Biodiversity in the Cacao Agroecosystem: Shade Management and Landscape Considerations

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Summary

Shade crops, such as cacao, provide habitat for plants and animals normally dependent upon tropical forest. This enhancement of biodiversity in the agricultural landscape occurs primarily on a local scale — providing homes and food for more generalized forest species that are intolerant of pastures or farm fields. Cacao plantations may also play a largely undocumented role in protecting biodiversity at a global scale, when it is cultivated in regions of high endemism suffering from heavy deforestation.

The ability of cacao farms to harbor biological diversity — particularly forest dependent species -- is known for only a few taxa (primarily ants and birds) and from a few sites. Much of what we suspect to be true of cacao farms with respect to biodiversity is based on research in similar systems (primarily coffee) or is inferred from established ecological principles. On this basis, we suggest that 1) overall biological diversity and the diversity of forest dwelling organisms is higher in cacao plantations than non-shade crops or pastoral systems; 2) diversity will increase with an increase in both floristic and structural diversity of the shade level; 3) diversity within cacao plantations will be highest when they are located adjacent to extant patches, corridors, or large tracts of forest. Shaded plantations may play a particularly critical conservation role for migratory organisms (birds and perhaps insects) that arrive seasonally from the Temperate Zone, or from drier or higher altitude zones.

Beyond any general concerns for protecting biodiversity, motivation for farmers to manage cacao holdings to optimize biodiversity are two-fold. First, consumers are increasingly conscious of environmental impacts of their favorite commodities. Since cacao historically has been grown in a biodiversity friendly manner, it may be possible to increase chocolate sales in the rapidly growing "green" or environmental market. Second, within the high levels "unplanned" biodiversity of traditional cacao farms, it is likely we will find many species that perform as unyet studied or quantified "ecological services" such as biological control of pests and disease.

For a program designed to promote traditional shade approaches to cacao cultivation we recommend the following activities:

- The firm empirical establishment of the value of traditional cacao as a conservation tool. The geographic and taxonomic scope of biodiversity surveys needs to be greatly expanded and conducted in a systematically comparative fashion — comparing cacao farms to other agricultural habitats, comparing among different management schemes of cacao, with the emphasis on the ability of cacao to harbor forest-dependent flora and fauna.
- A realistic assessment of the long term stability of populations of forest trees and other organisms (birds, epiphytes, fungi) in traditional cacao plantations.

An evaluation of the selection of shade tree species and the mode of shade management to optimize farm productivity and biological diversity. Research would include a detailed region by region assessment of the use of shade trees by forest organisms of selected major taxa overlaid on information garnered on the silvicultural and agronomic properties of the same tree species, as well as the use and value of tree products.

- A comprehensive testing of the concept that the greater unplanned diversity of traditional farms will dampen the population outbreaks of pest and disease organisms and improve pollination levels.
- The development of a full range of incentives for farmers to grow cacao in a biodiversity friendly manner including fair-trade practices, access to pre-harvest credit, carbon sequestration credits, avitourism, and environmental funds based on taxing agrochemical inputs.

If traditional cacao is actively promoted and does not continue to be simply the result of laissez-faire neglect, then a major research and extension effort will be required. Such a research program, ultimately aimed at improving the long term stability of cacao production, needs to be based on the explicit assumption that traditional cacao plantations are modified forest ecosystems. Because traditional cacao is a modified forest and not a field crop the research needs to be based on both the holistic understanding of the cacao forest ecosystem alongside of more traditional agronomic approaches. It remains to be seen how comfortably the ecological and agronomic approaches to cacao production can coexist.

Introduction

Last year, the interest of tropical conservationists became riveted — albeit briefly —

to the discovery of the Pink-legged Graveteiro (A*crobatornis fonsecai),* a new species and genus of bird, in the cacao plantations of Bahia (Pacheco et al. 1996). The occurrence of this uncommon forest endemic in Brazilian cacao, along with the already well-known, yet endangered Golden-headed Lion Tamarin (*Leontopithecus chrysomelas*; Alves 1990) underscores the role that such plantations might play in the protection of biodiversity. And even before this new bird was described, conservationists concerned with the conservation of migratory bird in the increasingly deforested tropical countryside had identified the promotion of cacao cultivation on forest-like farms as distinctly positive step (Petit et al 1993).

