Article

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Cacao Cultivation and the Conservation of Biological Diversity

Cacao (*Theobroma cacao*) is a crop of the humid lowland tropics produced largely by small-scale producers and often on farms with a canopy of shade trees. Where a diverse shaded canopy is used, cacao farms support higher levels of biological diversity than most other tropical crops. A host of viral and fungal diseases, loss of soil fertility, and numerous socioeconomic problems facing producers, often makes cacao production locally unsustainable. Continued clearing of new lands threatens biodiversity. Moreover, new frontiers for cacao expansion are rapidly disappearing. Such problems can be addressed by increasing the long-term productivity of existing cacao farms and restoring abandoned lands. Improved shade management offers guidance along this path. Institutions involved with cocoa should establish collaborations with groups concerned with development, environmental protection, and most importantly producers themselves to pursue a program of research, extension and policy initiatives focused on the ecologically and economically sustainable cacao production on farms with a diverse shade canopy.

INTRODUCTION

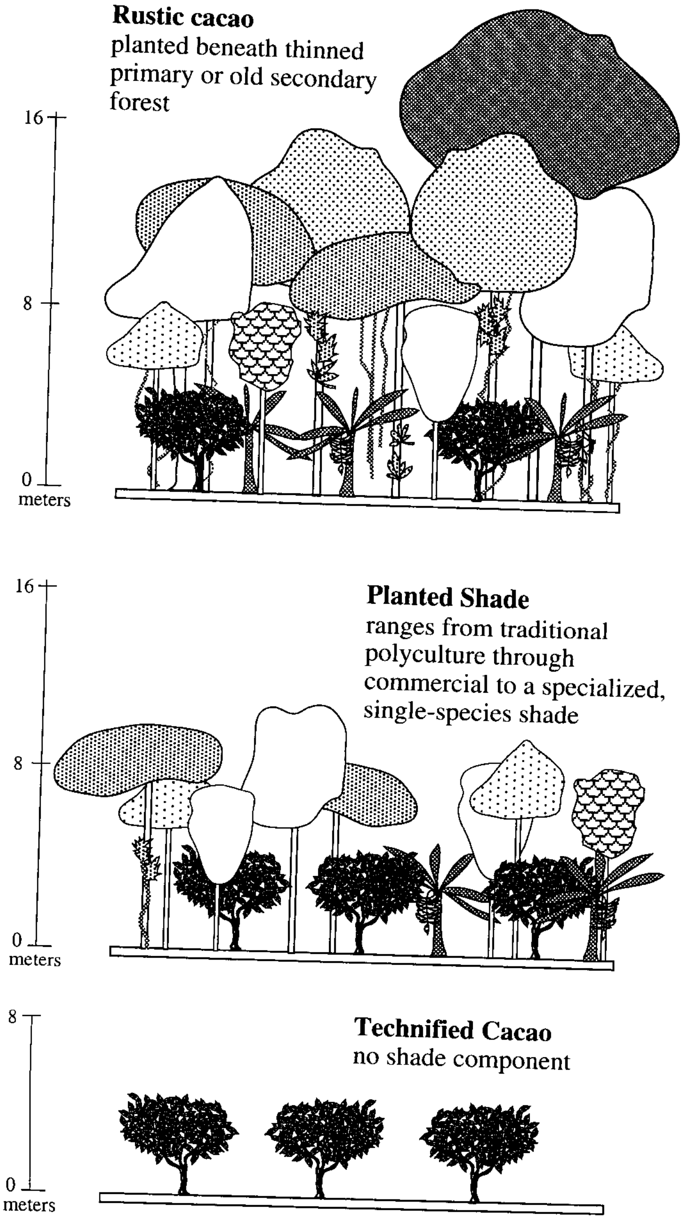
As the world faces alarming rates of tropical forest loss, some agricultural systems offer a glimmer of hope. In particular, agroforestry, where crops are cultivated in association with trees, provides some of the ecological benefits of natural forest while allowing farmers to make a living off their land (1–3). However, only in agroforestry systems that involve the production of globally traded and economically important commodities, such as cocoa (*Theobroma cacao*), can we realistically expect that enough land and people will be affected to make a difference. The environmental benefits that cacao farms may confer depend upon the management system. On one hand, we find a low-input and generally low-yield system that requires few, if any, agrochemicals. These farms often incorporate remnant forest shade into the farm management system. In contrast, are the systems characterized by high-input, high-yield farms, often with little or no shade. These are extremes of a continuum and between them we find managed agroforestry systems with planted shade trees and moderate levels of chemical inputs.

We will develop the argument that systems using diverse shade offer the greatest potential for long-term production, biodiversity conservation, and environmental protection. We begin our discussion of how different shade cacao systems influence tropical biological diversity, then provide a brief overview of patterns of production, and finally explore ways in which the pattern of production might be changed to optimize biological diversity, cacao production, and the livelihood of the millions of small farmers who grow the crop.

