects of the coupling of these two ecosystems such as damage by forest-dwelling wild pigs to root crops and by birds to grain crops. It is possible that one has to look for two seral stages that are complementary so that the net positive effects of increased productivity and homeostatic control are achieved.

**Design Agroecosystems to “Mimic” Advanced Seral Stages**

Long Yiming and Zhang Jiahe as cited in Rambo et al. (1984) reported that several benefits were derived from rubber interplanted with tea and rubber interplanted with devil pepper in Yunnan Province, Southwest China, which they termed artificial plant communities. These benefits were (1) substantial litterfall, which improved soil fertility, (2) soil and water conservation due to layering of canopy, (3) reduced stress from climate and other natural factors, and (4) greater economic returns compared with pure culture. This system mimics a natural and advanced seral stage. If supply of
carbohydrate foods is one problem in advanced seral stages, a secondary or primary tropical rain forest has species that can be managed to supply this, such as *Dioscorea* spp., a root crop, and also several palm species. This is a strategy that is particularly relevant to agroforestry. For example, planting of *Dioscorea* or *Caryota* sp. (a palm species which is a source of carbohydrate), can be intensified in a secondary forest or in combination with fuelwood species to provide adequate supply of carbohydrates. These two species are shade tolerant.

Ecological succession has profound implications for agroecosystem management in order to enhance agroecosystem productivity and stability. These implications must be taken into consideration in designing improved systems.

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No Free Lunch: 
A Reexamination of the Energetic Efficiency of Swidden Agriculture

A. Terry Rambo

During the 1960s, the high productivity of American agriculture was frequently favorably compared to the low efficiency of traditional subsistence farming. It was pointed out that mechanization had so greatly reduced the need for human labor that a single American farmer could feed 50 nonfarmers, thus freeing a large labor force for productive involvement in urban industries. A traditional farmer would have to work six times as long to produce the same quantity of food (Hirst 1974, 137), thus tying up masses of people in "unproductive" activity. Successful development was seen as requiring replacement of traditional labor-intensive farming systems with the more efficient American mechanized model. Throughout the developing world, substitution of tractors for oxen became synonymous with progress.

Only following the onset of the global energy crisis in the early 1970s was it belatedly recognized that while mechanized agriculture was indeed highly productive in terms of output of food per man-hour spent in farming, it was far from efficient in energetic terms. American farmers might need to work only nine hours to produce 81 bushels of corn, but they consumed the equivalent of 80 gallons of gasoline in the process, giving a return of only 2.8 kilocalories (kcal) of food for each kcal of fuel used (Pimental et al. 1973, 133).

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1 This chapter is a revised and expanded version of my article "Fire and the Energy Efficiency of Swidden Agriculture," which appeared in Asian Perspectives 23(2):309-316, 1980. Reprinted by permission of the publisher.
446). When all of the energy used directly and indirectly in mechanized food production is included in the calculation of energetic efficiency, a negative balance may even appear with raising of a single food calorie needing an “energy subsidy” of from two to ten fossil fuel calories (Hirst 1974; Steinhart and Steinhart 1974, Figure 5).

EFFICIENCY OF TRADITIONAL AGRICULTURAL SYSTEMS

The realization that energy-intensive mechanized agriculture did not necessarily provide a viable model for development of energy-limited Third World countries aroused renewed scientific interest in traditional subsistence farming systems. Although often requiring heavy human labor inputs, many such systems appeared on initial examination to be highly efficient in energetic terms, apparently yielding from five to fifty food calories for each calorie of work expended in farming (Steinhart and Steinhart 1974, 313). More recent analysis (Ward et al. 1980, 571) suggests, however, that traditional farming systems based on use of draft animals may be no more energy efficient than modern mechanized systems. However, the slash-and-burn or swidden system of shifting cultivation practiced in tropical forest areas of Africa, Asia, and Latin America still appears to many researchers to be particularly energy efficient, yielding up to 20 food calories for each calorie of human labor expended in working the system (Rappaport 1971, 127; Steinhart and Steinhart 1974).

Swidden farming also has a number of ecological advantages under tropical environmental conditions. It gives reliable yields with minimum susceptibility to pest outbreaks and, when practiced at appropriate levels of population density, it causes little long-term degradation of the productive capacity of the environment. These and other positive aspects of swidden cultivation have been described by Barney (1970), Conklin (1957), and Geertz (1963), among many others. So well is swidden farming adapted to the humid tropics that, despite much effort, agricultural researchers have yet to perfect alternative systems having comparable social and ecological merits. In fact, the thrust of much current work is to try to improve shifting cultivation rather than trying to replace it with fixed field systems (Grandstaff 1980, Greenland 1975). Swidden farming thus deserves much of the esteem in which it is currently held (Bennett 1973, Bodley 1976). What it does not merit, however, is the acclaim it has received as a farming system that utilizes energy with extraordinary efficiency.

Attribution of energetic efficiency to swiddening is largely derived from Rappaport’s (1971) field study of Tsembaga slash-and-burn cultivation in the New Guinea Highlands. His comparison of human labor inputs with crop yields showed that the Tsembaga received an average return of 16 food calories for each calorie spent in working their fields. This ratio places Tsembaga swiddening among the most energy-efficient agroecosystems known in the world (Steinhart and Steinhart 1974, 312, Figure 5). These favorable energy input-output ratios are wholly misleading, however, since
Rappaport failed to include the energy used in burning the field in his calculations, an oversight comparable to omitting the gasoline used by tractors in evaluating the energy efficiency of American farming. As will be shown in the following sections, when the overlooked energy input of fire is taken into account the reputed energetic efficiency of swidden agriculture disappears.

**ROLE OF FIRE IN SWIDDEN AGRICULTURE**

That the energy input of fire has been generally overlooked is not surprising in view of the relative lack of attention that has been paid to the role that burning plays in the functioning of swidden systems. Thus, although there is agreement among ethnographers who have studied specific swidden systems in tropical Asia that it is the quality of the burning, which largely determines the success of the crop (Barney 1970, 57-59), there is no similar consensus as to why this is true. Anthropologists, agronomists, and soil scientists have, however, suggested at least six major beneficial effects of burning:

1. Clearance of unwanted vegetation from the field,
2. Alteration of soil structure making planting easier,
3. Enhancement of soil fertility by plant ashes,
4. Decrease in soil acidity,
5. Increase in availability of soil nutrients, and
6. Sterilization of soil and reduction of microbial, insect, and weed populations.

Each of these suggested functions of burning in swidden agriculture will be discussed in turn below.

**Clearance of Unwanted Vegetation from the Field**

Farmers clearing new plots in forest lands face the problem of removing large quantities of vegetation from their fields. Given the fact that tropical rain forest often has an above-ground biomass of several hundred metric tons per hectare, cleaning off the fields using human muscle power alone would simply be unfeasible in any reasonable period of time. Burning quickly solves this major problem facing the swidden farmer (Conklin 1957, 71; Nye and Greenland 1960, 66-67).

**Alteration of Soil Structure**

The heat of the fire both softens the surface soil and makes it more friable so that it provides a suitable seed bed, which can be easily planted.

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2 Referring to this failure to consider the energy input from fire, Lewis (1977, 45-46, n. 2) has commented that “given the fascination which the control and flow of energy has had for many writers of the ‘Michigan School’ (of cultural ecologists), this lack of interest is perhaps paradoxical. Rappaport, for instance, makes only two very minor notations regarding the burning of swidden fields in his study of ‘ritual-ecology’ in New Guinea . . . The possibility of measuring the B.T.U.'s involved in the transformation of plant communities, domesticated or otherwise, would seem to be of fundamental importance to understanding energy expenditures.”
using a wooden dibble stick (Conklin 1957, 71). If fire did not do this work; it would be necessary for the farmer to do it himself by use of a hoe or other manually-operated cultivation implement. Hoe cultivation, however, causes much more rapid breakdown of soil structure with consequent increased vulnerability to erosion than does the minimal disturbance of the surface caused by dibbling (Nye and Greenland 1960, 84-85).

Enhancement of Soil Fertility by Plant Ashes

As Marten notes in Chapter 4, in tropical rain forest ecosystems, many critical nutrient elements are stored in the plant biomass instead of in the soil. For example, more than 90 percent of the available phosphorous is held in the biomass (Sanchez 1976, 354). Therefore, when the vegetation is burned, large quantities of nutrient-rich ash are deposited on the soil surface, providing the newly planted crops with the equivalent of the application of several hundred kilograms per hectare of chemical fertilizer (Sanchez 1976, 363-365).

It is true that much of the carbon, nitrogen, and sulfur stored in the vegetation is lost into the atmosphere in the course of burning the field but, contrary to common belief, stocks of these nutrients in the top soil are not depleted (Nye and Greenland 1960, 67-70) and incorporation of unburned charcoal and plant residues into the top soil may actually somewhat increase soil carbon and nitrogen levels (Sanchez 1976, 364, 368). In any case, relatively more of the nitrogen is stored in the soil component of the forest ecosystem rather than in the plant materials so that losses due to burning are not that large. Substitution of composting for burning would, of course, reduce the nutrient loss caused by burning but would require greater human labor inputs, would make nutrients available only slowly and gradually rather than as a flash treatment during the critical first weeks of cereal plant germination and growth.

Decrease in Soil Acidity

As Panchaban describes in Chapter 10, many tropical soils are highly acidic, having pH values below 4 or 5. Plant ashes are generally alkaline and cause an increase in soil pH levels to 6 or 7. This decreased acidity makes existing stocks of phosphorous, potassium, and other nutrients in the soil more readily available to the crop plants (Sanchez 1976, 365-367).

Increase in Availability of Soil Nutrients

For reasons that are as yet only poorly understood, heating of soil makes those stocks of nutrients already stored there more available to plants (Nye and Greenland 1960, 71-72). Professor K.T. Joseph (pers. com.) suggests that the application of heat causes organic matter in the soil to release some of the phosphorous and potassium it is holding, making these nutrients available to crops.
Sterilization of Soil and Reduction of Microbial, Insect, and Weed Populations

Experimental studies of burning of forest plots in North America show that temperature higher than 55°C are reached for periods exceeding three hours in the top 4 centimeters of the soil (Shearer 1975). In a swidden in northern Thailand, the upper 2 centimeters reached at least 75°C (Zinke et al. 1978, 144). Such heating is sufficient to kill most roots, weed seeds, and insect eggs and larva in the surface soil as well as to greatly reduce the microbial population of the plot (Conklin 1957, 71; Nye and Greenland 1960, 72). Elimination of weed seeds is probably the most beneficial effect of this partial sterilization of the soil as the crop plants are able to become well established before reinfiltration of the plot by new seed from external sources has time to occur. There is convincing evidence that it is often the increased demands for human labor in weeding to hold back natural succession rather than decline of soil fertility per se that leads to abandonment of swiddens after harvesting of only a single grain crop. Experimental plots that have been carefully weeded have often maintained high levels of crop productivity for several successive years, but the human effort needed for weeding greatly exceeds the labor needed to clear a new plot in the forest (Janzen 1973, 1215; Nye and Greenland 1960, 76-80; Sanchez 1976, 365-367, 383, 398).

All of the beneficial effects of burning cited in the preceding paragraphs might, at least in theory, be achieved by other means: Bulldozers can clear even primary rain forest, application of chemical fertilizer can enhance soil fertility, liming can raise pH levels, tractor or animal-drawn plows can soften the soil for planting, while insect pests and weeds can be kept in check by chemical control methods. Such work would demand greatly increased energy inputs, however, either from humans and animals or from petroleum-powered machines (Janzen 1973, 1213). Tropical forest cultivators rarely dispose of sufficient supplies of such energy; instead, they rely on fire to perform many of the necessary tasks of cultivation. The energy stored in the vegetation and used by the fire is thus performing useful work in the swidden agroecosystem comparable in character to that done by the fossil fuel, which powers agricultural machinery on the American farm.

ENERGETICS OF SWIDDEN AGRICULTURE

As far as can be determined, no one has yet actually directly measured the energy involved in swidden burning, but it is possible to derive an approximate set of energetic values of published ecological data on the biomass and energy value of tropical forests.

In the New Guinea Highlands, 12- to 13-year-old secondary forest of the sort cleared by the Tsembaga has an above-ground, dry-weight plant biomass of 72.5 metric tons per hectare (Manner 1977, 215, Table 1), or approximately 7 kilograms (kg) per square meter (m²). Tropical forest
vegetation is reported to have an average of 3,897 kcal/kg of dry-weight material (Golley 1961, 582). Thus, if 100 percent combustion were achieved, burning would utilize 28,250 kcal/m². Under rain-forest conditions, such complete combustion is improbable so that, although the Tsembaga are reported to burn with great care—collecting and reburning any materials left after the first firing of their fields (Rappaport 1968, 43)—it is unlikely that more than 75 percent of the original biomass is consumed in the fire, representing a total fire energy expenditure for working the swidden field of 22,188 kcal/m².

No data are available on the efficiency with which fire energy performs its work in swidden cultivation; presumably, much of the potential energy of the biomass is simply lost as heat rising in the convection column above the surface of the burning field. For present purposes of calculating comparative energetic efficiency of swidden versus mechanized agriculture, however, the question of efficiency of fuel use is irrelevant: What matters is only the total quantity of energy consumed in the operation of each system, not whether or not this energy is used in optimum fashion. Thus, while most of the fire energy may be misdirected, a poorly designed tractor may also deliver only a relatively small part of the petroleum energy that it consumes to the plow: The total energy cost to the operation of the system is the same per liter of gasoline, however, as that of a more efficient model.

According to Rappaport's (1971) figures for the Tsembaga, human labor represents an input to the swidden system of 138.7 kcal/m². The caloric value of food grown in the swidden is 2,416.5 kcal/m², giving an energy output-input ratio of 17.4:1. If the energy represented by burning is added into the calculations, however, a radically different ratio appears. Fire energy, plus human energy, equals an input of 22,327 kcal/m², giving an output-input ratio of 0.11:1. It is necessary, therefore, to expend approximately 10 calories for each food calorie yielded by swidden farming.

The figures used here to calculate energy efficiencies are only rough approximations at best but, even if the estimate of the energy value of burning is considerably overstated, the basic conclusion that swidden agriculture is not a highly energy-efficient system of food production remains unchanged. Swidden farming is just as dependent on an energy subsidy to achieve high production with low input of human labor as in modern mechanized farming. The fact that this subsidy comes in the form of tree trunks rather than barrels of petroleum is irrelevant to assessment of energetic

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In the Amazonian rain forest, stems compose 61 percent of the above-ground organic matter while leaf matter, branches and twigs, lianes and epiphytes, standing deadwood, deadwood of litter layer, and fine litter compose 39 percent of the total (Klinge et al. 1975, 116-117). As many of the smaller stems would burn completely in any moderately successful firing of the plot and even large trunks are usually partially consumed, the above estimate of 75 percent combustion is probably conservative.
efficiency. In both cases, the availability of energy is a critical limiting factor for the maintenance of productivity of the agroecosystem, and thus a determinant of the size of the human population that it can support on a long-term basis. In the case of swidden farming, increasing population densities can easily exhaust the available supplies of biomass energy. This normally leads to a shortening of the fallow period during which the forest regenerates. Plots are cut again before sufficient energy has accumulated in the vegetation to ensure a sufficiently hot fire to do the work necessary to achieve high productivity. Unless yields are to decline precipitously, more and more human labor must be substituted for the work formerly done by the fire in cultivating, fertilizing, and weeding the land. Such intensification is evident today in many areas of the tropics. The swidden farmer, just as much as the industrial farmer, is confronting an energy crisis. In fact, at current use rates, tropical Asian swidden farmers may well run out of trees to burn before Western farmers run out of gas for their tractors.

COMPARATIVE ASSESSMENT OF ENERGETIC EFFICIENCY OF AGRICULTURAL SYSTEMS

As has been recognized in the case of American mechanized agriculture, and as is suggested here with regards to swidden farming, analysis of the energetic efficiency of agroecosystems should take into account all energy inputs into operation of the system and not just human labor inputs. Different agroecosystems have very different hidden energy subsidies that must be recognized and taken into account in calculations of their comparative efficiency. Traditional Asian irrigated rice farming, for example, appears to rival swidden agriculture in terms of the efficiency with which human labor produces food (Steinhart and Steinhart 1974). It should be recognized, as Geertz (1963, 29-31) has pointed out, however, that the water that flows into the paddy fields does much of the work of farming by

4 It can be argued that energy use in swidden farming is qualitatively different than in mechanized farming since the former relies on the "renewable" energy of trees, whereas the latter draws down "nonrenewable" fossil fuel stocks. Such reasoning provides an unfortunate example of how rigid linguistic dichotomies can distort thought about natural phenomena: Whether an energy resource is renewable or not is simply a function of the rate at which the resource is used in comparison to the rate at which it can be replaced. If forests are cut and burned at a faster rate than allowed for by their natural regeneration, then they become a nonrenewable energy source for all practical purposes. Conversely, if fossil fuels are used at a lower rate than they are being replaced by geological processes, then they represent a renewable resource. That this may in fact be the case with regards to petroleum is suggested by Odum (1975, 7), who points out that the estimated rate of deposition of organic matter in the biosphere is of the same order of magnitude as man's present oil-use rate. Of course, only some fraction of this organic material is transformed into fossil fuel so that current use rates are certainly not sustainable for very many more years.

5 Malaysian aborigine swidden farmers appear to be well aware of the relationship between fire and human labor demands. A Temuan woman whom I observed struggling to dig out a heavy growth of weeds in a field that had been burned after only a three-year fallow period remarked that, "If the fire does not eat them, then there are many weeds."
softening the soil, suppressing weeds, and providing nutrients to the rice plants. In the Muda scheme area in Malaysia, for example, irrigation water flowing in from the mountain catchment area supplies almost twice the actual potassium requirements of the paddy plants (K.T. Joseph: pers. com.) The potassium is present in this water because the falling rain does the work of extracting it from the upland soils, while the force of gravity transports it to the field. In context, such energy seems to be free and therefore is ignored in most analyses of the energetics of irrigated systems.

When the context is changed, however, as when wet rice is grown in rain-fed paddys as is done in the Lower Mekong Delta of Viet-Nam, then the absence of this hidden energy subsidy makes itself evident. Peasant farmers in frontier areas there told the author that they were forced to employ chemical fertilizers because yields fell off rapidly after the first few years of cultivation of new land. This nutrient depletion occurs because there is no automatic replacement by in-flowing irrigation water of the nutrients taken from the soil in the harvest.

It is probable that closer scrutiny of traditional subsistence farming systems will reveal many other hidden energy subsidies that will account for what is now seen as their high energetic efficiency. Lacking such analyses, it is certainly premature to conclude, as has Bodley (1976, 51) that, "... primitive farming systems offer a reliable subsistence base that may actually be more efficient than the 'factory farm' techniques replacing them." As is the case with swidden agriculture, some traditional farming systems may be socially and ecologically better adapted to the tropics than are some types of modern agriculture, and such positive aspects are not to be lightly discarded in the current search for higher levels of productivity. Given what is already known about ecological energetics, however, it is certain that operation of such systems has an energy cost, and it is probable that this cost is greater than is currently realized. Neither traditional farming nor modern mechanized agriculture can produce a truly free lunch: The only difference between the two systems lies in who has to pick up the check—the farmer himself, the biotic or abiotic components of the ecosystem in which he participates, or, as in the case of our current reckless wasting of petroleum resources, future generations of farmers whom we are denying access to this energy subsidy and who will have to make good the loss with their own overtaxed muscles.

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Although, in principle, the year-round constant high temperatures of the tropics give them a higher agricultural production potential than other zones, a number of environmental factors limit the realization of this potential productivity. Soil factors are especially important constraints.

There are some highly productive soils in the tropics, but highly weathered, leached soils, with high acidity and low plant nutrient availability, occupy about half of the land area of the tropics. Such soils require special management measures to deal with problems of high acidity, low organic matter content, and low availability of plant nutrients. Moisture stress, extreme temperatures, and erosion due to high and intense rainfall are other major soil management problems in tropical agriculture.

**ACIDITY OF TROPICAL SOILS**

One of the main problems of tropical soils is soil acidity. Highly weathered and leached soils are generally acid. Acidity problems of these soils are associated with pH levels lower than 5.5. Exchangeable aluminum is the dominant cation contributing to soil acidity at pH lower than this 5.5 level.

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1 The author wishes to acknowledge Dr. Suraphol Ratanasophon, assistant professor at the Department of Soils, Faculty of Agriculture, Khon Kaen University, who assisted him in preparing the material in this chapter.
Acid soil infertility is due to one or more of the following factors: aluminum toxicity, calcium and magnesium deficiency, manganese toxicity, and low cation exchange capacity (CEC). Among these factors, aluminum toxicity and low CEC are the most common causes of acid soil infertility.

High aluminum levels in the soil solution do direct harm to roots and decrease root growth. Aluminum tends to accumulate in the roots and impede the uptake and translocation of calcium and phosphorus to the tops (Foy 1974). Thus, aluminum toxicity may produce or accentuate calcium and phosphorus deficiencies. Aluminum toxicity can be corrected by liming to pH 5.5 to 6.0, to precipitate the exchangeable aluminum as aluminum hydroxide. Manganese toxicity occurrence in certain soils high in soluble manganese can also be corrected by liming to pH 5.5 to 6.0. Often calcium and magnesium deficiencies occur together with aluminum or manganese toxicity; but in certain soils low in these two elements, liming serves as calcium and/or magnesium fertilizer.

Acid infertile soils usually have low CEC values due to mineralogy and coarse texture. The CEC is increased if soil pH is increased in these soils and vice versa. Liming acid tropical soils to pH levels of 5.5 to 6.0 can increase the CEC without causing adverse effects.

Liming to neutrality is not suggested for acid tropical soils. Overliming to pH values greater than 6 or 7 can seriously decrease yields, particularly in soils high in iron and aluminum oxides. This may cause structural deterioration. Overliming promotes the formation of smaller soil aggregates and thus reduces infiltration rates and makes soils more susceptible to erosion (Peele 1963, Schuffelen and Middleburg 1954). Overliming may reduce phosphorus availability and induce zinc, boron, and manganese deficiency. Liming management in the tropics should be aimed at determining the minimum level of lime needed.

Another strategy that can be used for acid soils is the planting of acid tolerant species of plants, such as Acacia spp. and Casuarina spp., or the inoculation of mycorrhizal fungi. As is noted by Rambo in Chapter 9, the ash resulting from burning of swidden fields also serves to raise pH levels significantly.

**SOIL ORGANIC MATTER**

Tropical soils have low organic matter contents because of the high temperatures and rapid decomposition rates. However, organic matter contents under natural vegetations of tropical soils are not necessarily different from those in the temperate regions.

In unfertilized soils, the beneficial effects of organic matter consist of supplying most of the nitrogen and sulfur to plants, maintaining CEC, blocking phosphorus fixation sites, improving structure in poorly aggregated soils, and forming complexes with micronutrients.
Organic matter depletion is quite rapid unless certain management practices are applied. The maintenance of organic matter is essential for no-fertilizer agriculture. Animal manure applications improve physical soil properties. Green manures are usually effective to the next crop, while mulching can conserve organic matter by decreasing soil temperatures.

**PLANT NUTRIENTS**

Many tropical soils are infertile, providing less than optimum supplies of nutrients—such as nitrogen, phosphorus, and sulfur—to crop plants. Nitrogen in soils originates from rain and dust, nonsymbiotic and symbiotic fixation, animal and human wastes, and chemical fertilizer. As in the temperate region, symbiotic nitrogen fixation is the main natural mechanism for soil nitrogen additions in the tropics.

Nitrogen is the fertilizer nutrient applied in the largest quantities in the tropics. Nevertheless, the actual amounts used are much lower than in the temperate region. However, in certain tropical areas—particularly for irrigated rice, sugarcane, other plantation crops, and some pastures—nitrogen use per unit area rates among the highest in the world (Sanchez 1976).

The most common nitrogen fertilizer sources used in the tropics are urea and ammonium sulfate. As far as sources of nitrogen fertilizer are concerned, there is little difference in the effectiveness between urea and ammonium sulfate in the tropics. In terms of residual effect, the topsoil pH is likely to decrease when ammonium sulfate is used in large quantities, whereas it remains the same with urea.

After nitrogen, the two most commonly limiting nutrient elements in the tropics are probably phosphorus (P) and sulfur (S). Phosphorus deficiencies are common in highly weathered soils. The deficiencies are mainly due to high P fixation capacity of these soils. Iron and aluminum oxides are the main components causing P fixation in highly acid and weathered soils.

When capital is available, one approach is to broadcast a high rate of phosphorus fertilizer sufficient to satisfy the fixing capacity of the soil. This approach, however, is probably beyond the economic reach of most farmers in the tropics; therefore, other strategies are required. Low-cost phosphorus sources, such as rock phosphates, could be used or the phosphorus fixation capacity of the soil could be reduced by lime or silicate application.

Sulfur deficiencies are widespread throughout the tropics. They are found in highly weathered soils, in sandy soils, in savanna areas subject to annual burning, and in inland, unpolluted areas. Sulfur is less tightly held by oxide particles than is phosphorus.

**SOIL MOISTURE**

Four soil moisture regimes, referred to in the U.S. Soil Taxonomy System (1975), are common in the tropics: (1) udic: the soil is dry for no
more than 90 cumulative days during the year; (2) ustic: the soil is dry for more than 90 cumulative days but less than 180 cumulative days during the year; (3) aridic: the soil is dry for more than 180 cumulative days per year; (4) aquic: the soil is saturated with water long enough to cause reduced soil conditions.

The udic soil moisture regime implies that during most of the year water stress will be absent and is roughly equivalent to the rainy climates for most soils. The ustic regime implies a strong, dry season of three to six months and is well correlated with the seasonal climates. The aridic regime implies a longer dry season, which is well correlated with the dry and desert climates.

Variation in soil properties and topography permit the existence of different soil moisture regimes under the same rainfall regime. A deep sandy soil may be ustic in a rainy climate because of rapid drainage. The aquic regime is typical of poorly drained sites and occurs even in the long, dry climates.

Water deficits of these four extensive soil moisture regimes occur during the dry season or even during the rainy seasons because of short-term droughts. The ability of soils to retain water and supply it to plants is one of the main limiting factors in tropical agriculture.

Drought periods of one week or more are a common occurrence during the rainy season in the semiarid tropics. Rainless periods of up to two weeks cause severe water stress in many crops. These drought periods can cause severe yield reductions when they occur at critical growth stages. Often only the A horizon is affected; shallow crops suffer greatly, while the subsoil remains relatively well supplied with water. Root development in the acid subsoil may be restricted because high levels of exchangeable aluminum or low calcium levels prevent roots from reaching the place where available water is plentiful. Thus, deep liming applications are feasible to promote deeper root development and result in improved water relationship between soil water supply and plant roots.

Protecting the soil surface with mulches or a continuous crop canopy, or both, is a sound management alternative to conserve soil water supply to plants. Deep plowing in order to increase porosity and promote root development is required to improve available water-holding capacity of soil. Management of soil organic matter in order to improve soil structure in poorly aggregated soil is also an effective practice.

Many traditional cropping systems show excellent synchronization between crop moisture requirements and available soil moisture supply. When attempting to increase yields through the introduction of high-yielding varieties of different growth duration, success will depend on the degree to which the new cultural practices mesh with the moisture regime.
SOIL TEMPERATURE

Soil temperatures in the tropics fall in the categories of the isotemperature regimes; that is, there is less than 5°C difference between the mean maximum and mean minimum temperatures within 50-centimeter soil depth. We can probably say that a unifying property of tropical soils is their relatively uniform temperature regimes throughout a given year.

Mean annual air temperatures closely approximate mean soil temperatures in the tropics (Smith et al. 1964). Unless exposed, soil temperatures even at the surface do not seriously exceed air temperatures.

Soil temperature is seldom considered a serious limiting factor in the tropics. There are two instances, however, in which soil temperatures can be limiting: excessive high temperature in certain sandy topsoils and cool temperatures in the tropical highlands. In soils recently cleared for cultivation, management of soil temperature by straw mulches or by keeping a crop canopy as long as possible is extremely important to neutralize the increases in topsoil temperatures. In addition, mulching decreases water consumption and the need for weed control and often increases yield. In this example, Lal (1974) found that mulching increased corn yields from 3.6 to 5.4 tons/hectare (ha) and decreased weed growth to one-third of that observed in the unmulched plots.

SOIL EROSION

In spite of the generally higher aggregate stability of many tropical soils, the extent of erosion in the tropics is reaching alarming proportions. The principal causes of erosion are human activities related to deforestation, overgrazing of pasture lands, and poor use of shifting cultivation practices in sloping topography similar to those described in Chapter 5 by Hutterer and Chapter 8 by Sajise.

The principles of soil conservation in the tropics are no different from those developed in the temperate region. The high intensity of some tropical rainstorms and the lower availability of capital, however, require some special adaptations. Planting along the contours is usually a feasible and sound practice but a difficult one to introduce to farmers used to planting up and down the slope. Keeping the soil covered with crop residues or under cultivation during periods of expected high rainfall is another sound principle. Planting tree crops or pastures on steep slopes, and terracing, seldom requires additional conservation practices.

The deep plowing practices recommended in the tropics are highly soil specific. For example, the deep plowing recommended for sandy soils of Senegal resulted in a reduction of soil erosion from an average of 10 tons/ha/year with shallow plowing to 3.7 tons/ha/year with deep plowing because of an increase in soil porosity and better crop growth (Charreau 1972 in Sanchez 1976). For highly aggregated soils of Sao Paulo, Brazil, deep plowing was practiced, and annual erosion losses increased from 8 to 16 tons/ha (Marques and Bertoni 1961 in Sanchez 1976).
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Soil Survey Staff  
INTRODUCTION

Soils are considered an important resource in the country, and the inventory and use of that resource will determine to a large extent the survival and progress of the nation. Increasingly, many disciplines, agencies, and institutions from both advanced and Third World countries work in cooperative projects to improve the usefulness of soil information and maps. Hence, soil scientists all over the world, map, describe, and classify soils, and interpret resultant information to assist in improving the uses of all soils in their countries.

THE NEED FOR SOIL RESOURCES INVENTORY

A thorough knowledge of soils is fundamental not only in planning but also in project development (Corpuz 1978). The reason is that soils in the tropics exhibit wide variability in terms of texture, type, color, capability, etc. Obviously, a need for soils inventory and classification is in order. To an agricultural planner, this is essential. For one, this becomes the determining factor in evolving a rational land use, which is one of the principal production
strategies to promote regional development as envisioned, for example, in the perspective plan for the Philippines for the year 2000.

Davide (1978) stresses that research data on crop production, soil management, experiences, and modern inputs are available, which provide greater opportunities for more efficient soil management so soils can be farmed more efficiently. The interaction of these data with basic soil information has to be organized in a format that the farmers can understand and ultimately must be put in terms familiar to them.

Figure 11.1 schematically represents the activities, products, and users of a soil resources inventory process (Nielsen 1977). The products column begins at the bottom with technical papers on soil genesis, proceeds upward through data banks, soil classification systems, basic land resource maps (at several scales), interpretation guides, and culminates at the top with maps showing potentials and hazards for various land uses. Products at the top of the column are in the greatest demand by the largest number of users. Inventory data move primarily upward through the soil inventory process, but some informational items are presented at various levels (laterally in Figure 11.1) to specialized audiences.

PROBLEM-ORIENTED SOIL SURVEY

Soil surveys are potentially the most useful source of land resource information available, but in order to make a significant contribution to the solution of land-use problems that developing countries encounter, these surveys should be problem oriented.

Soil surveys provide facts about the landscape, which are helpful in guiding as well as generating action in land-use planning. Figure 11.2 summarizes the three major sequential steps involved (Wohletz and Wildman 1971). The development of assumptions and criteria for each land use (step 2) is the focal point where soil and plant scientists, geologists, planners, engineers, and others pool their scientific knowledge and practical experience to form a strong link between soil facts and specific soil interpretations useful in planning.

Although a major part of the world’s agricultural technology was developed and applied to particular land areas without the benefit of soil survey and planning, soil surveys and development planning can substitute for trial and error to the fullest extent possible, thus eliminating predictable failures in production and in resource conservation (Knox 1977).

A soil survey is an investment that is almost certain to pay for itself and return a profit. Simonson (1974) states that the benefits to be realized from investments in soil surveys and interpretations are truly enormous. Klingebiel (1966) reported that in the United States the cost of detailed surveys is about US$1/acre and the surveys are useful for at least 25 years. Benefits from the uses of soil surveys are about .20US cents/acre/year for cropland, about
<table>
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<tr>
<th>ACTIVITIES</th>
<th>PRODUCTS</th>
<th>USERS/CLIENTELE</th>
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</thead>
<tbody>
<tr>
<td>Apply interpretation criteria to land resource maps</td>
<td>Land-use potential maps and land-use hazard maps</td>
<td>Land managers, planners, educators, the public</td>
</tr>
<tr>
<td>Identify practices that mitigate land-use constraints</td>
<td>Interpretation guides</td>
<td>Land resource specialists</td>
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<td>Investigate resource use relationships</td>
<td>1:1,000,000 State maps</td>
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<td>...for state perspective</td>
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<td></td>
<td>1:250,000 County maps</td>
<td>...for county (or its equivalent) perspective</td>
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<td></td>
<td>1:24,000 Survey area maps</td>
<td>...for management unit perspective</td>
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**BASIC LAND RESOURCE MAPS**

- Soils
- Geology
- Climate
- Vegetation
- Wildlife

**SOIL**

- Soil survey operations
- Test and modify soil taxonomy
- Laboratory investigations of soil chemical and physical properties
- Field observations of soil pedons and mapping units
- Soil genesis research

**CLASSIFICATION SYSTEMS**

- Data banks
- Technical papers

**USERS/CLIENTELE**

- Soil classifiers
- Professional soil scientists
- Scientists and students of natural history

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Figure 11.1. Activities, products and users of soil surveys for technology transfer and land-use decision making. Modern soil survey reports present much of what is noted in the products column, but most exclude maps showing land-use potentials and hazards (Nielsen 1977). p. 198. Reprinted with permission of the publisher.
1. Each individual soil is described, classified and mapped based on its external and internal characteristics.

2. Assumptions and criteria are established for each potential land use.

3. Interpretations are derived showing the soil suitability or limitations for various land uses.

Figure 11.2. Relationship of soil facts to land use interpretations (Wohlets and Wildman 1971). Reprinted with permission of the publishers.
US$5/acre/year for irrigated land, and probably more than US$250/acre/year for land being converted from farm to urban areas.

While the figures above apply to a developed country, the relative costs and benefits from the uses of soil surveys are applicable to any area in Southeast Asia or elsewhere; commonly adequate recognition is not given to soil surveys and they are not assigned the high priorities they deserve (USBR 1970). In the Philippines, for example, soil survey information, interpretation, and soil maps, while available for most of local soils on the provincial levels, are on a large scale and are generalized (Davide 1978). An agriculturally-oriented land capability interpretation was attempted from the reconnaissance level soil survey covering the whole country by province. This is a broad classification taking into consideration the soils, erosion hazards, and drainage problems as the limiting factors in the interpretation. While it was later recognized that the results of the reconnaissance survey have limitations, they are used most of the time by planners, researchers, and students of agriculture and forestry. These are then the only available sources of information for Philippine soils.

To make a soil survey, scientists examine and classify soils in the field; locate soil boundaries and plot these on a map; describe the soils shown on the map, including statements about their morphology and their important characteristics and qualities; and finally, they interpret the map units to serve especially the purpose for which the soil survey was made (Steele 1967).

Smyth (1977) suggests that discussion of different "kinds" or "orders" of soil survey is often hampered by misunderstanding arising from different interpretations of the terminology. Table 11.1 represents a system of terminology developed within FAO specifically to assist international discussion of this topic (FAO 1969). Table 11.2 represents additional information that places this terminology, which is based on intensity of observation, in clearer perspective. Terms such as "detailed," "semi-detailed," and "reconnaissance" are avoided because they carry a wide variety of connotations. Furthermore, the detail and, to a large extent, the scale of soil survey maps are matters of convenience within constraints of accuracy determined by the intensity of observation.