SHADE SYSTEMS

Shade management systems in cacao form a gradient (Fig. 1), analogous to that seen in coffee (3, 4). *Rustic cacao* management, widespread in the humid portion of West Africa and local in Latin America, is characterized by the planting of cacao under thinned primary or older secondary forest (5). *Planted shade* systems vary widely, from traditional polycultural systems—multiple species of planted shade trees with occasional remnant forest species—to commercial shade where other tree crops are interspersed among planted shade trees and the cacao, to monocultural, specialized shade, where the shade is dominated by one or a few tree species or genus (genera). Some indigenous shade systems are truly diverse agroforests. However, in most planted systems where a multitude of shade species is found (up to 30–40 in some planted systems), one or a few species generally comprise the "backbone" shade component in which other fruiting and timber species are inserted. Such backbone species, usually fast-growing, nitrogen-fixing legumes, include *Erythrina* spp., *Gliricidia sepium*, *Cassia*, and *Inga* spp. In some areas, cacao is grown under, or intercropped primarily with, fruit and fast-

Figure 1. Cacao shade management systems, showing shade gradient and canopy heights.



growing timber trees. *Zero-shade cacao* (6) cultivation, without shade, is common in Malaysia and becoming more widespread in parts of Colombia and Peru. These three basic systems contribute very differently to the conservation of biological conservation.

BIOLOGICAL DIVERSITY IN CACAO FARMS

Three fundamental questions concerning the relationship between the cultivation of shade-grown cacao and biodiversity are: *i*) How much of the original tropical forest diversity is maintained on cacao farms? *ii*) How does this compare with other agricultural systems? *iii*) What is the role of different cacao management systems in the maintenance of tropical diversity?

Rustic Cacao

A limited body of work upholds the notion that cacao farms with a diverse shade canopy support greater biological diversity, particularly of forest-dependent organisms, than other cash crop systems in the lowland tropics (7–15).

However, even the most diverse rustic shade farms are highly modified compared to natural forest—combining forest generalist and early successional species (7, 16, 17); tropical forest specialists are often missing. For example, one study found only two out of seven forest *Anolis* lizard species in rustic plantations in Costa Rica (18). In Brazil's *cabruca* system, large-bodied terrestrial mammals and larger primates were among the groups underrepresented in the cacao. Rustic cacao bird assemblages lacked many of the specialized understory species, and supported low abundances of foliage-gleaning insectivorous birds, understory frugivores, and relatively high abundances of canopy frugivores and omnivores (19). Rustic cacao farms form highly modified tropical forest systems. The change to the understory is obvious, and the canopy is also dramatically altered. For example, in the *cabruca* management system of Bahia, Brazil, trees and shrubs are thinned to 10% of their original abundance and most lianas removed (19), which substantially reduces plant diversity. More importantly, canopy regeneration is eliminated or the ecological conditions for regeneration are not met, and eventually the naturally occurring trees are replaced by planted trees —often nitrogen-fixing legumes, trees that provide optimal shade, or plants that produce useful fruits, wood, and other products. Management that removes or modifies specific microhabitats (mistletoe, epiphytes, etc.) may cause critical changes in overall diversity. The importance of specific microhabitats to ants and other invertebrates has been underscored in the research of Room (8, 20) and Young, (21, and ref. therein). At the landscape scale, cacao farms suffer from fragmentation and isolation, representing one land-use type within a mixed mosaic of uses. This alone leads to the loss of the original forest species and the increase in habitat generalists—organisms usually associated with disturbed or recovering habitats.

Zero and Planted Shade Systems

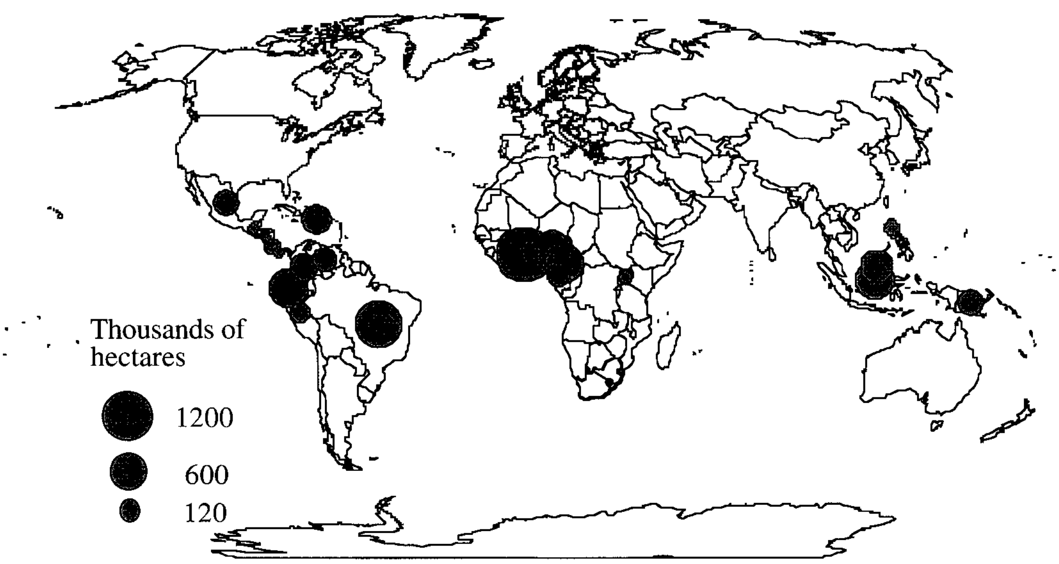
Although little research has examined biodiversity in zero-shade cacao systems, ongoing studies of bird communities in the Peruvian Andes have shown that zero-shade cacao supports a few early successional species (Greenberg, unpubl. data); further, it is reasonable to assume from work in coffee that cacao farms using few or no shade tree species support lower levels of biological diversity and relatively few forest-dependent organisms.

Some work suggests that planted shade systems are less diverse than rustic systems (2). Room (17) speculated that the aboveground ant diversity of Ghanaian cacao farms was substantially greater than that of New Guinea at least partly because the former are small rustic plantations and the latter larger planted shade farms. From studies of the ant-mosaics, there is some suggestion that in plantations of structurally simple shade, fewer ants are able to dominate the habitat more thoroughly (22).

Greenberg et al. (23) found that the bird diversity of cacao plantations in the Gulf Lowlands of Tabasco, Mexico, supported only a modest abundance and diversity of birds, even compared with other agricultural and disturbed habitats. These farms supported almost no resident forest birds, although migratory forest species were quite common. They speculated that the lack of bird diversity may, in part, be a result of the lack of small bird-dispersed fruit in the cacao understory and the shade canopy. However, the Tabasco cacao region has little forest and the lack of nearby natural forest may have played an important role as well.

It is likely that a number of forest organisms can occur in cacao, but require forest for part of their life cycle. A small amount of data (9–13, 19) sustain the concept that rustic cacao systems close to natural forest—particularly large tracts of forest—support substantially greater diversity of forest birds and mammals than those systems isolated from natural habitats. Young (21) has made a similar argument for invertebrates, including some of the pollinators for cacao. In fact, some noteworthy endemic vertebrates found in rustic cacao farms, i.e., the recently discovered Pink-legged Graveteiro, *Acrobatornis fonsecai* and the endangered Golden-headed Lion Tamarin, *Leontopithecus chrysomelis*, seem also to require forest patches and use cacao as a secondary habitat (19, 24).

Figure 2. Major cacao producing countries, hectares harvested.



The implications of this proximity effect are unclear. Cacao farms may be population sinks, unable to support populations of many forest organisms in the long run, but benefiting from periodic emigration from source forest habitats. On the positive side, mobile forest organisms may require resources not present in a protected forest patch on a seasonal basis. This is particularly true for altitudinally migrating birds and insects where forest remains only at higher elevations. Moreover, cacao farms may provide a suboptimal buffer habitat that would promote population stability in the optimal forest habitat. Finally, cacao farms might provide corridors or stepping stones of acceptable habitat for animals dispersing between small forest patches. Shade cacao is being promoted as a corridor forest and buffer zone crop in the Talamancan mountain region in Costa Rica (13). Other areas have been identified where cacao could be used in restoration efforts, as well, in particular as part of a reforestation aims in Vietnam.

In summary, a greater diversity of tropical forest organisms occurs in shaded cacao plantations than in most other lowland tropical agricultural systems. Rustic plantations incorporating natural forest shade trees are probably the best in this regard. However, to the degree that these rustic systems are not stable, they may not provide habitat in the long term. Cacao grown under planted shade may provide the best long-term protection for some tropical forest biodiversity. Systems that incorporate a high diversity of trees with animal dispersed and pollinated fruits and flowers, along with retaining epiphytes, lianas, and mistletoes, will support the greatest diversity. Research on the ecological and agronomic characteristics of trees, as well as an evaluation of their economic value, may help establish arrays of species that, when used, will optimize the economic value of farms and biodiversity conservation. Cacao grown closer to forest supports a greater biodiversity—perhaps forming a buffer habitat for mobile organisms. Cacao farms could be concentrated in the buffer zone of existing reserves or used to form corridors between small forest reserves.