SOIL DATA COLLECTION

Data collection in soil surveys is guided by standards that traditionally aim in the first place to solve soil classification problems (Beek 1977). However, it should be concerned with the solution of land-use problems, which requires a more complex body of information of which soil data are an essential part. Instead of only standardized data collection for a high category of soil classification, it should be possible to collect some additional data such as infiltration capacity of sloping land occupied by traditional farmers,
Table 11.1. Terminology of Soil Survey Intensity in Relation to Final Mapping Scale and Kind of Mapping Unit

<table>
<thead>
<tr>
<th>Kind of Survey</th>
<th>Range of Scale</th>
<th>Kind of Mapping Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high intensity</td>
<td>Larger than 1:10,000</td>
<td>Phases of soil series; soil series; occasionally soil complexes</td>
</tr>
<tr>
<td>High intensity</td>
<td>1:10,000 to 1:25,000</td>
<td>Phases of soil series; soil complexes</td>
</tr>
<tr>
<td>Medium intensity</td>
<td>1:25,000 to 1:100,000</td>
<td>Associations of soil series; physiographic units (enclosing identified soil series)</td>
</tr>
<tr>
<td>Low intensity</td>
<td>1:100,000 to 1:250,000</td>
<td>Associations of Great Soil Groups; occasionally individual Great Groups; phases of Great Groups. Alternatively, land units of various kinds (enclosing identified Great Soil Groups)</td>
</tr>
<tr>
<td>Exploratory</td>
<td>1:250,000 to 1:1,000,000</td>
<td>Land units of various kinds (preferably enclosing identified Great Soil Groups)</td>
</tr>
<tr>
<td>Syntheses</td>
<td>Smaller than 1:1,000,000</td>
<td>Great Soil Groups and phases of Great Groups (having essentially taxonomic significance)</td>
</tr>
</tbody>
</table>

*aBased on FAO (1969).

hydraulic conductivity of poorly drained bottom lands, and aggregate stability.

When collecting soil data to solve land-use problems, an awareness of the farmer’s soil-dependent activities is necessary to avoid what Conway in Chapter 2 referred to as disciplinary jargon that impedes understanding of the interactions between soils and the other components of the agroecosystem (Beek 1977). The soil scientist should be able to concentrate on the fundamental processes and activities of the specific land-use system and the role of measurable soil properties in these processes.
Table 11.2. Additional Information on Soil Surveys of Various Scales

<table>
<thead>
<tr>
<th>Kinds of Survey</th>
<th>Scale</th>
<th>Area Represented by 1 cm² of Map</th>
<th>Density of Observations a (0.5 obs./cm² of Map)</th>
<th>Approx. Average Rate of Progress b</th>
<th>Accuracy of Boundaries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high intensity</td>
<td>1:5,000</td>
<td>0.25 ha</td>
<td>1/0.5 ha</td>
<td>500 ha</td>
<td>Position of all boundaries checked throughout length on the ground</td>
</tr>
<tr>
<td></td>
<td>1:10,000</td>
<td>1.00 ha</td>
<td>1/2 ha</td>
<td>800 ha</td>
<td></td>
</tr>
<tr>
<td>High intensity</td>
<td>1:20,000</td>
<td>4.00 ha</td>
<td>1/8 ha</td>
<td>1,250 ha</td>
<td>Position of almost all boundaries checked throughout length on the ground</td>
</tr>
<tr>
<td></td>
<td>1:25,000</td>
<td>6.25 ha</td>
<td>1/12.5 ha</td>
<td>1,500 ha</td>
<td></td>
</tr>
<tr>
<td>Medium intensity</td>
<td>1:50,000</td>
<td>25.00 ha</td>
<td>1/50 ha</td>
<td>75 km²</td>
<td>Some boundary checking--most inferred</td>
</tr>
<tr>
<td>Low intensity</td>
<td>1:100,000</td>
<td>1 km²</td>
<td>1/2 km²</td>
<td>200 km²</td>
<td>Almost all boundaries inferred</td>
</tr>
</tbody>
</table>

a Density of observations: Figures represent the density of all soil observations averaged over the entire area of the map (acceptable density usually ranges between 0.25 and 1.0 observations/cm² of map on this basis).

b Rate of progress: Figures given represent an approximate average from the wide range of progress rates experienced in actual surveys.

Source: FAO (pers. com).
Description of a soil in the field involves a comparison of the properties of that soil with established standards that have been set up for describing soils (Olson 1977). Both internal and external properties are described. The internal characteristics of soils include genetic horizon (layer) designations, depth and thickness of each horizon or layer, color patterns (dry, moist, wet), texture, structure, consistency (dry, moist, wet), reaction (pH), boundary distinctness and boundary surface topography, rocks and coarse fragments, concretions, organic matter, roots, aggregate (ped) coatings, soil cracking and shrink-swell behavior, temperature, water movement, cementation, compaction, leached and precipitated materials, reduced and oxidized micro-environments, iron and manganese accumulations, claypan and hardpan conditions, and other significant and special features. The external characteristics described by soil scientists include slope, landform, relief, runoff, land use, vegetation, erosion, stoniness, geology, ground water, elevation, climate and weather conditions, relation of each soil to the landscape positions of the other associated soils and all other observable soil and land-use conditions and correlations. The descriptions made in the field constitute the most valuable and important data and information about soils; at the same time that descriptions are made, however, samples of selected soils are also collected for laboratory analyses including particle size, bulk density, shrink-swell, water retention and release, organic matter and carbon and nitrogen, phosphorus, cations, anion, sesquioxides, acidity and alkalinity, cation exchange capacity, base saturation, clay mineralogy, and other routine and special analyses. The laboratory data, however, are always supplementary and accessory to the data collected from the soils in place in the natural environment under field conditions.

With the aid of soil surveys, profile descriptions, and samplings, Coover et al. (1975) mapped tidal areas to provide a basis for planning and development for wildlife, recreation, marine biology, and urban development. Darmody and Foss (1979) employed soil data in similar marshland areas as a sound base for land-use decisions and management.

The descriptions of soil in the landscape have facilitated its classification according to its properties into a natural classification system. Martini and Macias (1974) provided solutions to the problem of classification, productivity, and management of tropical soils in Costa Rica through investigations of diagnostic horizons. Likewise, Mahjoory (1979) in Iran and Sanchez and Buol (1974) in Peru were able to define the proper taxonomic classification of their soils based on the standard survey procedures. Measurement of soil properties are used in the classification of problem marsh soils in Mexico for future land-use programs (Coulitas and Gross 1975).

In surveying, the relationships between the kind of soils and their various factors of formation and evolution assume great importance (Aubert 1977). Often, it is essential to make these characteristics a component of the system, especially for intermediate map scales.
With all other soil-forming factors relatively constant, the differences encountered in soils across several study areas relate directly to parent material (Anderson, Bailey, and Dhanpat Rai 1975, Hoyum and Hajek 1979). Studies on assessing the relative importance of various pedologic and geologic processes in terms of their separate contributions to the formation of present soils were conducted by Huddleston et al. (1975). Morphology and genesis investigations were essential in determining postglacial evolution of landforms (Daugherty et al. 1975); in confirming eolian origin of deposits on plateaus (Souster et al. 1977); in evaluating the influence of time on soil formation (Ahmad et al. 1977); in characterizing and classifying tropical soils (Philipson and Drosoff 1972) and mountain soils (Sneddon et al. 1972); in identifying alluvial soils with different depositional histories (Scullly and Arnold 1979) and eolian sediments (Gite 1979); in pinpointing bay soils (Bliley and Pettry 1979); in recognizing geomorphic divisions in watersheds and in valleys (Hanna et al. 1975); in associating soils with the landscape (Hakimian 1977); in examining the effects of weathering and clay translocation on genesis (Nettleton et al. 1975); in relating the effects of saline and alkaline ground water (Abtahi 1977) and volcanic ash (Fosberg et al. 1979) on soil genesis, soil properties, and classification; in ascertaining loss, gain, transfer, and transformation of soil constituents (Hassain and Swindale 1974); in relating changes in natural vegetation and landscape (Richardson and Hole 1979), and influence of parent material (Gamble and Daniels 1974; Tyler et al. 1978) to profile development; in estimating contributions of organic matter and clay content to the cation exchange capacity of soils (Wright and Foss 1972, Martel et al. 1978); in studying the formation of fragipans (Steinhardt and Franzmeier 1979, Ranney, et al. 1975), distribution of iron oxides (Richardson and Hole 1979), accumulation of organic carbons (Anderson, Silberman, and Dhanpat Rai 1975) and the fate of reactive minerals (Coffman and Fanning 1975) in the soil profile; in observing the relationship of water to morphological properties (Guthrie and Hajek 1979), to the degradation process in clays (Bullock et al. 1974), to soil mottling (Clothier et al. 1978) and to soil formation (Harian and Franzmeier 1974); and, in mapping similar polypedons in mountainous areas (Parsons and Herriman 1975), soils based on changes in soil properties (Campbell 1977), and soils based on mineralogical, micromorphological and physical characteristics (Alvarado and Buol 1975).

**SOIL SURVEY INTERPRETATION**

Steele (1967) stated that soil survey interpretations are predictions of soil performance under stated conditions. The predictions begin with observations and measurements of performance of a few representative soils and must always be extended in the form of prediction to cover other kinds of soil and combinations of management. The more reliable and abundant the data, the more reliable the predictions are likely to be. From field descriptions and data and laboratory analyses, yield predictions and other
interpretations are synthesized. Depending upon the nature and detail of the soil survey examinations, soils maps and soil information can be practical tools in the interpretations (Olson 1977).

Soil survey interpretations generally involve groupings of soil areas for specific purposes (Olson 1977). Thus the uses of soil maps are concerned with the design of map legends and the soil map complexities. Orvedal and Edwards (1941) have outlined the general principles of technical groupings of soils for agricultural uses. Classes of soils must be consistent and mutually exclusive; maps and soil groupings can conceivably be of four types: (1) categorically and cartographically detailed, (2) categorically detailed and cartographically generalized, (3) categorically generalized and cartographically detailed, and (4) categorically and cartographically generalized.

Furthermore, Orvedal and Edwards (1941) stressed that the technical groupings of soils is one of the important techniques that the soil scientist can use to interpret soil survey for the layman. These technical groupings or classifications can be derived from a modern, detailed soil survey.

Almost any conceivable technical grouping for agricultural purposes can be derived from a sufficiently detailed, fundamental natural classification. Echiverre (1978) noted the necessity of recognizing land capability classification in the Philippines. Of the 17 million ha to be classified up to the year 2000, approximately 1.2 million ha were already classified by the Land Capability and Classification Surveys Division of the Department of Agrarian Reform. The land capability classification adopted refers to the system of classifying or grouping of lands designed to emphasize or indicate the hazards and limitation of the various types of lands, showing the proper utilization with a minimal cost of production from the standpoint of agriculture as well as economic endeavor.

Another type of interpretation that can be derived from a soil survey is the rating of kinds of soils for selected crops. Even though such ratings cannot be based on measured yields or other data, they can be of great value in the first steps of a land development or other soil-using program. Olson (1976) illustrated the ratings of soils for particular crops generally made on the basis of four grades of suitability, assuming a given level of management practices: (1) well suited, (2) moderately well suited, (3) poorly suited, and (4) not suited.

In the same context of rating the suitability of individual soils, Protz (1977) expressed the assumptions used in the process:

1. It is assumed that crops will be grown with at least a moderate level of management as determined by up-to-date research in equivalent environments. This means that fertilizers, lime, and green manures will be used in accordance with the needs of the crop and that erosion and competition from weeds will be controlled.
2. The ratings are based on current levels of agricultural technology. Advances in technology may require a reevaluation of the rating.

3. Crops considered are those widely grown or that have been considered for commercial production. Absence of a crop from the list should not be interpreted as an indication that the crop cannot be grown.

4. The skills and resources of individual operators who can put in a higher level of management are not taken into account in the rating. Under extreme levels of management applied with unusual skill, satisfactory yields of crops can sometimes be obtained on highly unfavorable soils. The ratings do not reflect such extreme levels of management.

5. The ratings are based on subjective rather than actual yield information and should be interpreted in relation to this.

**LAND-USE POLICY GUIDELINES**

Land-use changes are frequently brought about by the process of land-use planning. The need for land-use planning often results from changing needs and pressures that involve competing uses for the same tracts of land. Land-use planning should be based on an understanding of (1) the natural environment, (2) the socioeconomic conditions, and (3) the kinds of land use envisaged. There have been many examples of unsuccessful land-use enterprises causing damage to natural resources through failure to take into account the mutual relationships between land and the uses to which it is put. It is the function of soil and land resources inventory to bring about such an understanding during the process of land-use planning. At the same time, soil and land resources inventory and evaluation should be formulated to guide planners in their decisions on land use in such a way that the land resources are put to the most beneficial use for man, while simultaneously conserving these resources for future use.

The soil scientist, in joint efforts with other sectors, has a big responsibility for the wise use of soil and land resources through, for, and with the people. This is where technical data on these resources are necessary in appraising and safeguarding their potential values. Basic inventory of the soil resources and their properties are needed in order to guide and assist the farmer not only on how his land and soil can best be used and managed but also on how they can be preserved for future use.

The Philippine experience tells us there is a need to safeguard the soil and land resources of developing countries from unjustified use, for successful development continues to be closely related to the inherent productivity of the soil. Unless natural resources, public funds, scientific research, appropriate technology, improved management, and the people are welded into a versatile, even more powerful agricultural capability, what will ultimately result is a depleted community and an impoverished rural economic base.
Ahmad, M., J. Ryan, and R. C. Paeth  

Abtahi, A.  

Alvarado, A., and S. W. Buol  

Anderson, J. U., O. F. Bailey, and Dhanpat Rai  

Anderson, J. U., D. Silberman, and Dhanpat Rai  

Aubert, G.  

Beek, K. J.  

Bliley, D. J., and D. E. Pettry  

Bullock, P., M. H. Milford, and M. G. Cline  

Campbell, J. B.  

Clothier, B. E., J.A. Pollok, and D. R. Scotter  

Coffman, C. B., and D. S. Fanning  

Coover, J. R., L. J. Bartelli, and W. C. Lynn  

Corpuz, E. G.  
COULTAS, C. L., and E. R. Gross

DARMODY, R. G., and J. E. FOSS


DAVIDE, J. G.

DUMAG, A. R., C. SEMA, and A. S. LIBERATO

ECHIVERRE, H. C., Jr.

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FOSBERG, M. A., A. L. FALEN, J. P. JONES, and B. B. SINGH

GAMBLE, E. E., and R. B. DANIELS

GITE, L. H.

GUTHRIE, R. L., and B. F. HAJEK

HAJKIMIAN, M.

HANNA, W. E., I. A. DAUGHERTY, and R. W. ARNOLD

HARIAN, P. W., and D. P. FRANZMEIER
Hassain, M. S., and L. D. Swindale

Hoyum, R. A., and B. F. Hajek

Huddleston, J. H., J. A. Walsh, D. Jowett, and F. F. Riecken

Klingebiel, A. A.

Knox, E. G.

Mahjoory, R. A.

Martel, F. A., C. R. De Kimpe, and M. R. Laverdiere

Martini, J. A., and M. Macias

Nettleton, W. D., J. E. Witty, R. E. Nelson, and J. W. Hawley

Nielsen, G. A.

Olson, G. W.

Orvedal, A. C, and M. C. Edwards

Parsons, R. B., and R. C. Herriman
Philipson, W. R., and M. Drosdoff

Protz, R.

Ranney, R. W., E. J. Ciolkosz, R. L. Cunningham, G. W. Petersen, and R. P. Matecki

Richardson, J. L., and F. D. Hole

Sanchez, P. A., and S. W. Buol

Scully, R. W., and R. W. Arnold

Simonson, R. W. (ed.)

Symth, A. J.

Sneddon, J. I., L. M. Lavkulich, and L. Farstad

Souster, W. E., R. J. St. Arnauad, and P. M. Huang

Steele, J. G.

Steinhardt, G. C., and D. P. Franzmeier

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Interaction between ecosystem components occurs not only through the flow of energy and materials but also through the exchange of information.\textsuperscript{1} Transmitted by means of organized or patterned energy or material (e.g., vision is usually dependent on reflected solar light rays, smell is dependent on airborne molecules), information can be defined in the ecological context as any signs or indicators about the past, present, or future state or behavior of individual components of an ecosystem or of the system as a whole. A fossil bone in a sedimentary rock layer offers information to the palaeoecologist about the past state of the system. The howling of a band of gibbons tells the hunter that they are present in the forest. A bright red sunset informs the sailor that the chances of a fair day tomorrow are excellent, whereas a red sunrise warns him of an impending storm. There is a continuous flow of information between the various components of the ecosystem and most, if not all, living organisms are influenced in their behavior by reception of such environmental intelligence.

Perhaps the most striking illustration of the significance of information flow to the functioning of ecosystems is provided by the evolution of animal coloration. As anyone who has visited a zoo should be aware, animals display a vast variety of color schemes ranging from the mottled browns and greys of many terrestrial jungle mammals to the bright reds and yellows of the

\textsuperscript{1}In contrast to the circulation of energy and materials, the flow of information in ecosystems has received relatively little attention in the ecological literature. Perhaps the most comprehensive discussion is by Duncan (1964).
tree-dwelling birds. Far from reflecting chance development or the work of a mad artist, animals are colored as they are because of natural selection acting on the kinds of information they supply to other organisms in their ecosystem (Cott 1940). Color serves to convey, distort, or suppress the flow of information between organisms. Use of color for concealment (suppression of information flow) in the form of camouflage is perhaps its best-known function in nature. The spots of young deer, the stripes of the tiger, and the black and white shades of the tapir are all color patterns that serve to make the animal less visible to the eye of the observer. By serving to impede the flow of information from one organism to another, camouflage can aid both the predator in stalking its prey, and the prey in evading the predator.