CACAO PRODUCTION AND DEFORESTATION

Cacao production shows rapid expansion in recent decades. In 1970, the global cacao harvest was only 1.5 mill. tonnes on 4.1 mill. ha. By 1995, 3.0 mill. tonnes of beans (25) was harvested from 6.57 mill. ha. This represents a doubling of cacao production and a 50% increase in area cultivated in only 25 years. Current production is concentrated in African, and to a lesser degree Asian countries (Fig. 2; Table 1), particularly Côte d'Ivoire and Ghana, each with more than a mill. ha harvested in 1996 (26).

How has this increase impacted the scarce remaining lowland humid tropical forests? On a worldwide scale, cacao accounts for only (and very approximately) 0.3% of the original tropical forest lands, 1.3% of all forest converted to agricultural lands, and 0.5% of all lands converted from primary forest to agriculture or secondary and degraded forests (27). Cacao's contribution to deforestation varies considerably between regions (Table 3). In particular, 13.4% of the original forestlands of Côte d'Ivoire are now in cacao plantations. Almost one-sixth of the cleared lands is in cacao farms.

Table 1. Cacao area harvested and percent of global area represented, by country, 1996. Source: FAO, 1996 (26).

Country	Area (000s ha)	%Global Cacao Area
Côte d'Ivoire	2150	32.7
Ghana	1200	18.25
Brazil	688	10.47
Nigeria	430	6.54
Cameroon	360	5.48
Ecuador	350	5.32
Indonesia	332	5.05
Malaysia	205	3.12
Dominican Republic	137	2.08
Colombia	124	1.89
Mexico	91	1.38
Papua New Guinea	88	1.34
Venezuela	65	0.99
Equatorial Guinea	60	0.91
Peru	36	0.55
Togo	25	0.38
Sao Tome	24	0.37
Costa Rica	20	0.3
Philippines	16.6	0.25
Uganda	10.5	0.16
Guatemala	4.6	0.07
Panama	4	0.06
Honduras	2.1	0.03
Nicaragua	1.5	0.02
El Salvador	0.4	0.01
Others	149.2	2.27

Note :Total world area harvested in 1996 was 6574000 ha; not all producing countries shown in chart.

Cacao historians generally concur that the expansion of "cacao frontiers" has often occurred at the expense of forestlands. During recent decades, when cacao area expanded upwards of 2.1 mill. ha worldwide, Côte d'Ivoire in West Africa, and Malaysia and Indonesia in Southeast Asia, accounted for some 82% of that growth. During the 1970s and 1980s, approximately 90% of the cacao expansion in Côte d'Ivoire took place in forestlands (Ruf, pers. comm.). In Malaysia, the advance of the cacao frontier into forested areas characterized 60% of the new production zones overall; however, whereas in Sabah and Sarawak 80–90% of the expansion occurred in forests, in peninsular Malaysia, where producers opted to place cacao beneath extant coconut groves, only about 20% of the growth took place in forested lands. In Indonesia, and especially in Sulawesi, the 1980s and 1990s saw about 50% of the cacao area appearing in formerly forested areas (Ruf, pers. comm.). The direct connection between cacao and deforestation, however, must be viewed within the dynamic of other agricultural activities and logging interests. For instance, the alluvial soils of the Indonesian coastal cacao region were previously planted to other crops. In this particular instance, cacao displaced those crops due to the rich soil and favorable rainfall patterns. Moreover, cacao often moved in after logging activity in Indonesia. Thus, approximately 50% of the cacao expansion took place at the expense of forest, with only half of that (25%) being the direct result of small producers advancing into forested zones (Ruf, pers. comm.).

SMALL-SCALE PRODUCERS

With a few regional exceptions, such as Brazil and Malaysia, small-scale producers form the backbone of the industry. Even when the average size of holdings is large, such as in Brazil, those farms at the small end of the size spectrum greatly outnumber larger plantations. Cameroon and Ghana have typical distributions for farm size, with a predominance of holdings ranging in size from less than 1 ha to 5 or 10 ha (see Table 2). In Nigeria, the average farm size is 1.7 ha, in Ecuador it reaches 4.5 ha, and in Côte d'Ivoire, farms average 2.8 ha (Ng, pers. comm.). Brazil, by contrast, has farms larger than 1000 ha and farms average about 28 ha. Yet, for nearly all countries, the small end of the farm-size spectrum dominates the cacao landscape.

In general, small- to medium-sized farms are both more productive (pods per ha) and more efficient (pods per dollar input) than larger corporate holdings (28). Moreover, small producers accomplish this despite government policies favoring larger plantations dating back to colonial times in Asian and African countries (29). Governments in Java and East Sumatra, for instance, delivered the tripod of production—land, labor, and capital—to large producers in efforts to keep estate production costs competitive. Export regulations in Cameroon favored large holdings. And in the Dutch East Indies, state authorities accused smallholders of spreading dreaded pests into estate properties, a charge that resulted in the uprooting of small producers' tree stock. Suitable cacao lands were monopolized by larger holdings in Ecuador in the late 19th century. Even so, small producers around the world have remained competitive despite the institutional obstacles placed before them. Large-scale planters generally paid more for their land, used more expensive labor, and had higher fixed and working capital costs compared to their smallholder brethren (29).

The tendency to favor plantation production over smallholdings, as well as European planters over local residents, derives largely from unquestioned belief by people in government agricultural institutions in western "scientific" growing practices (29). Part of this belief system has held—even until the 1980s in the case of Malaysia—that advantages from economies of scale could be obtained with larger production units. Malaysia provides a textbook case of plantation production. With at least 85% of its production coming from holdings larger than 40 ha (30) upon which high levels of costly agrochemicals are applied, we should expect some ecological and social consequences now commonly attributed to monocultural systems (31–33).

The Malaysian problems involve high production costs (labor, agrochemicals, etc.), the aging of the tree stock, and shortages of labor (34, 35). Regularly scheduled sprayings, whether needed or not, increase production costs. The cost of labor has also climbed as the work force opts for higher industrial wages. Furthermore, prices have dropped in the 1990s and other crops have shown better relative returns; especially oil palm.

In general, small producers tend to have lower per unit production costs. Peasants depend upon and benefit from family labor working long hours and receiving scant pay. But there are other reasons for the greater efficiency of small growers. Smaller farmers are positioned to have an intimate knowledge of their plots. This knowledge and careful tending is ideal for a crop like cacao, a crop often characterized by small plots of 1000 to 3000 cacao trees. As one Malaysian cacao research manager stated, "Cocoa is like horticulture: the planter must almost know each tree" (30). This small-scale approach can result in incredibly high yields. For example, smallholders in Sulawesi obtain up to 2000 kg ha^{-1} of marketable beans; figures rarely achieved by commercial estates (28).

Individual pioneering farmers have often been responsible for the new expansions of much of the world's cacao area. Whenever prices increase, and sometimes even when they do not, pioneering peasant producers turn to cacao as a survival strategy. With low barriers to entry and the crop's ability to produce something with relatively little strenuous labor, it has been classified as an "easy crop" (28). In forested areas, producers benefit from untapped soil fertility—augmented by the burning of aboveground biomass—and the lack of weeds. From the standpoint of a small grower, it is more attractive and profitable to go into a forested area, clear the forest for new planting, and produce therein than to replant areas already devoted to cacao. The fundamental force behind this attraction resides in differential yields and labor demands. A newly cleared forested area produces, at least for the first few years, 15% to 25% higher yields than a replanted area (Matlick, pers. comm.). Moreover, the labor involved in clearing primary forest for cacao *versus* replanting is nearly half. Ruf (36) found in Côte d'Ivoire that forest clearing and preparation required 86 days ha^{-1} of labor, compared to 168 days under a replanting regime.

CACAO CYCLES

As in any agricultural commodity, cocoa suffers periodically from the crisis of overproduction. These wavelike variations lead to global price fluctuations. Cyclical fluctuations in the international price translate, in turn, into boom/bust cycles at the level of production. When prices are high, one or more production zones boom onto the global scene. As supply creeps up, prices fall. Simply stated, prices follow a supply and demand model, whether real or perceived. However, as with other major commodity pricing, the variables featured in the complex price equation all relate in some way to future supply, and include weather

Table 2. Structure of the cacao sector in Cameroon, Ghana, and Brazil, showing number of farms and hectare according to size category of holding.

	Cameroon		Ghana		Brazil	
Size category	Farms	ha	Farms	ha	Farms	Hectares
<0.1	14 200	600				
0.1–0.5	92 300	22 100				
0.6–1.0	57 700	43 700				
<1.0	(164 200)§	(66 400)§	119 850	98 963		
1.1–2.0	65 500	95 000	87 529	159 258		
2.1–3.0	24 100	57 800				
2.1–4.0			84 535	276 532		
3.1–5.0	14 400	54 900				
4.1–8.0			40 330	258 694		
<5.0					401	1350
>5.1	8200	75 700				
5.0–10.0					1031	5674
8.1–20.0			13 323	182 398		
10.0–20.0					2475	19 998
20.0–30.0					2386	25 261
20.1–40.0			1175	37 382		
30.0–40.0					1848	27 512
40.1–100.0*			258	190 062	5030	129 711
100.1–200.0					2043	107 979
200.1–400.0					962	81 777
400.1–1000.0					482	62 020
>1000.1					122	23 738
Total	276 400	349 800	347 000	1 203 280	16 780	485 380

Notes : § This size category for Cameroon is the sum of all smaller ones; this intermediate sum has of course not been added to the total. * this size category is ">40" for Ghana; also size category relates to total farm area whereas "hectares" for Brazil refer only to cacao area cultivated.
Source : Recensement Agricole 1984 Republic du Cameroun Ministere de L'Agriculture Volume 1 (Cameroon); Cocoa Services Division unpubl. data obtained from Dr. Beatrice Padi (Ghana); CEPLAC data provided by Dr. Keith Alger (Brazil).