Warning coloration serves the reverse function from camouflage. The vertical black and white stripes of the skunk; the red, yellow, and black rings of the coral snake; and the black and yellow stripes of poisonous toads all serve to advertise the presence of these species to other inhabitants of the ecosystem. Such color patterns are precisely those that researchers have found to give greatest visibility based upon sound optical and psychological principles. Thus, it is no accident that warning signs on highways also make maximum use of reds, yellows, and black and white stripes. In nature, animals with such coloration are frequently those species that are highly poisonous or otherwise unpalatable to predators. Their best defense is to advertise their presence so that other species do not mistake them for more suitable prey. Bright colors are also important for purposes of species identification at mating time. Thus, tree-living jungle birds, who have little need for concealment from predators, frequently display very bright color patterns, which serve to distinguish one species from another, reducing the chance of error in selecting mates. It is significant that it is almost always the male bird that has bright colors, whereas the female, who needs to stay hidden while sitting on the nest, often has dull, mottled camouflage dress.

Coloration is also used by some species to mislead or to disseminate false information about their character. They do this by mimicking the colors of an unrelated species that is protected from predators by poison or bad taste, so that predators also avoid the mimics on the false assumption that they are also protected. Such false information may also be conveyed by gesture as when a harmless snake pretends to strike in the manner of a cobra.

The human species also makes use of color to manipulate information flow through the ecosystem. It has been suggested, for example, that the often very dark skin color of tropical forest people has evolved as a result of its camouflage value in the deeply shaded jungle. Facial and body painting, tattooing, and, in more recent times, of course, the wearing of green and brown mottled uniforms have all helped to conceal human warriors from the searching eyes of their enemies.

Mimicry has also frequently been a tactic of human hunters to fool their prey. North American Indians stalking bison in the open plains would don the
skin of a wolf and crawl on all fours mimicking its movements in order to lull the bison into a false sense of security. Bushmen in the Kalahari Desert of Southern Africa disguise themselves as ostriches so as to be able to approach the game herds without frightening them.

Use of warning coloration is also highly developed in human societies. Each culture tends to have a distinctive dress style and color that sets its members apart from members of neighboring cultures as in the case of the Black T'ai, White T'ai, and other tribal groups of Indochina. Even social classes within a particular culture often wear clothes of distinctive appearance and color. Thus, in traditional Southeast Asia, only royalty could wear yellow or carry umbrellas—identification marks that quickly informed any knowledgeable observer of their special social status. Even today, in Malaysia, a commoner would be ill-advised to drive a gold-colored car, although as far as I know it is not actually illegal to do so.

Color is perhaps the most obvious means of conveying environmental information to the human observer, reflecting the dominant position of vision among our senses. Primitive man hunts game animals and seeks wild plant foods primarily on the basis of visual information so that color blindness is a great disadvantage to him. It has been suggested that natural selection tends to hold down the frequency of color blindness among hunting people, whereas it achieves quite high proportions in agricultural populations who are less dependent for survival on detailed visual scanning of their environment. Other senses are less important to man in obtaining environmental data. The sense of smell and the related ability to taste are mainly important in assessing the palatability of food stuffs. Other animals are, of course, acutely sensitive to the odor of man and use such information to escape from hunters. Thus, a careful hunter always approaches wary game animals from downwind so that his scent will not panic them.

Sound plays a secondary role in direct acquisition of ecosystem data by man although, since the development of spoken language, aural perception has been central to obtaining secondary intelligence on the environment. Man's sense of touch and his ability to sense heat radiation in the infrared part of the spectrum are, by comparison, less well developed and play relatively minor roles in human acquisition of environmental information. Other organisms, however, have very different perceptual capabilities. Bats, for example, are able to navigate successfully in total darkness due to their ability to hear the echoes of high-pitched sound waves that they bounce off obstacles in their flight path. Owls and other nocturnal predators have eyes able to gather the very limited available light with far greater efficiency than man's essentially diurnally adapted eyes. Many of the light receptors in human eyes function only in color vision so they are useless after nightfall, whereas owls, with their black-and-white vision, are able to use all of their receptors efficiently. Mosquitoes evidently home in on their prey initially by
its emission of carbon dioxide and, when in close proximity, by its infrared emissions, much as modern anti-aircraft missiles seek the heat of the jet engine exhaust. Leeches are thought to locate their victims through the vibrations sent through the earth by their footfalls, whereas many insects are attracted to flowers by their odor.

Since the beginnings of the scientific age, man has invented artificial receptors that greatly increase the range of environmental information he is able to perceive. Our unaided senses, for example, cannot detect the presence of radioactivity, but the clicking of a geiger counter now tells us when we are entering contaminated areas. Special film allows us to observe infrared radiation, the compass allows us to home in on earth’s magnetic pole, and radar allows safe navigation in total darkness following principles analogous to the echo location technique of the bats. Earth-scanning satellites now allow continuous monitoring of the entire biosphere. The greatest problem for modern man is not the acquisition of additional raw environmental information; it is the processing and analysis of these data as a basis for appropriate action toward the environment.

Probably all living organisms have some information collection capacity, although there is a great variation in the nature and capability of their receptors and thus in the kinds and amount of information that they can receive. In general, members of the plant kingdom are equipped to collect different kinds of environmental intelligence than members of the animal world. The higher mammals, especially the primates, generally have a broader spectrum of sensory capabilities than the lower orders. Although other species may surpass man in the data collection ability of any particular sense (the owl’s eye, the leech’s vibration detector, the mosquito’s heat tracking), few possess the overall range of sensory capabilities that man does. This fits with the fact that, ecologically, man is a generalist rather than a specialist species. Unlike the owl, which fills a very narrowly defined niche (hunting for small animals under conditions of minimal light), man carries out a wide range of activities under many differing environmental conditions. Like all generalists, man is the master of no particular set of environmental conditions, but he has at least limited ability to collect useful information in almost any situation in which he finds himself.

The most significant difference between man and all other living species, however, lies not in the ways in which information is collected but in what is done with it once it has been received—the processing, analysis, and selection of appropriate responses to the environmental information that continually flows into the organism’s receptors. Man is unique in that almost all human handling of information is based upon culturally determined learning. Some other animal species must also learn how to respond to environmental information, but they do so almost entirely on the basis of individual experience rather than being taught by other members of their species who have already acquired such knowledge.
A leech lying among the soggy leaves on the jungle floor picks up vibrations sent out by the footfalls of an aborigine hunter. The leech does not sit there saying to itself, "Hmmm, I feel vibrations. Vibrations are given off by aborigine hunters; aborigine hunters are good to eat. I'm hungry so I think I'll go and bite that man." As far as we know, leeches have no cognitive ability at all. Vibrations felt by the leech's body simply automatically trigger movement of the leech in the direction from which the waves are coming. The response to environmental information is "instinctual," that is, it is a genetically inherited process that requires no learning by the individual organisms to implement it.

A tiger may also be crouching in the jungle foliage. It may detect the approaching aborigine in several ways; by the man's body odor that drifts to its sensitive nostrils, by the sounds of his walking, or by catching sight of his movement through the trees. On receiving information of the man's approach, the tiger performs a much more complicated analysis than the leech: First it identifies its potential prey before initiating any action. It has the cognitive capability to discriminate between a deer, a man, and an elephant, whereas to a leech all probably appear the same—a potential hot meal. After identifying the animal, the tiger makes a decision as to what to do about it; we might even say that it "thinks" about a proper response although we really do not know what goes on in the mind of a tiger.

There is good evidence, however, that the course of action that the tiger selects after receiving information about a man's presence is strongly conditioned by learning. Most tigers will try to avoid contact with a man, perhaps due to the offensive odor of the human species, but some tigers, those who have been wounded by hunters in the past or who have tasted flesh and come to like it, may choose to attack. Tiger learning, however, is entirely an individual affair so that one tiger who discovers that people are tasty despite their bad smell does not go around teaching other tigers about this new addition to the jungle menu.

The first knowledge the aborigine will have of the leech's presence in the environment will be derived from a sense of touch—he will feel motion on his leg or a slight itching caused by the biting. If the aborigine perceives a leech on his leg, he simply flicks it off and goes on his way. He has learned about leeches from his fellow aborigines and has no concern about them. A city person, on the other hand, particularly a European who has never even heard of leeches before, may become very frightened and upset. He receives the same environmental information as the aborigine, but he lacks the cultural background to properly analyze it and select the correct response.

The aborigine will probably first perceive the tiger when it roars. Even the human species' limited sense of hearing can detect sound at that level of intensity. He is unlikely to smell the tiger—man has very poor olfactory capability. He may see it, although its striped skin effectively serves to camouflage it even from the hunter’s keen vision until it moves. On receiving
sensory information of the tiger's presence in his environment, man will first analyze it—he will match the sound against his memory of other jungle sounds or the visual image against the mental catalog he carries of forest-dwelling animals until he finds one that is similar. He will then try to remember what he has been taught about correct behavior when encountering this particular species. In the case of a tiger, he will probably slowly sit down and then quietly cough because as a young man he was taught by his father or the other men of his tribe that such behavior will cause the tiger to go away peacefully. A city man in the same situation will probably panic and try to run away, which may provoke the tiger into attacking. The panic state of the city person is also a learned response, albeit in this situation an incorrect one. He is afraid of tigers, not because he has ever had a bad experience with one or because men are instinctively afraid of big cats but because he has been taught by his culture that all large wild animals are dangerous. Place a child who has never heard about tigers or been hurt by animals in the same jungle and expose him to the same environmental information and he will feel no fear because he will not know that he is supposed to be afraid (small children frequently try to climb into the tiger and lion cages at zoos). Likewise, the aborigine, if suddenly transferred into a city, will be equally handicapped by a lack of culturally learned response patterns to urban environmental information. He is likely to be run over by a car while crossing the street, not because he did not hear its horn but because the sound of the horn has no more meaning to him than the roar of the tiger has to the city child.

In dealing with environmental information, it is necessary to recognize several analytic levels. First, there is the totality of information flowing through the ecosystem. The variety and quantity of this information is immense and a complete description is impossible. Second, there is that share of the total information flow that any particular species is capable of perceiving. As Bates (1972) has pointed out, each species has a distinctive "perceptual environment" so that even though two species share a common ecosystem they do not perceive exactly the same share of the total information flowing within its boundaries. Finally, at least in the case of man, there is the "cognized environment," which includes only those aspects of received information that are recognizable in terms of human cultural categories of thought (Vayda and Rappaport 1968).

For humans, interaction with environmental information flow is almost entirely at the cognitive level and thus represents individually and culturally learned responses. Man has only a few instinctive reactions to information although newborn infants do display a startled reaction to loud noises. Some response patterns are acquired by unique individual learning experiences: A child that has been bitten by a puppy will afterwards show fear when seeing a dog, whereas one that has not had such a bad experience may squeal with delight. Most responses to perceived information are culturally learned ones, however, so that identical perceptual information inputs often have totally different significance to men belonging to different cultures. The eyes of
Chinese and Americans are equally capable of perceiving light rays in the red part of the spectrum, but the Chinese associates red with prosperity, whereas the American is likely to associate red with danger.

So strong is the influence of culture on human behavior that perception itself is affected by cultural categories. For example, all normal human eyes are able to see light waves falling within a certain range of the spectrum, but different cultures divide up the spectrum in different ways, so that recognition of colors differs from group to group. Research by psychologists has shown that if a color has a name in their language, it is easier for people to recognize it and recall it correctly later than if it is a shade that they do not linguistically identify. Thus, some years ago the Malaysian Press reported public complaints about a new hospital where facilities were color coded to help patients find them. The idea was an admirable one for assisting nonliterate rural people but unfortunately some 14 different colors were employed, many of them lacking Malay names. The result was chaos rather than clarification.

It is in the significance attached to information flow as a system property that human ecology of the type advocated in this book may most differ from more conventional approaches to understanding agroecosystems. Farmers relate to their agroecosystem not just through caloric and nutrient exchanges but also, perhaps primarily, through tapping into the flow of information and using it as the basis for management decisions. Farmers in northeastern Thailand, for example, observe the growth of certain weed species and the egg laying behavior of water beetles in order to anticipate possible droughts (Suphanachaimat and Grisnaputi 1983). Senoi swidden farmers in Malaysia employ the presence of nutrient demanding plants such as wild bananas as indicators of soil fertility when choosing new plots (Rambo, pers. observation). Traditional farmers in Southeast Asia have a rich store of knowledge and beliefs relating to the significance of environmental information. As Lovelace makes evident in Chapter 13, understanding these cultural beliefs can be of profound importance in agroecosystem research.

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INTRODUCTION

Human ecosystems are particularly complex phenomena in that their components, processes, and interrelationships include not only those of both the natural and the human worlds, but also others that link these realms in mutually interacting manners as described by Rambo in Chapter 3. Although our understanding of certain aspects of these complex systems, and especially those aspects related to the natural world, have increased considerably in recent decades, our knowledge and awareness of other components and processes, particularly those of the human realm, are much less complete.

Perhaps the most difficult to examine and, as a consequence, the most poorly understood components of the human realm are those related to the human psyche, to the beliefs, values, and feelings that humans possess. Yet, it is these and other ideational patterns that make the human ecological experience special and serve to differentiate it from the ecological experiences of other species.

Rural development programs frequently encounter and, indeed, are often specifically aimed at groups of indigenous people who possess cultural beliefs and values that are different from those possessed either by the people who originally designed the development program or by the people who are
charged with carrying out the program. Quite often, the initial reactions of the planners, scientists, and others who are involved in the development process to these different beliefs and values are negative. Traditional beliefs and values are generally viewed as superstition and as reminders of a "primitive" past. At best, these beliefs may be deemed unworthy of scientific consideration; at worst, they are seen as direct obstacles to development — obstacles that must be overcome or replaced if progress is to occur.

In this chapter, I take a different point of view and focus upon traditional belief and value systems as bodies of knowledge—knowledge that is related at least in part to the natural environment and to human interactions with and within that environment. In doing so, I suggest that these bodies of knowledge are highly adaptive for human-environmental interactions and that cultural beliefs, values, and similar ideational phenomena often play critical roles in determining behavioral patterns that, in turn, affect, modify, and regulate many interactions within the human ecosystem. With regard to the development process, I further suggest that, rather than ignoring or attempting to replace or overcome traditional beliefs, it may be more useful to consider how these systems of ideas can be usefully incorporated into the analysis of human ecosystems and into the processes of development and modernization.

**CULTURAL BELIEFS AS AN ASPECT OF HUMAN ECOSYSTEMS**

It is useful to view human ecosystems as composed of two interrelated and interacting subsystems. One subsystem includes the natural world and the biophysical context of human existence, while the other subsystem includes the sociocultural components of human life (e.g., social organization, politics, economy, the arts).

Although each subsystem is internally dynamic and in large part autonomous, it is nevertheless clear that many of the elements within each subsystem frequently interact with and systemically affect elements and patterns of the other subsystem. Components of the natural world, for example, heavily influence the pattern of economic activity, which, in turn, affects still other sociocultural components, such as technology and social organization. In the opposite direction, the economic, technological, and social components of the sociocultural world greatly influence behavioral patterns that affect the natural world. In a similar fashion, cultural beliefs and other ideational phenomena, while integral parts of the sociocultural world, both affect and are affected by the natural environment.

The study of cultural beliefs as components of human ecosystems usually requires the comparison and integration of two complementary kinds of analysis. One kind, referred to as "emic analysis," is concerned with the elements, aspects, and interpretations of the belief system as these are perceived and/or conceived by the members of the culture or society under consideration. Emic analyses provide the details of the belief system and the
indigenous understanding and appreciation of both the environment and human interactions with it. The second kind of analysis involves the consideration of *etic* categories, those that the researcher employs for the purposes of scientific classification, analysis, and understanding—in this case with regard to the study of human ecology and of the relationships and roles of beliefs in human-environmental interactions. Both kinds of consideration are critical. In the absence of *emic* considerations, it would be impossible to learn what cultural beliefs exist, what their details and perceived meanings are, and to which aspects of life they are thought to be most directly related. It would also be impossible to discover the indigenous conceptions and perceptions of either the natural environment or the constraints and opportunities the environment is believed to present. Without *etic* examinations, on the other hand, neither analysis nor interpretation would be possible because the researcher would be without a framework for determining either the effect of beliefs upon human behavior or the possible ecological significance the beliefs may possess. Although *emic* and *etic* data, categories, and explanations should be considered as conceptually distinct, the comparison and integration of these two kinds of analysis are, nevertheless, important steps in the ecological analysis of cultural beliefs. Through comparison and integration of the *emic* and *etic*, we come to appreciate the wide-ranging significance of cultural beliefs and the particular roles that they often play in helping to shape patterns and specific instances of human and environmental interaction.

**ADAPTIVE FUNCTIONS OF BELIEF SYSTEMS**

Belief systems serve a variety of adaptive functions for human societies and their members. In many instances, these adaptive functions are "psychological" in nature in that belief systems provide meaning and explanations for those aspects of human experience that are neither easily nor fully comprehended through normal experience and thought. The possession of beliefs about the nature of the world often reduces anxiety about what may or may not happen. Beliefs are often the source for support and hope in times of stress. Beliefs also allow humans to proceed toward particular goals with greater confidence — confidence both in themselves and in the Universe's willingness to cooperate with them toward these goals.

Another group of important adaptive functions that belief systems frequently serve may be labeled "social." A shared pattern of beliefs can often provide a strong sense of group solidarity that unifies different individuals or groups of individuals of diverse backgrounds, ages, and/or socioeconomic interests into a larger and more cohesive unit. In this sense, shared beliefs may be seen as unifying threads of a larger social fabric. Beliefs and the ritual activities that are frequently associated with them may also serve important educational functions that provide for the maintenance and continuity of the society. For example, initiation rites and similar rituals normally involve the transmission of information about the cultural traditions
and practices of the group. Beliefs, as have been noted by many writers including Marx, may also serve to encourage certain types of social behavior and expression and to discourage other types. In this sense, they may be extremely important forces in effecting social conformity.

Still other adaptive functions, which are focused upon here, relate to human conceptions of, and interactions with, the environment. One of the characteristics that all human societies seem to share is the need to be able to account for their existence in relationship to all other things. This characteristic need tends to be accompanied by the conceptual segmentation and organization of their perceptions and experiences. There is a need not only to possess some understanding of the world in which the society dwells as well as of other worlds it may believe to exist, but also of the society’s position and its member’s roles with respect to these worlds. In the process, the dimensions of space and time become conceptually segmented and systematized as parts of a culturally bound world view that provides explanations and an understanding of the events its members experience and witness and that bring order and appreciation to those aspects that seem unexplainable (Tuan 1977). This unique, human tendency to conceptualize produces cultural ideas about the nature of the Universe and its patterns, processes, and controlling forces (cosmology), as well as beliefs about how the Universe was created and developed (cosmogony).