Table 3. The geography of the global cacao cycle.

Country	Stage in cacao cycle	Comments
Côte d'Ivoire	middle*	little land available for expansion; about 20% of tree stock >30 yrs old; labor difficulties fewer, now that workers are coming in from neighboring countries; low incidence of pest and disease; 66% of cacao unshaded
Ghana	late*	some land available in southwest; nearly half of tree stock >30 yrs old; labor limited but functional; considerable losses from disease and pests; most of the cacao area is managed with shade
Nigeria	late	little land for expansion; 60% of tree stock >30 yrs old; no labor shortage; severe problems with Black Pod, which reduces production up to 70%
Cameroon	late	average land area available for expansion; nearly half of tree stock >30 yrs old; acute labor shortages except in newest production areas; high incidence of disease and pests
Malaysia	middle to late	little to no land left for expansion; tree stock quite young; labor shortage on peninsula
Indonesia	early	considerable land available for expansion; very young tree stock; plenty of labor, except on Sulawesi, where access to workers has become difficult; potential future problems with Cacao Pod Borer
Brazil	late	virtually no land available for expansion; 50% of tree stock >30 yrs old; labor supply good now, but mobile and able to seek higher wages in other sectors—possible long-term shortages; severe disease problems with Witches' Broom

Sources: Ruf, (3); Taylor, (35); John Lunde, pers.comm.
*pending liberalization schemes aimed at reducing/eliminating government price controls could bring higher prices to growers, thus reinvigorating the cacao sector for some period.

and yield forecasts, changing consumption habits, social conditions in producing countries, disease and pest problems, and institutional interventions. Historical data on cocoa show a pricing cycle of about 25 years (36). The development of genetic stock that can tolerate marginal conditions, in conjunction with policies that have allowed for their dissemination with human migration, are also factors favoring boom/bust cycles in cacao (6).

Focusing on the behavior of small cacao producers, Ruf and Zadi (6) present a profile of the regional progression of cacao systems. Placement within the model depends not merely upon how long cacao has been associated with a region, but also upon the management technology used, available labor, and exploitable forest regions (Table 3).

Regions newly opened to cacao show boom periods, during which the harvested area, the number of producers, and exports, all increase as prices remain relatively high. Over a period of 15 to 20 years or more, the aging process of the cacao holdings proceeds, characterized by falling yields that can be linked to increasing disease and pest problems, and decreasing soil fertility. Ecological changes are accompanied by shifts in human demography: migration of landless people slows; emigration may begin; the farm population ages (36).

Establishing a cacao farm involves the use of shade trees to help form an erect habit and provide a windbreak for young cacao trees (5). As the cacao matures, shade is often removed or reduced; shade reduction leads to increased short-term yields, but yields may decline dramatically unless chemical fertilizers are applied (37). The "zero-shade" system is a recurrent temptation, capturing the imagination and hopes of small growers, extension agents, and policymakers. The final stage of the cocoa cycle often finds growers replanting shade to create an agroforestry system. Diversification is a response to the falling cocoa yields and diminished income brought on by continued shadeless conditions. At this stage of the cocoa cycle, farmers may shift entirely to the production of another commodity crop (see ref. 21 for discussion of shifts between cacao and banana production in Central America).

Because of predictably changing ecological and social conditions, regional cacao production is often unstable, moving to agricultural frontiers, areas of primary tropical forest. Although cacao zones of long-term stability do occur (Trinidad, Ecuador), the overall pattern of instability and the search for new lands predominates and needs to be addressed. First, the continued clearing of agricultural frontiers is a threat to biodiversity conservation. Second, concentration of activity at particular frontier regions makes the global cacao crop vulnerable to the invasion of new diseases or pests. And third, there are few forest frontier regions left in the world.

ENVIRONMENTAL BENEFITS OF SHADED SYSTEMS

The impact of cacao cultivation on biodiversity will be minimized if production is focused on already cleared lands, if existing cacao farms show greater long-term stability, and if the farms themselves support greater levels of biodiversity. Improved shade management can address all three of these problems. The greatest long-term incentives for promoting the management of a diverse shade canopy can be found in the ecological and agronomic services provided by the shade itself (38). Many of the long-term economic advantages of shade already exist and need greater recognition. Some of the potential value to be obtained from shade will require research focused on shade management sections.