Quite often, these patterns of belief contain highly detailed conceptualizations of many phenomena and aspects of the occupied environment. As humans adapt to their surroundings through time and through the processes of trial and error, they observe, experience, and experiment with many elements of the environments in which they reside. In doing so, they are exposed to vast amounts of empirical information concerning the nature, the spatial and temporal patterns, and the uses of the various phenomena that occur within these environments. As this information is discovered, it is often translated and categorized by reference to, and in terms of, the society’s beliefs about the nature of the Universe. Translation and categorization allow the observations and experiences to be more easily comprehended and provide the basis for explanations of their occurrence. The linking of the newly acquired information with the religious, cosmological, and cosmogonic conceptions of the society serves other purposes as well in that it imparts an element of “sanctity” and special significance, which not only increases the likelihood that the knowledge will be retained, but also serves to reinforce, in a feedback manner, the assumed validity of the beliefs themselves. The pattern of beliefs may also provide a framework in which the information and impressions can be organized, stored for later use, and eventually transmitted to other members or other generations of the society. For example, as the younger members of the group become acquainted with and learn the details of their society’s beliefs through acts of ritual and divination, through the telling of folktales, and other forms of traditional education, the new generation is often provided with a variety of ecological knowledge that
allows it to take an appropriate stance toward, and to operate within, the environment in manners that allow the society to survive and prosper.

The ecological significance and impact of cultural beliefs and belief systems are not limited, however, to their roles as systems of environmental information and knowledge. Beliefs and the ideas, emotions, and motivations that beliefs frequently generate often serve as important stimuli for a wide range of human behavior that directly or indirectly affects the environment. Beliefs affect how humans position and organize themselves within, and with respect to, the landscape. Beliefs also affect human decisions about which environments to occupy, which resources to exploit, and how, when, and to what degrees these should be occupied or exploited. Cultural tabooos represent an interesting case in point. By prohibiting or restricting the utilization of certain plants, animals, or areas, tabooos can sometimes fulfill adaptive functions in that they regulate the use and prevent the depletion of particular resources (Harris 1966, Rappaport 1971, Ross 1978). In discouraging or restricting the use of certain resources, however, tabooos may also indirectly encourage and intensify the exploitation of other resources, stimulating the development or further development of economic practices that are involved in supplying these “replacement” items.

Although I have discussed the psychological, social, and ecological functions of belief systems somewhat separately, it should be clear that these are often closely intertwined. A pattern of beliefs that encourages group solidarity and brings individuals together at particular periods of time, for example, may be adaptive both for the maintenance of the social and cultural system and for carrying out joint agricultural activities. Similarly, beliefs that inspire individual or group confidence and that are, therefore, psychologically adaptive may well be ecologically adaptive in times of environmental stress.

In suggesting that beliefs and belief systems often have adaptive significance, I do not wish to imply that they are always adaptive at either the individual or the group level. Indeed, in certain situations, the possession of a particular set of beliefs may actually be maladaptive. Throughout history, beliefs and differences in belief have been bases for conflict, conquest, and colonization. To the extent that beliefs encourage social conformity, they have often been used, as well, as a means of social control by individuals, such as shamans, priests, and rulers, who were in privileged positions with respect to the application, maintenance, and control of the belief system. In other instances, beliefs that are adaptive in one set of circumstances may be rendered maladaptive or neutral as context and circumstances change through time or space. Yet, even if a particular set of the beliefs are maladaptive in the new context, the set may continue to persist, either because it is held to be “sacred” or because it is tied to other traditional beliefs or to cultural and social institutions that continue to possess some adaptive significance.

Despite these possibilities, however, it seems reasonable to suggest that under most circumstances, cultural beliefs and similar ideational phenomena
are potentially adaptive. Beliefs often provide interpretations, explanations, understanding, security, and the basis for social solidarity and action; and in these senses, beliefs are adaptive and sometimes even critical for the survival and continued well-being of the society and its members.

THE CULTURAL NATURE OF AGROECOSYSTEMS

The physical environment is, and has always been, an important source for much of the variation we find in human life. The environments we occupy and use help to shape many of our basic characteristics as individuals and as members of groups. Our environmental surroundings affect not only the ways in which we live and work, but also the ways in which we think and feel. Yet, just as the environment greatly influences many aspects of human existence, so too do human activities and beliefs affect the structure and the characteristics of the natural components of the human ecosystem.

Although we now recognize that all societies, including even the most "primitive" hunting and gathering groups, interact with and affect the environments they inhabit, the transition from a hunting and gathering way of life to one involving the domestication of plants and animals and their cultivation or husbandry as described by Hutterer in Chapter 5 certainly marked one of the most important developments in the historical evolution of human interactions with the environment. This is because, with this transition, humans began to play increasingly active roles in shaping and maintaining both the form and the structure of the environments they utilized.

We can see the human and cultural impacts of agriculture on the environment in most of the activities we normally associate with this economic practice. The clearing of vegetation, field preparation, the introduction of new species, cultivation, irrigation, fertilization, weeding, and so on; all are activities that in varying ways and to varying degrees affect and alter aspects of the physical world. Often these modifications are undertaken so as to either allow or enhance cultivation, the results being preconceived, intentional, and usually visible within a relatively short period of time. On occasion, however, the resulting modifications may be unintended and perhaps even harmful for both the agroecosystem and the human population that rely upon it. Such unanticipated effects are often indirect and delayed because their manifestations are in part the product of complex, systemic chain processes within the ecosystem, which obscure the relationships of the activity to its eventual consequence.

Human impacts on the environment, however, are not solely the direct products of economic behavior. Often, the ultimate stimuli for their occurrence can be traced to human ideas and emotions. Indeed, ever since our species began to perceive, conceptualize, and reason, human thoughts and feelings have played important roles in determining the nature and the path of our interactions with the environment.
Just as the transition from a primitive hunting and gathering way of life to agriculture affected and intensified human interactions with the environment, it also affected how early societies conceptualized the world around them. In hunting and gathering societies, for example, belief systems often seem to reflect directly of the natural world they inhabit. Indeed, as Reichel-Dolmatoff (1976) has recently argued, the codified natural environmental information contained within the cosmologies of hunting and gathering groups is often so detailed that it is possible to conceive of these patterns of belief and myth as primitive man’s “systems analysis” of the natural world. With the development of agriculture and the relatively settled way of life it usually entailed, however, human beliefs about the nature of the world seem to focus more intensely upon localized areas where natural and cultural elements are combined (Gill 1982). Traditional agriculturalists tend to see and plan the spatial characteristics of their communities as micro-versions of the Universe as they perceive it to exist. Their houses, structures, villages, and fields are invested with cosmic and religious significance. Conceptions of time also change and intensify, in large part, because the practice of agriculture demands an intricate knowledge and awareness of time and temporal process. Traditional farmers not only must be able to recognize but to predict with relative success the onset and passage of seasons and the critical moments that occur within these periods. They must often be aware, as well, of the temporal changes that can occur in particular environmental variables, such as the patterning of sunlight, rainfall, and vegetation growth. In line with the recognition of these temporal changes, farmers must also be able to plan and schedule the various human tasks that are parts of the overall cultivation process. The importance of “time” in the agricultural pursuits of traditional societies is usually reflected in the cultural beliefs of the society, and it is frequently manifested in ritualizations of the agricultural cycle (Rappaport 1968). Such ritualizations can take many forms including feasts and the occurrence of special rites that pay homage to agricultural and environmental deities.

In suggesting that belief systems are often directly and intimately related to, and reflective of, the occupied environment, its patterns and processes, and its management, however, I do not wish to convey the impression that beliefs only mirror the environment or that beliefs only encourage people to live in “harmony” with the environments they inhabit. Beliefs and ideas, as I have pointed out, also engender a variety of behaviors that directly and indirectly result in the ecosystem’s modification. Beliefs can sometimes cause individuals to introduce new, ritually significant, species of flora into their environments. The historical spread of certain types of fruits from the Mediterranean region to Europe, for example, seems to have been partly connected with the spread of Judeo-Christian religious beliefs from the Near East. Similarly, the spread of Buddhism from India eastward seems to have been accompanied by the spread of certain plants that had ritual importance (Soper 1967). Beliefs and values may also cause people to promote the
growth of certain types of species that are found within their environment and to discourage the growth of other species, thereby differentially affecting the distribution of flora.

As I have mentioned, farmers in many agricultural societies position, structure, and orient their new settlements, houses, and fields in line with their interpretations of the forces of the Universe. Although these interpretations may possess some ecological basis, they may also be heavily influenced by a variety of social and cultural factors that result in an overall modification or restructuring of the local environment through time. In situations involving the migrations of traditional farmers into new environments, for example, even environmentally based belief systems can affect the form and the nature of the local ecosystem due to the tendency for arriving agriculturalists to construct and structure their agroecosystems and villages based upon previous knowledge and upon the previously occupied environment, rather than solely upon the environment they have just entered. To the extent that the characteristics of the old and the new environments are different, the organization of the new fields and villages according to the previous habitat may well bring about dramatic changes in the newly entered ecosystem (Lovelace 1981a). Sometimes, these changes are unintended and unanticipated. In other situations, however, the environmental changes that result seem to be entirely intended and aimed at creating, or rather “recreating,” a modified environment that is believed to be better suited to the activities of the entering group. Something like this appears to have taken place in southernmost China during the Tang and Song dynasties when much of the region was intensely settled by wet rice farmers migrating southward from central China. In settling this frontier area, these Chinese farmers transformed an area previously known for its heavily forested uplands and swampy lowlands into a modified landscape of denuded and eroded uplands and of expansive lowlands ideally suited to wet rice agriculture. Important among the elements that contributed to this interrelated pattern of settlement and environmental modification was not only the high value placed on rice by the Chinese culture, but also the folk belief systems of feng-shui (“wind and water”), which encouraged the settlers to undertake certain environmental changes to increase their luck (Lovelace 1981b).

**IMPLICATIONS FOR DEVELOPMENT AND MODERNIZATION**

I shall now briefly turn my attention to the implications of traditional belief systems for development and modernization. Development poses a number of challenges to the human ecologist as well as to the planner who wishes to use the models and information of human ecology in the development process. Employing a “systems” perspective, ecologists are aware of the susceptibility of ecosystems to change and of the potential for multiple consequences to result from each implemented action. Most are aware, as well, of situations in which unplanned or poorly planned development has led to rather dramatic and all too often negative changes in
particular ecosystems, changes which have not only involved and affected aspects of the natural environment, but also the human inhabitants of the environment. This awareness of delayed, systemic consequences has made many ecologists wary of development to a point where some seem against any form of modernization. At the same time, however, development in one form or another is probably an inevitable aspect of the twentieth century, with or without the input of human ecologists. It is further clear that many individuals in the societies and the environments we wish to protect from the ravages of poorly planned development are nevertheless willing to subject themselves to the risks that accompany development and modernization in order to gain access to potential opportunities for employment, education, and advancement.

A large share of the problems that result from development programs seem to stem from either a limited understanding of the human and natural environments we are attempting to improve and use, the imposition of new patterns and technologies upon ecosystems that are poorly suited to these developments, or some combination of the two. It is therefore imperative that we learn as much about the ecosystem and its suitabilities and capacities as early in the development process as possible.

The recognition that traditional beliefs contain potentially vast quantities of empirical data related to environmental phenomena, process, and historic change carries with it the implication that these traditional systems of knowledge can provide information useful to the planning and process of development. This is especially so in situations where prior knowledge of the local ecosystem is limited and/or where scientific manpower is scarce.

Traditional knowledge of the local environment might be used, for example, in the compilation of data concerning the presence, distribution, and use of previously unknown or only poorly known environmental resources. Working with the Hanunoo, a group of shifting cultivators in the Philippines, Conklin (1957) found that the use of traditional knowledge could substantially increase previous scientific information related to flora, fauna, and land use. Conklin’s analysis revealed that the average adult could identify approximately 1,600 different varieties of plants, whereas an earlier, systematic botanical survey had recorded only 1,200 species. Researchers in Africa have also found that by using the knowledge of local agriculturalists during the course of soil survey, it was possible to generate perfectly usable soil maps in a fraction of the time that would normally be required by more conventional methods as described by Panchaban in Chapter 10 and Bartolome in Chapter 11 (Howe 1980, 344). Certain details are missed, of course, and no one should rely entirely upon traditional knowledge to compile resource inventories and soil maps. Yet in situations where there are extreme budgetary and time constraints and/or shortages of trained personnel, a data collection strategy that employs some combination of traditional informants and more scientifically recognized procedures may be well worthwhile.
Traditional knowledge may also contain extremely valuable historical data related to process and change in the natural environment and in human interactions with it. Although such temporal information is critical to our understanding of how the local ecosystem might be affected by the introduction of new species or by changes in technology and land use, this information is quite often unavailable to the natural scientist or the ecologist whose temporal experience with the local environment is usually limited. The interpretations of environmental phenomena, processes, and relationships contained within traditional belief systems may also serve as sources for preliminary hypotheses about the local ecosystem—hypotheses that can then be refined and tested. These examples of how traditional beliefs might be used in acquiring data useful to development planning are but a few of many that might be envisioned (Howe 1980), but I think are sufficient to illustrate the potential of using information derived from the realm of traditional beliefs.

The immediately preceding comments primarily apply to the development of undeveloped or underdeveloped regions. What about the traditional groups that dwell in these regions? Can the concepts and ideas represented within traditional beliefs also be used to improve the process of sociocultural development and to help traditional groups adjust to the changes that accompany modernization?

Although modernization takes many forms, quite often the initial step consists of technological familiarization and educational programs. These programs frequently present traditional societies and their members with beliefs, values, ideas, and techniques that are radically different from their own. This new information is often difficult to conceptualize, understand, and assimilate within the traditional framework. As a result, it may ultimately be rejected or, if accepted, improperly used. A potentially more negative consequence might be the total acceptance of the new information accompanied by a rejection of a set of traditional beliefs that are integral to the maintenance of the society.

In such situations, it seems likely that technological familiarization and educational programs might proceed more smoothly and with less negative consequences, at least during their initial stages, if the new information and ideas are rephrased in traditional terms that are conceptually more meaningful to a broad segment of the traditional population. Research in Ghana, Africa, suggests, for example, that traditional concepts of time and physical space might be usefully employed in the teaching of mathematics and elementary science within formal educational programs, as well as within informal programs geared to the teaching of more practical skills (Fink 1980).

In considering the implications of traditional beliefs and knowledge for development and modernization, my point has been to emphasize that planners, scientists, and/or educators need not view traditional patterns of belief as obstacles that must be overcome or removed for development and
progress to succeed. Instead, it may be more useful both for the development of particular regions and ecosystems and for the societies that are affected by the development process to view traditional beliefs as important sources of empirical information and knowledge that can increase, complement, and enrich overall scientific understanding; that can help prevent us from making costly mistakes based on inadequate data; and that can aid traditional groups in their adjustments to the developed and the developing worlds. Rather than discouraging traditional beliefs, values, and knowledge, it may be, in many cases, better to encourage their maintenance and the continued accumulation of information within the indigenous ideational framework.

CONCLUSIONS

In this chapter, I have tried to briefly consider cultural beliefs as an aspect of human ecology. In particular, I have stressed that traditional belief systems are often highly integrated into the patterns and processes by which humans relate to and adapt to their environments. In doing so, my intent has been to suggest that our considerations as human ecologists should not be limited to the most tangible kinds and aspects of human environmental interaction. We should consider as well how humans conceptualize their relations to the environment because these conceptualizations often play significant and critical roles in determining the nature of their interactions with the natural environment and within the human ecosystem.

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INTRODUCTION

Population and development pressures have forced all nations, rich and poor alike, into placing increasingly greater demands on agricultural resources. Resources used in direct human consumption and in agricultural production are derivable from the total environment, which consists of physical and biological components governed by physical, chemical, and biological laws. Thus, agricultural resources from such ecosystem components as land, air, water, plants, animals, and bio-microorganisms can all be exhausted or renewed depending on the nature of their basic supplies and the characteristics of their use.

Man's economic activities have an impact on the environment in two fundamental ways: (1) utilizing environmental resources as inputs for consumption and production, and (2) using the environment as a receptacle for by-product wastes that result from consumption and production processes. Cutting forest wood for fuel and diverting stream water for irrigated farming are examples falling in the first category. The production of smog from fuelwood burning and the discharge of wastes from animal enterprises are cases in the second category.

Not all man's impacts on the environment are ecologically harmful. The intensity and the type of cultural practices of human activities will affect the
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environmental variables in varying forms and degrees. For example, primitive sustenance systems involving hunting and gathering of food, or simple domestication of plants and animals, leave the natural environmental condition almost undisturbed. However, things can go awry with such systems as in the case of public pasture shared without control by an increasing number of participants leading eventually to the loss of natural grasslands. On the other hand, intensive, mechanized, chemical input subsidized agricultural systems, which characterize modern agriculture, are often associated with such problems as soil erosion, pest outbreaks, and water pollution, which ultimately result in the decline of agricultural yields. A crucial question for future agricultural development is the extent to which environmental resources can be utilized and managed without creating harmful effects on the environment and human welfare. It is not within the capacity of a single discipline to provide complete solutions that will solve all economic and ecological problems and provide for the sustainable use of natural resources as earlier indicated by Rambo in Chapter 3.

Economic science illuminates the relationships within a part of a more complex total system, that is, the economic system in which human beings interdependently determine the ways scarce resources may be allocated for different uses and the ways products may be distributed among different individuals. Classical and neoclassical economics provide conventional theories, which have some shortcomings, for the study and analysis of today's economic problems although they are still useful in many contexts and form the basis for further theoretical development. Their weakness lies in the failure of these theories to consider other scarce resources that are not transacted in the ordinary market exchange systems, namely, the environmental resources. It may be more accurate to state that the traditional approach of economics is valid at certain times and in certain situations, when and where environmental resources are plentiful, and that ecological disruption has few implications for human welfare.