Shade Trees, Soil Protection, and Crop Health

Shade trees provide protection from the physical impact of precipitation and hence can reduce soil erosion (39–41). The leaf litter from trees provides mulch and a supply of organic matter for the soil. This, in turn, can increase aeration, infiltration, and drainage, as well as result in a slow and steady release of nutrients into the mineral soil. The decaying litter provides resources for a greater diversity of soil and litter organisms, which may be critical in nutrient breakdown and cycling (41). In particular, fungal symbionts such as vesicular-arbuscular mycorrhizae play a key role in the nutrient budget of moist forest understory plants (42) and cacao has long been known to harbor such fungi (43). Depending upon the species involved, shade trees can also fix atmospheric nitrogen and hold it within the soil layer. However, any shade tree can potentially compete with the cacao for nutrients, and wood or fruit products removed from the shade component represent nutrients leaving the agroforestry system (38).

Young cacao plants benefit from the protection of shade trees and the influence shade has on growth form. One study has shown that shade also promotes greater long-term production of older cacao plants with low levels of fertilization (37). Shade trees also serve to lessen the winds at or near ground level within the cacao agroforestry system. Perhaps more important is the protection shade trees can provide from windborne spores of fungal diseases. We have long known that shade reduces the spread of coffee leaf rust (*Hemileia vastatrix*) spores within plots (44). Evans (45) demonstrated the benefits of shade and disease spread in cacao, at least in the cases of Witches Broom (*Crinipellis perniciosa*) and Frosty Pod Rot (*Moniliophthora roreri*). Much more work is needed to untangle the relationship between shade and disease control.

Economic Value of Shade Trees

In agroforestry systems, additional plant species mixed with the target crops can provide an array of valuable products (46–48). In Côte d'Ivoire, cacao producers make use of some 27 mostly wild forest species as shade, 13 of which (48%) provide fuelwood and medicine, 11 of which (41%) offer food products, and 6 of which (22%) are used in construction (49). Researchers (50) showed that low-input cacao systems that include commercial fruit production fare quite well during times of low cocoa prices. The break-even cocoa price for these virtually chemical-free holdings is just over 50% of the price needed to break even in cacao without fruit trees.

Shade trees themselves may also be valuable as timber (38, 51, 52). These trees have low maintenance costs (41). Trials in coffee show that laurel (*Cordia alliadora*), planted at a density of 100 trees ha^{-1}, yields up to 6 m^3 ha^{-1} yr^{-1}. Earnings from timber could compensate for lost coffee yields of 17% when coffee prices are high, of 33% when prices are intermediate, and up to 100% of any lost production when prices are low; likewise, we assume similar earnings could apply to cocoa.

Carbon sequestration is a poorly assessed potential value of shade trees, although Newmark (53) has been exploring the possibility of using emissions trading to provide small farmers with additional economic incentives for shade tree establishment and protection. Some work (15) found mature (40-year-old) cacao agroforestry systems in Cameroon to be fixing carbon at around 154 tonnes ha^{-1}; cacao systems in place for 15 and 25 years show average carbon amounts of 111 and 132 tonnes, respectively. Although these sequestration values are less than for primary forest (307 tonnes ha^{-1}), they are generally greater than for annual crops. Based on fallow periods of 7 year and < 3 years, 106 and 87 tonnes ha^{-1} of carbon, respectively, are sequestered.

The Role of Shade in Pest and Disease Control

Agrochemicals are commonly used to control pests, diseases, and weeds, in cacao holdings (32). In addition to the health and environmental problems this may engender, the chemicals themselves often induce resistance in target species. Capsids

(Miridae), small plant-sucking insects that attack cacao pods and are the vectors of viral disease, developed resistance to aldrin and lindane in the early 1960s in Ghana. Several authorities have suggested that the removal of shade and the spraying of insecticides are two major contributing factors in the development of pest species in cacao (5, 7).

The use of shade can lessen a farmer's dependence on chemicals. Shade usually inhibits weed growth (38), and has also been shown to help control outbreaks of at least one of the important fungal diseases (Witches' Broom, *Crinipellis perniciosa*). In addition, shade reduces the activity of capsids (54,55). Shade is thought to affect the physiology of the cacao plant and the physical environment as well, which affects disease and pest organisms. MacVean (56) has suggested that natural predators of nematodes, which damage plant roots, are dependent upon leaf litter created primarily by shade trees in coffee farms. The role that mycorrhizal and endophytic fungi might play in conferring disease resistance is an active and promising area of research (Herre, pers. comm.).

A central hypothesis in need of much more investigation is that organisms are less likely to reach pest or epidemic proportions in the presence of more complex predator assemblages. Such research is related to the "enemies hypothesis" (57–59), which posits that increased vegetational diversity of polycultures supports a relatively greater abundance and diversity of predators and parasites of herbivorous insects. This explains why herbivore populations are often lower in the same species of plant grown in a polyculture than in a monoculture. Rather than manipulate specific predator-prey relationships, as some have done (60), manipulation of the cacao habitat in order to retain the coevolved ecological relationships characteristic of natural forest should be the first approach to be taken to prevent disease or pest problems.

Much more research is needed to address the role of an increasingly diverse predatory community associated with shade. Trophic relationships are often complex. Ants, for instance, are the most abundant arthropod predators in many cacao farms and the dominant ant species can be important predators. But they also defend homopterans, e.g. mealybugs, which themselves can be pest species. Furthermore, in discussing the role of increased biological diversity in controlling pest and potential pest populations, it should be noted that buffer habitats may also provide resources for pests themselves. In particular, mammals and birds, e.g. squirrels and woodpeckers have been noted to damage cacao pods (61).

SHORT-TERM INCENTIVES

Many of the ecological services provided by shade management play out over time, yet the decisions must be considered in light of short-term profits for farmers. If there is a short-term cost of reduced production associated with shade management, it may need to be addressed by additional market and institutional incentives.

Market Incentives

Recent years have seen the development of the shade coffee concept, followed by a number of efforts to bring such a product to the market. The goal has been both to reward producers through a premium and provide consumers with a product with highly verifiable standards. Conceivably, a similar program could be established for cocoa producers. Among the myriad issues are who pays for and what institutions administer the certification program, of course, how large can the market premium be and who realizes the increase?

Because no shade certification for cacao currently exists, and since the organic standards for cacao include a shade component (62), certified organic ("ecological" in Europe) cocoa is probably the best surrogate for marketable shade cacao. Organic certification confers an added value to the product. However, certified organic cocoa production is in its infancy and currently represents a minuscule fraction of total world production of cocoa. Estimates now put total certified organic area at 8000 ha worldwide, coming mostly from Latin America. Its market share within the United States is less than 1% (USD 15.4 million out of USD 13 billion in the US). In Europe, organic cocoa weighs in with about USD 18.2 mill. in sales (Daniels, pers. comm.). Still, as in the case of coffee, organic cacao is growing rapidly. Between 1990 and 1996, organic foods in general grew by 20% a year (63). The organic chocolate market grew by 36% in 1996/97, with companies like the Organic Commodities Project reporting a doubling in sales within the first six months of 1998 (Daniels, pers. comm.).

Other Financial Incentives

Given that no developed consumer demand now exists for shade cocoa, the emergence of a price premium in the near future is doubtful. But there are other ways to encourage shade grown cocoa. Growers producing cocoa on farms with shade that meets specific criteria related to biodiversity could receive higher prices, inexpensive credit, and relevant extension services through nationally or internationally managed environmental funds. In addition, a tax on agrochemicals could act as a disin-

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centive toward habitat contamination and alleviate worker exposure to toxic chemicals. The taxes, in turn, could go into the aforementioned environmental funds that reward growers for land stewardship meeting biodiversity criteria. Finally, the cocoa industry itself could invest more of its research and development funds to support sustainable cacao initiatives as a way of ensuring stable supplies long into the future (64).

CONCLUSIONS

Cacao cultivation has a complex effect on global biodiversity. Because of continued increasing demands for chocolate, the amount of cacao produced has doubled and the area of cacao cultivation increased over 2.5 mill. ha in the past 25 years. Much of the expansion of cacao production has taken place in areas of primary forest in West Africa and on Borneo and Sulawesi. Even if demand for cacao were constant, cultivation for cacao would continue to involve the clearing of new lands because of the dynamic cacao cycles described earlier in this paper. Cacao is one of many crops that form the first step in a natural progression from forest to agricultural and degraded landscapes.

However, cacao cultivation plays a relatively small role in tropical deforestation on a global scale. Furthermore, cacao farms with diverse shade have the potential to support greater local diversity and act as a more effective refuge for some tropical forest organisms than alternative lowland tropical crops, particularly annual crops and cattle pasture. Therefore, the approach to improving the role that cacao cultivation has in biodiversity conservation should be two-pronged. First, in each cacao-growing region, programs should be established to replant abandoned or failing cacao holdings using diverse shade that is useful to farmers and supports wildlife, as well as to protect remaining forest lands. Second, in regions of new cacao production, farms should be established on already deforested lands so that cacao would provide a mode of reforestation, and particular efforts should be made to incorporate cacao as a buffer zone crop for established forest reserves and parks.

If traditional cacao is to be actively promoted rather than continuing to be simply the result of *laissez-faire* neglect, then a major research and extension effort is required. A comprehensive program needs to be established that will increase the long-term production of small shade-grown farms in a manner that protects biodiversity and addresses the needs of small-scale cacao farmers (65). To ensure adequate and sustained funding, such a program must receive backing from the diverse stakeholders with interests in cocoa, producer groups, traders, manufacturers, etc., as well as from institutions concerned about global biodiversity, rural communities, and sustainable agriculture.

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