Two major types of environmental problems arise with population growth, the ascendance of technology, and accompanying changes in economic institutions: (1) the rapidity of the depletion of both nonrenewable and exhaustible resources, and (2) the limited capacity of the environment to assimilate residuals resulting from man's production and consumption activities. These problems have led to the development of economic theory and method such that economic and ecological problems can be dealt with simultaneously. Recent theoretical developments, particularly the concept of externalities, help to provide explanations as to how the economy and environment interact, how the rules and institutions of the economy can affect this interaction, and how this interaction can lead to the evolution of social and economic institutions.

The objective of this chapter is to present to scientists in other disciplines the economic concept of externalities that deals with the issue of why the allocation and distribution of scarce resources and commodities including
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environmental goods may not be efficient even in an ideal market situation. Application of this theory to environmental problems has required the integration of the basic understanding of physical and biological sciences into a sophisticated economic analytical framework. This chapter attempts to provide a simple interpretation of economic phenomena such that economic dimensions can be understood and considered in the studies of other disciplines.

Although the focus of this book is on human interactions with Southeast Asian agricultural systems, this chapter incorporates a fairly lengthy discussion of the relationships between the economy and the environment in a larger context as a necessary precursor of any attempt to understand or develop research and policy guidelines.

Consequently, this chapter has four major sections: (1) concept and theory of externalities, including theoretical solutions to the problems; (2) nature and characteristics of externalities in present-day agriculture; (3) externalities and human ecology research; and (4) conclusions and comments.

THE CONCEPT AND THEORY OF EXTERNALITIES

The notion of externality is not new. It can be traced back to the time of Marshall (1920) and Pigou (1932) when, in their writings, some economic activities were seen as having external effects and creating divergences between net private products and net social products. The concept has since been applied to work done in many fields related to economics such as public finance, sectoral planning, fishery, agriculture, pollution, and other environmental protection problems. However, the economic theory of externalities is not yet in consensus nor close to complete development. This discussion does not attempt to synthesize various hypotheses or to review the literature that can be found elsewhere (Lin 1976, Mishan 1971). It shall deal instead with fundamental issues regarding externality problems.

Externalities, in a broad sense, occur whenever the activities of an individual or group of individuals create some external effects on the welfare or productivity of others who have no direct control over those activities. Those who generate externalities may be excluded from charging for all the benefits they created for others, or from paying for all the costs for which they should be responsible. Problems arise because rational individuals are always concerned with their personal survival and the returns and satisfactions they can secure for themselves and their families. An individual generally makes a decision on the basis of benefits and costs that are relevant to him, without considering the incidental benefits and costs that will occur to the others or to society at large. Often individuals are not even aware of the impact of their activities on the larger system (e.g., Southeast Asian swidden farmers do not know they are likely to change global carbon dioxide balance in the atmosphere). Therefore, an externality exists whenever the summation of private benefits (or costs) of an action is different from the
actual benefits (or costs) falling upon society as a whole. In economic terms, this result represents the case of inefficient use of resources. To be in economic optimality, some measures need to be taken in order that resources are allocated for more use in activities that will potentially create social benefits greater than social costs.

An externality may take a simple and obvious form. For example, smoking in a bus will disturb other nonsmokers and possibly cause health hazards to all aboard. Also, it may take a highly complex and less obvious form. The burning of fossil fuels, or the clearing of forests that releases carbon stored in trees and soil humus, may increase the level of atmospheric carbon dioxide. A higher concentration of carbon dioxide may mean rising atmospheric temperature, melting of sea ice, changing global sea levels, with consequent impact on agriculture. It should be noted that the very same activity may not generate externality if it took place in a different context. Smoking in the open air or in a private area does not affect other persons. The increased concentration of atmospheric carbon dioxide has no consequence on agriculture, if it is adequately absorbed through natural processes by the sea, vegetation, and other "sinks."

The "tragedy of the commons" arising from grazing too many cattle on a given area of land has been widely cited as a classic case of externality. Hardin (1968), in his original article on the Tragedy of the Commons, asserts that as long as it is profitable to raise another animal, the herdsman has an incentive to add another animal to the herd that is grazed on a common range. Adding without limit to a limited world will soon lead to the tragedy of the commons. In this example, the common range is the resource potential open to all participants who have no direct control over one another's activities. For each individual, up to a certain point, the private benefit of grazing an additional cow on a common pasture exceeds the private cost, but part of the actual cost he does not pay is incurred by the entire society that is engaged in grazing the same land. This will inevitably result in overexploitation or inefficient use of productive resources and, finally, the tragedy for the whole community. One of the suggested measures to prevent the tragedy of the commons has been the imposition of private property rights. By making the public aspect of the pasture lands private, users will internalize the externality: all actual benefit and cost are now taken into private account and the use of the resource becomes efficient. However, as we progress further in this discussion, it shall be seen that sharing a common property does not necessarily lead to tragedy and that, if the above example is a case of externality, changing systems of property rights may not be the best or the only solution. Often a false assumption or perception of the phenomena brings about incorrect interpretation and analysis of externality problems.

Changes in technology, farming organization, and economic institutions, which are traditionally believed to facilitate agricultural growth and development, may be responsible to a large extent for the increase in intensity and complexity of ecological problems in agricultural sectors throughout the
world. This argument is supported by the fact that more and more economic activity is now being operated in the conditions that tend to bring forth externalities. The latter statement will be elaborated later.

Formerly, increased agricultural yields were obtained through on-farm physical and biological management. Common practices employed included rotation of crops, land terracing, seed selection, and systems of crop-animal production and farm consumption enterprises, which represented a closed input-output model. These production processes had minimal effects on the environment or the productivity of other farms. Output in agriculture could also be increased simply by the extension of land use, either through land purchase, or through clearing of public land, which commonly happened in some less developed economies. In the first case it did not involve the so-called externality problem. In the second case, however, the expansion of land use would have negative impact on the society if the loss in the value of forest land service was greater than the net private gain of converting the lands into farm uses when evaluated for the long term.

The transformation of agriculture into more specialized and more open systems has significantly modified the relationships between production and environment. Food production strategies are no longer based exclusively on the on-farm recycling processes but rest mainly on outside systems for inputs and the marketing of outputs. Many features that accompany technological and structural changes in agriculture have produced certain economic, biological, physical, and social impacts that extend beyond the individual farmers who make production decisions. The Green Revolution technology, for example, constituting the uses of high-yielding seeds, chemical fertilizers, pesticides, and water management has markedly reduced food prices in the consumer sector and also generated employment in the agrochemical producing industry. However, the technology itself, to an important extent, has often led to a set of problems such as loss of native seed varieties having disease-resistant traits that are not found in the high-yielding varieties and that can be usefully transferred to the latter; deterioration of soil quality; pest outbreaks; competition for water uses; and the export of pollutants or contaminants to the environment. Hence, external impacts can be of a beneficial as well as a detrimental nature.

At this stage, it is important to make a further note that some externalities are of a pecuniary type as distinct from a pure or technological type.

**Pecuniary Externalities**

Almost every economic act involves an external effect upon others. The invention of farm machinery such as harvesters or tractor plows has made the production cost per unit of output lower for mechanized farming compared to that of the traditional labor-intensive method. The result is that farmers tend to replace the employment of manual labor with machinery. This will tend to reduce wages of farm labor as more laborers compete for limited jobs
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in the farm sector. This kind of external impact that exerts its influence through the market mechanism is called a pecuniary externality. The decline in the wages of farm labor as a result of the substitution of labor by machines reflects change in the scarcity value of goods or services, namely, farm labor, that are bought and sold in ordinary market systems. Value is basically determined by the supply and demand conditions of the goods or services in the market. Although pecuniary externalities are the impacts that an individual or group of individuals have on others, the effects are not necessarily wholly undesirable from the social point of view. Farmer's decisions to change their input combination to produce a certain amount of output at a lower cost indicate economic efficiency. It is also worthwhile for society to enjoy the same quantity of products at a lower total cost. Therefore, the presence of pecuniary externalities has no implication on the efficiency of resource uses or on the symmetry between private and social costs and benefits.

The undesirable consequence that pecuniary externalities may have is the distributional effect—the transfer of wealth from one group of people to another. From the preceding example, the farm laborers suffer loss of their income while farm operators or machine producers enjoy the gain. In theory, if everything in the world can be transacted in a perfectly competitive market situation characterized by homogeneity of the items, a great number of sellers and buyers, and perfect information and perfect mobility, then the allocation of resource uses will always be efficient and the distribution of wealth will always be fair. In reality, such an ideal situation does not exist. Thus, the distributional aspect of pecuniary externalities becomes a social issue with which we must deal. In most economic literature, this problem is regarded as negligible because if we subtract the total loss from the total gain, the remainder can and should be positive if the change is socially beneficial. The example of substitution of machines for labor indicates a net gain for society, as long as under this new technology the same level of agricultural output is maintained by paying less for total cost outlays for the use of machinery rather than paying more on total wage payment for use of labor. Theoretically, the problem of income distributional bias could be resolved in a manner that assures gain for all individuals and groups through compensation programs, which are devised so that those who suffer initially receive redress for their losses. For a simple illustration, consider that part of the profits incurred by farm operators and machine producers may be taxed and that the proceeds may be used to compensate for the income loss of farm workers. This leaves the first group still better off and the latter group no worse off than before the change in farm technology. This philosophy has become the basis for various farm support programs, particularly in the United States. In practice, some operational problems remain such as how to quantify individual loss and gain, or whether compensation can really be made in most cases. It is also possible that the administration in redistribution might cost the society more than just leaving the original problems intact.
Procedures for handling income distributional issues must be considered in a more complex public policy and in a welfare economic framework, a subject not covered in this discussion.

**Technological Externalities**

They are related to the external impacts of the activities of one decision maker upon the activities or welfare of the others, which are otherwise exerted through the market. The problems are attributable to the general features of certain resources that are essential for production processes or consumption but for which the costs of using or the benefits of improving such productive resources are not, or cannot be, accounted for in monetary values by individual decision makers. Environmental resources such as air, water, and biotic organisms are examples.

The incidence of the “tragedy of the commons” ascribable to the “freely accessible” feature of the common range is one of the paradigms, and the pest problem that resulted from extensive use of pesticides is another.

At a certain point in time when pesticides become a cheaper and more readily available means of increasing production as compared with additional land or labor input, a profit maximizing farmer will adopt the first alternative. His resource allocation decision is said to be economically efficient within his own frame of reference and also within the context of traditional economic theory as technological externality effect is assumed away. Nevertheless, because the farmer makes his decision without regard to the fact that the pest may be effectively controlled at the beginning but later can emerge in a more virulent form necessitating a more powerful dosage of pesticides, he produces external impacts both intertemporal and interpersonal. All farmers, including some that may have never used pesticides at all but who share the same ecosystem, will in subsequent crop seasons either experience drop in crop yields or incur higher real production cost\(^1\) in order to maintain the old level of outputs.

Such damages in input-output mix take place despite no change in relative price of input and output\(^2\); in other words, they are not produced by the effect of market mechanism. In this case, the changes are caused by changes in the basic supply of environmental resources, which are not bought and sold in the market and which, therefore, have no market price that an individual farmer needs to consider. However, these extramarket goods, namely, the certain form and level of pest organization and population in a

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\(^1\) The higher cost is more appropriately referred to as physical unit of input because the monetary cost may be lower due to stronger competition in the pesticide industry, or it can be higher due to stronger competition among farmers for pesticide purchase.

\(^2\) Given a set of relative price of input and output, there must be a unique set of (planned) input and output that provides maximum profit. The condition is in equilibrium. If there is no change in relative price, there is no reason for making production change. The condition does not hold, however, when technological externalities exist.
particular area, are useful for agricultural production. The weakening or destruction of the natural biological control system by the extensive use of pesticides obviously involves some economic cost. To an individual farmer, the relevant cost of using pesticides may be the dollar he spends but to society it must also include the cost of environmental damages. Thus, the problem of externalities is linked to the difference between private and social evaluation of benefit and cost regarding a course of action. Furthermore, the real cost of pesticide use after accounting for environmental cost may be higher than the price which the crop output can cover for and society might otherwise obtain greater yield of agricultural products if alternative input strategy were employed by the decision makers. Thus, the allocation of resources is not an efficient one.

Technological externalities may also have a distributional effect. Just as in the above case, early adopters of pesticide technology can reap some entrepreneurial profit but only by taking wealth from future generations and from other farmers.

Externalities discussed in the literature are usually related to the technological type that involve two conditions in their definition: external effect and nonoptional resource allocation. For pecuniary externalities only the first condition is true. Following this line of reasoning, the term externalities as used hereafter shall refer to the technological type with which we are concerned.

Although externalities are fundamentally the outcomes of economic behavior on the part of decision makers who tend to be concerned only with their own interests and benefits but not the possible consequence of their actions on others, the problems normally arise and persist under specific conditions. The general attributes of externalities include the characteristics of goods consumed and produced, the presence or absence of certain social and economic institutions, the availability of necessary information, personal expectations, and transaction costs. These factors are in fact not mutually exclusive but the present discussion attempts to deal with them separately to help identify the causes of problems.

Nature of Public Goods

Externalities are often due to the public nature of some goods and services. Goods and services such as air, fish in sea, public grazing land, roads, and parks are available or provided free to the public. Their use by one individual or group, however, can effectively reduce the potential use by others, and the cost of using them may be imposed on others.

As a pasture is owned by one but open to all, the likely result is overexploitation and destruction of the commons. This is only one example

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There is another type of public goods called pure public goods. Pure public goods such as national defense and radio broadcast are provided free to all, but the consumption by one individual does not affect others.
of structurally similar problems that include traffic congestion, overharvesting of common fishing grounds, depletion of underground water resources, deforestation of public timberland for fuelwood, and pollution of air and water resources.

Because the use of road is free of charge, an individual will decide on the basis of his own costs (e.g., time and fuel) whether or not to take a trip. But his own costs do not include the additional congestion cost he imposes on others; and as many motorists are using the same road, each increases the average travel time and fuel costs for everyone. Since no one owns the fish in the sea, fishermen take into account only their own costs in deciding on the level of their fishing activity. As fish are extracted, the stock is depleted and it becomes increasingly expensive to catch fish. However, no fisherman will consider this depletion cost when deciding how much to fish. This then will result in overfishing, the fish population will be depleted, and some fish may eventually become extinct. If underground water is freely available, a farmer may invest in a water pump to increase his crop income, but his activity also has some effect on the level of the water table. If every farmer in a common ground-water basin is doing the same thing, water table levels would decline more rapidly forcing everyone to get rid of his existing water pump and install a more costly and powerful one. The overmining of ground-water resources can give rise to the irreversible destruction of the storage capacity of the aquifer, which can occur when continued long-term overpumping leads to compaction of the aquifer.

The residuals discharge problem is the inversion of the overexploitation problem so far as it is a question of “overadding” rather than “overtaking.” For example, if everyone can make free use of a public lake, a factory can save on its production costs by emitting discharges into the lake. This causes higher lake pollution as the factory’s production activities increase.

The nature of public goods per se does not always bring about overrapid depletion of resources although this may be the case with respect to nonrenewable resources, namely, the extraction of oil and natural gas from a common reservoir. For most renewable environmental resources, however, there is some minimal threshold level that must be exceeded before externality problems will occur. This threshold is determined on the one hand by the scale of human activities and on the other hand by the reproduction or absorptive capacity of the environmental resources. Externality in fisheries, for example, only arises in a situation where the harvest rate is greater than the natural reproduction rate of the fish stock. The depletion of fish stock may cease at the point where it becomes too expensive to catch fish, and this allows the fish stock to stabilize but at a lower level than formerly. Likewise, the inefficient use of groundwater begins at the point where the drawing rate is greater than the flow or average recharge rate of the usable water portion (nonsaline level).
The problem of public goods may lie in the fact that the goods cannot be divided and assigned private property rights in order to internalize all costs and that measures to restrict public access are difficult to set. To prevent externalities and make efficient use of public goods resources, possible solutions are to impose user fees or taxes and an administrative limitation of activities. Charging or taxing an individual at the amount that makes private cost coincide with social cost should discourage exploitative activities. Limitation of activity such as seasons that fishermen can fish and number of horsepower of water pump that farmers can have should reduce the rate of exploitation.

Absence of Markets

Inefficiency may be due to the nonexistence of markets for some input and output. Meade’s article (1952) illustrates the case. As bee and honey production depends on apple production for a good yield and as the relationship is not reciprocal, apple producers will evaluate only the costs and returns of their production but not the potential benefits to the beekeepers. Meade called the service the apple blossom provides to bee and honey production the unpaid factor—it is provided free of charge. He concluded that the apple farmer is paid less than the value of his marginal social net product and the beekeeper receives more than the value of his marginal social net product. If some charge could be made or if a market were to exist for service of the factor, the apple farmer would consider this as a return and would have an incentive to expand production and consequently help increase the honey yield. Meade recommended appropriate rates of tax and subsidy be allocated to have all factors paid at the values of their marginal social product; this also assures an efficient resource allocation. In the case of the reciprocal relationship—that is, apple production also depending on bees for pollination service—Meade suggested a subsidy be made to whichever of these two industries would give a stronger external benefit.

Another situation rather similar to the unpaid factor is what Meade called the creation of atmosphere. Reforestation, for example, might increase the level of rainfall in a farming district and as a consequence improve the efficiency of wheat farming regardless of how land, labor, and capital are allocated in wheat production. The timber industry therefore should be subsidized as it generates a favorable atmosphere for the others. Similarly, any activity that creates an unfavorable atmosphere should be taxed. The slight distinction between the two cases is that the unpaid factor is considered a direct and necessary input of production, whereas the creation of atmosphere is a contributor to the efficiency of some or all factor inputs in the production.

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4 This measure will be effective only if the burden of charge or tax cannot be shifted to others and will be efficient only if the spending of tax proceeding does not further create other “inefficiencies.”

5 His example, however, is difficult to substantiate from the scientific point of view.
Tax and subsidy are not necessary if appropriate forms of market arrangement could be made. In Meade's example, the beekeepers can compensate the apple farmers enough for the latter to carry out more activities while making themselves better off, if beekeeping has to depend on apple production. If the relationships are reciprocal, both parties can bargain for their mutual optimal level of production. The implication on allocative efficiency will be identical to tax and subsidy solutions.

Cheung's "Fable of the Bees" (1973) provides empirical evidence to support the above hypothesis. The beekeeper provides pollination services for the surrounding fruit growers and the growers in turn provide nectar for the bees. This is a clear case of externality. The beekeeper does not collect a price per pollination activity, nor does the beekeeper pay for the nectar extracted from the trees. Such social benefits are not reflected in the price system because there are no markets for nectar and bee services. Cheung discovered that contractual payments were the characteristics of beekeeping and fruit farming and that they actually eliminated the externality. The fruit growers obtained hives to provide pollination of those trees that gave little suitable nectar, and the beekeepers received the privilege of grazing their bees on the superior nectar-producing trees.

It becomes clear that nonexistence of markets opens room for externalities to arise, but institutional arrangement such as negotiation and contract can be perfect or near perfect substitutes for markets that would exhaust externalities. The convergence of the outcomes from different approaches to solve an externality (i.e., tax or subsidy and negotiation or contract) may be explainable by two theoretical concepts in efficient resource allocation.

The fundamental concept is the theory of "competitive" equilibrium characterized by a universal market, wherein markets and prices exist for all commodities and activities that people can utilize for consumption or production. Any change in the price of a commodity implies a change in the competitive demand and supply situations, and the price will indicate the true scarcity value of the commodity. An individual can make his resource allocation decision on the basis of market prices alone without going into interpersonal negotiation. This proviso gives a noncooperative solution to allocative efficiency. In the case where a market does not exist for a particular commodity or activity, the universal market solution is to include a market for it. For example, a market can be created by taxing the benefited party to pay for the activity that Meade called the unpaid factor. Similarly, for environmental goods, the solution is to institute a market for "polluter's rights" by using a tax as a proxy for price. Then the allocative effect is believed to be optimal.

Another concept following the "core" theory is the cooperative game solution. This notion basically refers to a situation where individuals can make a costless bargain to determine a cooperative solution and where
defaulting is not possible. As the individuals participating in a cooperative game increase in number, the solution is getting closer to the “competitive” equilibrium solution. Thus, the externalities consequential of market non-existence disappear when all individuals involved are willing and able to bargain and cooperate for mutual advantage. Any situation like the “tragedy of the commons” may not end up with an inferior outcome. If all members sharing the common pasture can make a costless negotiation and agree to cooperate in limiting the number of cattle that each can graze on the land, their productive resource will be preserved and no tragedy will result. The cooperative institution shall be stable as long as nobody can defect. Defaulting can be prevented if there are some societal rules or sanctions and information that help to assure the actions of the members.

Cooperative solutions are not likely to be successful if the public goods nature is dominant and the members of the group are in the “isolation paradox” situation. For example, where the limit of access to common land is difficult to enforce and when individuals are uncertain about the actions of others, people tend to “free ride.” Free riding occurs because an individual has no incentive to refrain from overgrazing when he expects others will not, so he grazes exploitatively although he knows someday the resource will be depleted. He also does not have an incentive to bring any action against those who overgraze the land, if he can enjoy the benefit when somebody else takes the action. Sen (1967) argues that cooperative arrangements are more likely to succeed when the unit of decision making is a relatively small, cohesive body. Contractual arrangement between beekeeper and fruit growers may serve as an example. It is not the size of the group that counts; it is more a matter of information that individuals can be furnished through transaction and communication to assure the actions of others.

While the existence of markets or market substitutes presumes efficiency, the absence of them does not readily imply inefficiency if optimality theorems are appropriately interpreted (Demsetz 1964). In his example of free parking at shopping plazas, the shoppers, by the prices they pay, confer unpaid-for benefits on nonshopping parkers. At first glance, most economists probably argue that the number of spaces is not optimal. There are too many unnecessary parking spaces, and those who enjoy external benefits do not pay for the services. However, free parking is allowed because the expense to control the use of parking spaces is too costly. It also appears that free parking is allowed more frequently in suburbs than in centers of town because of price of land in town is greater. The control of parking-for-shoppers-only is a preferred strategy if it costs less than buying additional land to construct more free parking spaces.

Demsetz’s argument, in fact, is equivalent to saying that an externality is internalized whenever any possible cost and benefit that extends beyond the current activity is accounted for. Hence, shadow prices for the implicit market exist and our previous assumption still holds.
Property Rights. The issue of externalities is primarily the matter of property rights. By definition,

Property rights, inextricable from technology-resources, serve to delimit the alternatives open to choice-making individuals in a society. The conjunction of individual choices yields an outcome dependent upon the tastes and technology-resources-property rights extant in that society (Stubblebine 1972, 39).

Property rights are an institution of a society, which are significant in that they determine individuals' expectations and resulting behavior in a given situation. Property rights also determine who benefits and/or who is harmed; therefore, it follows that property rights and externalities have a close relationship.

As the oceans are not owned by anyone, every individual possesses the right to extract fish and other raw materials from the sea without consent from other individuals, leading to resource from the sea being overexploited. This notion becomes the basic rationale behind the continual extension of national fishing rights—a nation's private property rights to limit overfishing that occurs in international water.

Underground water brings about conflict and externality because on the one hand it possesses the characteristics of a public goods resource and on the other hand its property right is usually implied by private ownership of the overlying land. Although the right to pump water is restricted to those who occupy land over the aquifer, the right for each landowner to extract the common water resource is not limited. Therefore, one alternative to deal with water resource depletion is through changing property rights in ground-water use by separating them from land ownership into a communally owned resource. Then the control of the resource is vested in the community for which the decision making essentially expresses a social interest.

A useful example is the Correlative Rights doctrine, which has evolved out of the California experience in dealing with ground-water externality. The doctrine is based on the communal property concept, which specifies a distribution of property rights in resources in which a number of owners are coequal in (nontransferable) rights to use the resources, and the owners' rights are not lost through nonuse. Under this Correlative Rights doctrine, all users in a given ground-water basin are coequal in rights but adjudicated within the limits of the safe yield of the basin in proportion to their historical use. This principle provides an effective institutional basis for efficient resource use because it enables the societal or public regulation of groundwater to be established and because it increases the certainty of tenure to all users with respect to water use in the event of insufficient water supply.

The role of property rights in the internalization of externalities can be made clear with the previous examples. Externalities, especially when they

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6 For a detailed discussion, see Ciriacy-Wantrup (1955) and Hutchins (1956).
occur to a critical extent, can also play a role in the adjustment of property right systems. The following examples provide some evidence.

The question of why dissimilar property right systems exist in different societies of the same "civilization" level has never been answered more satisfactorily than that the difference was due to dissimilar human values and cultural background. Nevertheless, Leacock's "The Montagnais 'Hunting Territory' and the Fur Trade" has been cited as clearly establishing the fact that the property right adjustments were linked to the process of eliminating externality—the overhunting of game in northern Canada (Demsetz 1967).

When private property right was not yet established, there was no measure to exclude others from hunting and there was no interest on the part of the individual to invest in maintaining or increasing the stock of game. Overly intensive hunting resulted. The externality was clearly present. Before the fur trade took place, however, hunting was carried on primarily to provide only the hunter's domestic food and clothing. The external effects were of such small significance that it did not pay for anyone to take them into account. Private right to land was not developed.

The advent of fur trade had two immediate consequences. First, the value of furs to the Indians was increased considerably. Second, the scale of hunting activities correspondingly rose sharply. Both consequences must have increased significantly the extent of the externalities associated with free hunting. The property right system began to change, specifically in the direction of increasing externality effects resulting from the intensity of the fur trade. The geographic distribution of fur trade centers reported by Leacock shows that the older the fur trade center the more complete the development of private hunting territories.

The absence of private property right system among the Indians of Southwest America can also be explained by the concept of externalities. First, there were no animals of commercial importance comparable to the fur-bearing beavers of the northern areas described by Leacock. Externality effects might not be significant. Second, the animals in the area were primarily grazing species that wandered over a wide area. The cost of establishing private hunting territory and preventing animals from entering others' lands became prohibitive. On this account, the private rights of land is not expected to develop until the potential benefit of doing so becomes greater than the expected cost.

However, many resources with strong public goods attributes such as clean air, oceans, or desirable insect communities are not possible or suitable for property rights assignment and hence for pricing, which reveals their scarcity. Because property rights imply the right of the resource owner to trade his goods in the market and enable the resource owner to value the goods subjectively, the absence of ownerships entitles the resources to be zero priced for private individuals. The result is inefficient use of resources unless
solutions other than property rights assignments are available to halt externalities.

Transaction Costs. Externalities can persist and remain unsolved due to the lack of institutions ensuring that individuals pay for all costs resulting from their activities and paying for the benefits resulting from their actions. Many institutions such as markets, contracts, cooperation, property rights, laws and regulations that are believed to be capable of solving externality problems in a given situation do not come into play as they are prohibited by high transaction costs. Loosely defined, transaction costs are the costs necessary in bringing about efficiency.

Consider the example of a factory that produces higher stream pollution as its production activities increase. The pollution increases the cost of farming in the community. One theoretical solution would require that the firm be taxed so as to induce a lesser production activity to a level that seems optimal. Nonetheless, the analysis should be pursued further. The fact that the factory produces too much pollution will certainly have an effect on the rent value of neighboring farm land. If the factory owner also owns the farm land, he will adjust his production level until the advantage in the production process no longer pays for the loss of rent value. The production of goods and pollution is said to be efficient, and the externality would have been internalized.

Now consider the case where the factory owner does not own the farm land and he has the legal right to pollute as much as he wishes. This does not necessarily mean that the farmer has no choice but to suffer in silence. The farmer will be willing to pay for the reduction of emissions as long as the increase in rent resulting from the less polluted stream exceeds the necessary payments. The factory owner will agree to modify his activity as long as the payments received to reduce production could cover the profit foregone. So there seems no reason why efficient allocation of resource use should not exist.

Suppose that the legal conditions deny the right of the factory owner to emit pollution without compensation to the victims. Now the farmer can sell the factory owner the privilege of polluting the stream at a price sufficient to cover loss in rent or farm output, and the factory owner will be willing to pay for pollution rights if the gain from his production can cover the payments. Again, the process of individual bargaining shall bring about the optimal allocation of resources.

In his famous article, Coase (1960) put forward this very remarkable result and established this theorem: 7

Coase Theorem: If costless negotiation is possible, rights are well-specified, and redistribution does not affect marginal value, then

1. The allocation of resources will be identical, whatever the allocation of legal rights.

As summarized by Layard and Walters (1978, 192).
2. The allocation will be efficient, so there is no problem of externality.

Furthermore, if a tax is imposed in such a situation, efficiency will be lost.

The Coase theorem assumes that there are no transaction costs. In actuality there are. The transaction costs involve real resources in terms of money, time, or energy; and if they are high they can prevent the arrangement of a bargain, coordination, or enforcement that would confer potential benefits in the absence of them.

Transaction costs can be nil if only two persons bargain and coordinate. However, externalities often involve many individuals. Therefore, negotiation and any other kinds of contractual arrangement in dealing with an externality require a cooperative action and collective organization. The process of getting people together to reveal their preferences is, nevertheless, not a costless undertaking. There is also a tendency for individuals to act as free riders when they can benefit from whatever other people do. As a consequence, externalities tend to persist in a situation where the external costs or benefits are shared by a great number of individuals. However, it seems clear that whenever the expected benefits from a change outweigh the relevant transaction costs there is an incentive for people to take action.

*Information, Uncertainty, and Expectations.* Most economic units are now operating as more open systems and thus becoming only part of a broader and more complex total system. Herdsmen sharing a common range today no longer raise cattle for family consumption but rather for commercial purposes. Agriculturists now no longer depend on on-farm biological management to improve farm yields but are increasingly dependent upon material and energy inputs drawn from other sectors. While more choices are made available to individuals through economic and technological development, information and certainty attached to each choice variable seem to become more staggering, making it more difficult for individuals to form expectations about their performances. Analysis of present-day externality problems cannot contend only with such aspects as public goods nature, institutions to internalize externalities, or transaction costs. These analyses must also consider information and uncertainty factors as causes of divergence between private and social costs/benefits.

The cooperative solution to prevent the "tragedy of the commons" may be able to provide a stable and productive pattern of resource use in more traditional societies where all members are more dependent on each other for individual and community welfare. Expectations can easily be formed regarding the immediate consequences of different human behavior interacting in such a way that all will survive if they coordinate or all will perish if they free ride. The effectiveness of this internally arranged economic institution may be further reinforced by other systems such as kinship relationships, which supply additional information concerning others'
probable actions or reactions. This type of economic institution may be destabilized as population grows, technology progresses, and social relations change. The breakdown of the system is due to many factors but also includes the loss of information and communication, which can help one predict others' behavior. Other factors involved may be higher transaction costs needed to coordinate activities and the loss in effectiveness of local sanctions to compete with external economic incentives.

To overcome the problem of inefficient resource use, alternative institutional rules must be sought, and establishment of private property rights is one possibility. However, private ownership of resources in free market economies can easily give rise to intertemporal externalities. Herdsmen may decide to deplete their grassland instead of providing sufficient investment to maintain its sustainable use, if they place a high value on immediate returns and if they have larger expectations about alternative economic activities.

In agriculture today, perhaps the increasing intensity of externality problems is due only secondarily to the questions of individual profit motives, public goods nature, or institutional rules and primarily to the loss of information about the performance of the cultivation method practiced. The fact that most material and energy inputs needed for intensive and modern production systems are obtained from distant rather than nearby markets can produce environmental spillovers, regardless of whether or not individual farmers and communities are concerned to internalize all externalities. It is very unlikely that farmers, when applying fertilizers or pesticides on their fields, will recognize that synthetic compounds in the inputs can cause ecological damage in a complex and cumulative manner. The sphere of farmers' knowledge and information has changed from a deeper understanding of traditional practices to a more superficial and incomplete understanding of the implications inherent in modern production methods. Social costs resulting from the loss of information may be considerably higher if the situation takes place in agricultural research and extension institutions. One example is the ex post analysis of the severe soil acidity problem on Chiang Mai University's Multiple Cropping Project experimental plots, which revealed the causes of the problem were associated largely with the use of chemical inputs; a similar situation is now appearing on farmers' fields (Gypmantasiri 1980, 92).

**Summary.** Although externalities are a general occurrence in the working of present-day economies, there are a number of ways that an individual or society can cope with the problems, provided their nature and extent are adequately understood. In principle, the alternative approaches for private individuals to handle positive or negative externalities include:

1. Negotiation, as well as merger, voluntary, and cooperative internalization of externalities;
2. Political or legislative process, namely, in changing legal property rights or setting environmental standards; and
3. Litigation.

Where externalities cannot possibly or effectively be solved by private individual approaches, then the problems are by nature targets for public policy considerations. There are three distinct alternatives of solving externalities through policy: regulation, user charges, and tax and subsidy incentives. They are all designed to distribute the costs and benefits to the appropriate parties or individuals through the creation of incentives or disincentives for people to modify their behavior such that the outcomes of private individuals' decision making become consistent with social interests.

THE NATURE AND CHARACTERISTICS OF EXTERNALITIES IN PRESENT-DAY AGRICULTURE

The previous discussion focused on the ways and the extent to which the interaction among various economic components in a given environment and circumstance can affect quantitatively and qualitatively the resources necessary for human existence. This section will give some examples from the scientific viewpoint on the ecological consequences of human economic activities, as an important link to the understanding of contemporary externality problems in agriculture.

The seemingly serious and complex externalities in agriculture today are mainly the results of two major developments: the overall organization of production systems, and the increased application of chemical inputs. Both developments, if their negative external effects can be abstracted, are yield-increasing technologies; however, this is not always the case.

Changing Agricultural Production Systems

The most often cited example may be the intensification and the specialization by farm or by geographic region in livestock production. This animal production system has altered the formerly complementary relationship between crop and livestock enterprises. The trend has shifted toward the substitution of pasture and grassland by confined animal feeding operations, creating the problem of controlling and disposing livestock waste that was formerly utilized by the process of on-farm recycling.

Discharge of waste from animal confinement operations, if not properly controlled, is associated with eutrophication of waters; fish kills; nitrate contamination of soil and water; annoying odors; depreciation of recreational values of land and streams; dissemination of agents infectious to plants, animals, and man; and breeding of insect pests (United States 1969).

Agricultural wastes, whether in the form of manure, fertilizer, or decomposing crop residues, produce plant nutrients that fertilize the water and increase the rate of productivity of the aquatic ecosystem. However, excessive supply of plant nutrients to waters enhances eutrophication and results in tremendous growth of algae and rooted plants, which in turn causes
lakes to become repulsive, malodorous, and prematurely aging (FAO 1971). Excessive amounts of nutrients also change the algal community from one of diversity of species to one of a few; the species damaged are usually those that form the food of the herbivorous animals, which in turn feed the fish community in the area. The fish species able to survive under this changing environment are often those of less economic value (FAO 1971). Organic matter from animal waste also increases the biological oxygen demand in the receiving water during the process of organic material decomposition. This might reduce the total oxygen concentration to levels detrimental to some forms of aquatic life, resulting in fish kills (FAO 1971, Loehr 1969). It is obvious that the change in aquatic environment indirectly causes changes throughout the entire ecosystem, including organisms, which are not directly affected by the pollution.

The increased leaching into the ground water system of nutrients and toxic materials associated with contaminated water resulting from livestock waste can affect the quality of future water use in farm production and household consumption. The toxic level in ground water is likely to become acute as more feed additives, which can change the biochemical properties and physical characteristics of the wastes, are used in livestock production. Nitrogen from wastes and chemical fertilizer, for example, when passing into ground water, will increase nitrate concentration in the water. If this water is used for drinking, the nitrates may be biologically changed to nitrites in the human digestive system causing methemoglobinemia. Nitrates are also harmful to livestock (United States 1969).

It is also possible that organic pollutants such as large amounts of animal waste may provide an environment suitable for the development of disease producing bacteria or viruses. Diseases are further dispersed and transmitted to man and other animals through runoff, particularly into surface water. Diesch (1970) reported several cases of diseases that originated from livestock and transmitted through water to both man and animals.

In several states of the United States, the offensive odors generated by the confined livestock production facilities have been a source of complaints and have become an important consideration in legal action against such animal production operations (Loehr 1970).

The ideal solution to all the above problems is the disposal of animal waste by recycling and reuse of the materials in crop production. However, because of high transportation costs due to geographic specialization of crop and animal production, increased labor costs, and the availability of inexpensive chemical fertilizers, recovery of the nutrients in animal wastes by on-farm disposal has become relatively less economical. Therefore, the solution has to be the use of various treatment systems to destroy the waste or to clean up water, which means higher costs.
Agricultural Chemical Inputs

The use of chemicals to control pests and to fertilize soil has been a major factor in increasing the productivity of modern agriculture and the capacity of world food and fiber production systems to provide adequately for growing human needs. Chemicals are an important part of production systems because they play the role of land and labor substitutes when the latter factors are relatively more expensive. However, in recent years much controversy has surrounded the use of chemicals in agriculture as the practice has increasingly created ecological disruptions.

The drawbacks to chemical pest control, for example, became a public concern after the publication of Carson’s *Silent Spring* in 1962. A voluminous literature is now available on this complex subject regarding the undesirable aspects as well as the optimal control strategy of pesticide use.

Three types of pesticides generally used in agriculture are the organo-chlorine or chlorinated hydrocarbons including DDT, the organic phosphates, and the carbamates. The short-term benefits of using pesticides in crop yield promotion and in disease control (e.g., malaria) are so great that it has led to extensive use of pesticides in agricultural production throughout the world.

All pesticides have undesirable as well as desirable characteristics. Ideally, pesticides should be highly effective against target pests without harming beneficial or desired organisms. However, most modern pesticides and insecticides are broad-spectrum biocides, which modify the whole environment. When applied to crop, these pesticides kill not only pests but also other species in the insect community, including natural enemies that suppress harmful species. Often these natural enemies suffer excessively because they are generally less able to tolerate chemical control than the pest species and because their food supply—the pest species—are reduced so that they starve or leave the field.

As a result, pesticide application frequently provides a substantial vacuum in which populations of surviving or reinvading target pests, after significant natural enemies have been removed, and with their remarkable adaptive ability to tolerate drastic changes in environment, explode. It is this combination of pest persistence and biological effects that has demanded a higher production cost as more frequent pesticide application is necessary for the same degree of pest control. This may cause financial losses among individual farmers or even destroy the entire industry as what happened with cotton in northeastern Mexico (Bosch 1978). Another example is the case of pesticide-induced beekills in California’s agriculture where the application of pesticides in citrus production has also reduced bee populations, resulting in financial losses for both beekeepers and other crop growers who depended on bees for crop pollination (Siebert 1980).

Agricultural use of pesticides can have dreadful impact on human populations, fish, wildlife, and a variety of things in the environment. Organic pesticides can enter the human body by ingestion of toxic residues in food,
dermal absorption, or direct inhalation of the pesticide spray (Headly and Lewis 1967). Many animal and plant species are not directly sensitive to toxicity, but toxic concentrations can build up through the food chain and eventually reach the level detrimental to their predators (FAO 1971, Macek 1970).

Increased use of herbicides to control weeds may also be followed by serious problems. A study on weed control management in tropical Asia provided evidence that continuous use of the same or similar herbicides made room for a highly chemical resistant perennial weed species to grow, causing substantial losses in grain yield and quality and demanding more efforts and higher costs for subsequent weed control (de Datta 1977). Application of herbicides may incidentally kill other useful crop and pasture plants besides weeds, since they are closely related and are sharing the same habitat (Woods 1974).

Commercial chemical fertilizers are another source of agricultural inputs that can cause environmental problems, although the addition of inorganic fertilizers has proved to be a significant factor in crop yield improvement. The use of inorganic fertilizers, particularly those containing nitrogen and phosphorous, is necessary for intensive agriculture because intensive cultivation of certain crops can deplete particular natural nutrients in the soil; for example, corn, which has a high removal rate of nitrogen. Erosion, runoff, and subsurface leaching can also cause loss of organic phosphorous. Despite their value, chemical fertilizers also have some adverse effects on humans, animals, and the larger environment that we need to consider.

The spillover effects of inorganic fertilizers are similar to those of animal waste. Phosphorous and nitrogen fertilizers, upon entering surface waters, improve the productivity of aquatic plants in these ecosystems. Eutrophication may be desirable in some conditions, but the excessive productivity of organic matter in the aquatic systems can lead to detrimental ecological changes as described earlier. Nitrogen fertilizer, if it contaminates ground water, increases nitrate concentration in the water to a level that may be harmful to human and animal health.

Evidently, the application of certain agricultural technology, while primarily bringing gain to those who adopt the practices, has created several ecological problems. Social losses associated with these externalities can be in terms of reduced consumer utility as what happens with polluted lakes, environmental clean-up costs, loss in agricultural yields, or expense to set up legal protection of the environment. Certain costs seem to be internal to the decision makers, such as increased pest and weed control costs, but they are actually the social costs related to interpersonal and intertemporal externalities.

**EXTERNALITIES AND HUMAN ECOLOGY RESEARCH**

Externalities are an economic issue because they involve the relation between man's economic activities and the resulting welfare conditions of the
human race. The basic economic questions are whether economically important commodities are used in most sensible ways; if otherwise, how individual’s economic motives, state of knowledge, and institutional structures can be modified to induce desirable performances. It seems that the problems can be understood and analyzed in economic terms. But externalities are another class of economic problems as distinct from the issues of inflation, employment, marketing, international trade, and so forth, in that in most cases they relate to the use of environmental resources. These resources have economic values that ordinary market systems in most cases fail to assign prices reflecting their relative scarcity. Moreover, knowledge regarding their physical, biological, and chemical properties and hence their scarcity as affected or unaffected by human activities lies beyond the domain of economic discipline. It suffices to state that tackling an externality problem must be in the “human ecology” context. The tools of economic analysis cannot alone provide an adequate intellectual basis for solving these problems.

The objective of this section is not to suggest guidelines for conducting interdisciplinary research, as this will be handled in other parts of the text, but to raise some difficulties that economists may encounter when they undertake practical research on an externality problem.

The previous discussion on theory and concept of externalities was an abstract one in order to maintain its comprehensibility by a broad audience. In applying theory to empirical investigation, those simple concepts and relationships among various elements in an externality problem may need to be carefully redefined or reinterpreted for theoretical consistencies. However, before proceeding to concentrate on the practical and technical problems we may have in the economic study of externalities, it is important to emphasize the need for economists to recognize and have some understanding of the noneconomic aspects of the problems that may have important bearing on economic explanatory and predictive abilities. One such aspect, which we have briefly touched upon, is the ecological relations relevant to the unit of study. There are two additional issues that are significant in the context of economic study on externalities but that are too broad to be discussed here: the political economy of resource use and the organization of social systems. However, some digression is made to help conceptualize their significance.

The political economy of resource use and the organization of social systems each involve a complex set of issues with many dimensions. Broadly, they determine what are “desirable” from the political and social points of view, which are not necessarily identical with economic theoretical standpoint. As an example, destitute peasants gather wood from the forest to provide fuel for domestic use and the combined effects of their activities lead

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8 This is a weak statement made for the purpose of understanding an externality situation. Strictly speaking, all political, social, and economic goals are identical when the concepts of valuation are used to defend the proposition. However, this subject matter is so broad that it cannot be treated explicitly here.
to deforestation and other environmental damages. The question is whether or not in an attempt to stop externality it is a desirable solution to prohibit the peasants from freely cutting fuelwood. The political economy of resource use and the organization of social systems may play a role in either encouraging or constraining a potential externality. A country may choose to promote commercial logging to earn foreign exchanges or to save on foreign exchanges that otherwise would be paid for by imported materials. This may result in deforestation and related environmental consequences; whereas, certain sets of customs, norms, and beliefs in a society can be interpreted as agreements to improve the efficiency of the economic system that common economic thought might lead to the conclusion of inefficiency. A speculative analysis can be made of what happened in the persistence of a "shared poverty" situation in Java prior to the widely diffused Green Revolution technology. Java corresponds to a situation of very small and poor farms and a large landless or near landless class in a densely populated area with no further land that can be brought under cultivation. Yet, it has the peculiar characteristics of rice farmers with surplus family labor relying on hired labor for approximately 85 percent of their labor force. Even at the initial phase of Green Revolution practice, any increased labor demand to intensify agriculture was absorbed by hired labor. In short, the whole phenomena does not make any economic sense. A challenging explanation is that the tradition was functioning as a means to provide subsistence to the landless and near-landless labor sufficiently to prevent them from exploiting the natural resource systems on which efficient rice cultivation depended. It is also possible that this customary practice acted as a process to internalize the costs of potential thievery or local political disorders.

Perhaps the most difficult tasks in performing an economic analysis of an externality problem are (1) the identification of problematic situations and relevant factors/variables; and (2) the measurements of nonpriced extra-market commodities. Oversimplification and a failure to perceive the true nature of the problem will inevitably result in intuitively incorrect solutions regardless of how well research survey and modeling are prepared.

Identification of Problematic Situations and Relevant Factors/Variables

As stated previously, almost every economic activity has some external effects, but it becomes an externality problem only when the resources will be or are used in an "inefficient" manner. Yet externality may arise only in certain situations. Therefore, often an externality problem in itself represents a unique case for investigation.

Analysis of externality either performed ex post or ex ante must begin with defining a unit of analysis (e.g., competition for water use in a given water basin; overfishing in international seas or domestic seas; overgrazing in a common range; pest outbreaks in a village or in a valley; or increased global carbon dioxide levels). It is observed that often the unit of analysis is geographically determined. This is not surprising since one of the factors that
determine whether or not an externality becomes a problem is the characteristics of natural systems. The systems can be diverse in different localities such as forests or may represent a single global system such as atmosphere. The human actor is the basic factor that produces externality, and his decision-making context is comprised of his economic motives, perception about his social and physical environments, and the existing institutional rules that govern his behavior. Identification of the problem can be usefully approached from the question whether goods that man utilize for consumption, for production inputs, or for waste receptacles are ascribed as public goods or common property resources. These two characteristics are closely related and also closely linked to the situations of market non-existence and high transaction costs to eliminate externality. In addition, the patterns and processes of consumption and production indicate certain technology that man employs in his economic activities. The type of technology adopted should provide some clues as to whether externality is an unavoidable attribute of the technology. Intensive agricultural chemical input uses, or cropping systems demanding high ground-water input, for example, when adopted at large scale provide a tendency for an externality problem to emerge.

Since the diversity of externality problems is extraordinary, it is difficult to generalize the ways to identify problematic situations and the factors involved. However, once the concern over efficient use of resources is expressed, in many cases the important issues hinge upon the nature of property rights in the resources. It is difficult to establish such rights; yet, the absence of them may lead to externality. For instance, in fisheries, it is necessary to decide whether property rights should be defined by geographic factors or by fish species. This problem is further complicated if the fish population is a highly migratory species. Although property rights may be established in an effort to exclude others from exploiting the resources, the enforcement of such laws may prove impossible in practice. Thus, fishery resources remain in effect common property or open-access resources that also possess public goods character, which in our definition refers to goods freely available to all but where consumption by one person may reduce the potential use by others. "Free riding" and "isolation paradox" are invariably the inherent characteristics in the utilization pattern of this type of resources. Individual fishermen, a fishing community, or a country may well perceive the externality problem but believe that competitors will not pursue a policy designed to conserve the fish stock for future use; then there is no incentive to carry out such a policy. Cooperative solution in this case is highly unlikely because high transaction costs are involved in coordinating and enforcing effective agreements. The absence of appropriate ownership prevents the resources from being transacted in ordinary market systems and hence there is no market value for the resources. Fish traded in market places do have market prices, but the prices are undervalued simply because the costs of fish resource are not accounted for. Thus, the systems of property rights
identified as the cause of inefficient resource allocation in many cases are closely related to all other attributes of an externality problem.

Yet, the mere absence of property rights does not necessarily imply externality to be present if the notion is appropriately interpreted. For example, private rights to land usually do not exist among hunter-gatherers and shifting cultivators, but the private ownership of fruit trees or crops is often recognized. Consequently, the contents rather than the forms of any concept in externality are the primary indicator of economic behavior. The same caution also applies to various definitions used in the literature. Different terms meaning the same thing or the same term referring to different situations often occur in classifying resources/goods and property right systems in theoretical literature. For example, the term “common property” is applied to extremely heterogeneous types of resources and property rights situations. Gordon (1954) and Hardin (1968) are among those who referred common property externality to the case when there is free entry to the common property by an unrestricted number of potential firms. Ciriacy-Wantrup and Bishop (1975) defined common property concept as a distribution of property rights in resources in which a number of owners are coequal in their rights to use the resource. Krutilla and Fisher (1975) use the term to refer to an open-access resource owned or used by all the members in the community. The conceptual and terminological confusion may be a serious barrier to analytical understanding of specific resource problems and to the design of public policy (Ciriacy-Wantrup 1971).

The Measurements of Nonpriced, Extramarket Commodities

Another crucial part in any economic study and analysis is the quantification and valuation of variables. Quantification involves the measurement of inputs or outputs (e.g., yield of rice per acre, concentration of carbon dioxide per million by volume, or kilogram of nitrogen fertilizer). Valuation is related to the measurement of worthiness of a commodity. Quantification and valuation present no problem if there are universally accepted measures. For instance, some items that are traded in a competitive market have market prices or monetary value attached to them, which reflect their scarcity value or “worthiness.” However, in analyzing an externality problem, both quantification and valuation of the variables represent the most controversial aspect of the analysis. This is because the problems are often associated with the use of nonpriced, extramarket resources.

Let us consider the example from Cheung’s “Fable of the Bees.” Without any contractual arrangement, the production of honey and/or citrus may be suboptimal. One corrective measure is to subsidize the industry that generates positive externality, assuming that it is the citrus industry. If all bees collect pollen from only one place, then the incremental quantity of honey received as a result of subsidizing a particular citrus farm can be estimated and may be valued at market price. Appropriate rate of charge or subsidy can be made to
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bring about efficient production. However, market prices are always fluctuating, leaving another difficulty in choosing appropriate market price. Normally, honey bees from different farms collect pollen from fruit trees that also belong to different owners. The difficulty is how to quantify and value the honey each beekeeper receives as benefits from different fruit-tree growers.

Water pollution is another example. If a factory emits pollutants that affect commercial fishing, the question is, “What is the social cost that the factory does not consider in their production activities?” Among the alternatives to impute “shadow price** as a basis for tax or charge are the costs to restore or improve the water condition to an acceptable level; the willingness of commercial fishermen to pay for nonpolluting actions, or the market values of the fish lost. All criteria present us difficulties to evaluate and choose.

CONCLUSION AND COMMENTS

Externalities present us the problem of allocative efficiency in resource use. The problems arise from the fact that costs of some resources utilized in man’s economic activities are either deliberately or inadvertently neglected in the decision-making process. In economics, efficiency has a precise meaning: Is there any possibility that goods available for consumption can be increased to improve the welfare of some members of the society at the same or different times? If there are ways to make goods more available, the existing pattern of resource use is said to be inefficient. The task for economics is to perceive why the prevailing institutions fail to control the efficient use of resources and to identify alternative avenues to achieve a more preferred performance in the working of economy.

Externalities range from trivial spillovers like smoking in a theater to major irreversible damages like soil erosion that created the American Dust Bowl in the 1930s. The Dust Bowl was a name applied to a part of the Great Plains region of the Southwestern United States which covered some 20 million hectares. Much of the soil there had been damaged by wind and rain, and severe dust storms occurred. The soil in this area was subjected to water and wind damage because the protective cover of vegetation was impaired or destroyed through poor farming practices and through the grazing of too many animals. The first settlement and farming in this area began after the Civil War. However, the soil began to drift as a result of heavy sowing of wheat to meet high demand for this grain during World War I. The most severe dust storm began in the Dust Bowl in the early 1930s and appeared again in the 1950s, and 1970s. The effects of externalities can be limited to a small locality or may be global in character.

In agriculture, externalities are a problem of human ecology as they emerge from the social interactions of various factors in the economy with the results that affect the physical environment in a variety of ways. This
state of affair was tolerable when the environmental resources were more plentiful and the use of these resources had virtually no disruptive effect upon them. Until recently, the utilization of resources such as forest products and agricultural lands was through simple technology and directed largely for home consumption and in many cultures was also closely regulated by social institutions and customs. The results of changes in population, technology, economic infrastructural development, and commercialization on the changing relationship among components within various ecosystems were so striking that the knowledge of externality intensity and extent becomes beyond the capacity of economic discipline. Externalities in present-day agriculture are not related only to the deliberate exploitation of "free" resources but also to the losses of information pertaining to the intrinsic value of dismissed technology (e.g., genetic resource of local cereal varieties and the adverse effect accompanying the adopted technology e.g., pesticides).

Adequately equipped with some understanding of ecological and other noneconomic systems, economists may be able to suggest alternative solutions to externality problems. The relative merits of various corrective measures are too broad and diverse in different situations that we cannot deal with them here. But for the purpose of simple illustration, we consider the case of cigarette smoking that has negative external impacts on others. Since legal damage of lung cancer caused by smokers on buses is difficult to prove and the charge proportional to the amount of smoking is also impossible to make, the best solution we can expect is an injunction to stop smoking in public enclosed areas.

Externalities have more implications than the allocative efficiency. Literature on this subject has devoted too little attention to the distributional aspect, which is another desideratum of economic performance. Wealth distribution has much to do with externalities, whereas various solutions to externalities also have something to do with wealth distribution. The poor tend to place relatively low importance on environmental quality if they are close to starving, and the rich may have a tendency to do the same since they can afford to pay for any legal damages. The authoritative restriction on fuelwood cutting to halt deforestation will certainly have an impact on the well-being of destitute peasants.

Pecuniary externalities is another area in which we should place more concern. The poor farmer tends to be a prime loser in the structural adjustment of agriculture because the big farmer produces at a lower cost, bringing down the market prices of farm products. In this case, the efficiency condition holds but the distributional effect can be socially undesirable and may lead to technological externality problems. Another concern is that externalities often produce international bias in wealth distribution, considering various cheap agricultural products that are exported from the poor to the rich countries, which are often priced below their social costs.
The last and perhaps the most important consideration for economists is probably the efficiency of their profession. The failure to perceive the complex interaction of variables in an externality problem may be ascribable to the fact that some of the variables lie outside the purview of a single discipline and consequently some of the key relations may not be recognized. The lack of information and understanding of the real characteristics of an agroecosystem is the chief source of divergence between aggregated private benefits and social benefits.

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