In the face of alarming rates of tropical deforestation, the cultivation of crops under the canopy of diverse shade trees offers a glimmer of hope for the conservation of otherwise doomed biological diversity. Cacao, which evolved as an understory or subcanopy tree of Amazonian forests, is one such crop plant that has traditionally been cultivated under a modified forest or planted shade canopy. The continued cultivation of cacao under a diverse shade canopy will probably enhance, at least on the local level, biodiversity in the tropical agricultural landscape.

However, the continued cultivation of cacao in a relatively biodiversity-friendly manner is by no means assured. In many areas, large tracts of cacao have been converted to low diversity shade or even full sun systems. Meanwhile, small-scale farmers employing the most traditional technologies are struggling to survive low and fluctuating prices and the constant threat of disease and pests. An important question is how much shaded cacao farms can be altered in attempts to improve yields and still maintain the environmental benefits of the traditional systems.

In the face of these economic threats with their day-to-day impact on the well being of millions of farm families, a case has to be made for biodiversity being an important factor in a farmer's decisions concerning plantation management. Outside of the value that farm communities might place on biological diversity, we suggest four factors that might provide incentive for continuing to manage traditional cacao farms to optimize the diversity of forest flora and fauna: 1) an outward appeal to the growing market for products with low environmental impact; 2) the short-term and long-term ecological services — pollination, protection from pests and diseases, reduction in need for chemical fertilizers etc. — that come from managing for biological diversity; 3) economic value that comes from products of the shade canopy plants; and 4) policies or programs that provide non-market incentives that might compensate for any productivity loss to farmers experience by using the traditional shade management techniques.

Before the cocoa growing world embraces the concept of biodiversity friendly coffee anew, a stronger empirical basis for this management approach needs to be established. As a first step towards establishing this basis — in this paper we briefly assess what is well established and what needs further investigation with respect to three critical questions: 1) How well do shaded cacao farms protect biological diversity, particularly species of forest dependent organisms? 2) How does the management of cacao farmland influence levels of biological diversity; and 3) What is the value of biological diversity associated with shade to the production of cacao as a sustainable crop.

A brief overview of the diversity of shade management systems in cacao

Shade component of cacao farms varies from natural forest canopy, to a small number of planted and uniformly trimmed shade species, to largely non-existent — where any required shade is provided by the cacao tree itself (Wood and Lass 1985). Whatever the shade management system, we would argue that shade is more than just another farm attribute, but rather, shade is a central characteristic of farms reflecting the biological and socioeconomic setting of cacao production. Shade management is also strongly related to the degree of agrochemical usage, as well. The following is a brief overview of the shade gradient of cacao farms (Fig. 1).

Rustic Cacao Management

Rustic cacao management, widespread in the humid portion of West Africa and local in northern Latin America (southern Mexico to Brazil and Peru), is characterized by the planting of cacao under thinned primary or older secondary forest. The resulting habitat is in many ways similar to degraded tropical forest in its floral and faunal composition. This is particularly true at the canopy level, where untrimmed epiphytes, mistletoes and lianas support many other organisms.

Planted Shade Systems: Traditional, Commercial, and Specialized Shade

The planted shade system can range from having multiple species of planted shade trees with occasional remnant forest species (*traditional polycultural*), to *commercial shade* where other crop trees are interspersed amongst planted shade trees and the cacao, to monocultural, *specialized where* the shade is dominated *by* one or a few tree species or genus. 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) — generally one or a few species comprise the "backbone" shade in which other fruiting and timber species are inserted. Such backbone species, usually fast growing, nitrogen-fixing legumes, include *Erythrina* spp., *Gliricidia sepium*, *Cassia* spp., *Inga* spp.

In some areas, cacao is grown under or intercropped primarily with fruit trees.

Technified Cacao Systems without Shade

Cacao cultivation without shade is common in Malaysia and becoming more widespread in parts of Colombia and PerÃº. It is also common to cultivate young cacao under a sparse shade of banana. Although no studies have evaluated biodiversity within these "sun" systems, it is likely that they provide little benefit to biodiversity conservation.

Abandoned Cacao Plantations

As a result of political instability, disease problems and low prices cacao farms are sometimes abandoned where cocoa may sometimes be harvested but all serious farm management ceases. Because the cacao farm gradually reverts to secondary forest, with the asociated forest faunal and flora, abandoned cacao may be particularly valuable for biodiversity conservation. Such a pattern of succession is probably more common for diverse shaded systems that are close to forest or forest patches (see Heinen 1992 for study of reptiles and amphibians).

Biodiversity in Cacao Plantations — The Concepts

Focusing the spotlight on the role of cacao plantations in the protection of tropical diversity reveals a promising avenue of research and management. But the current assessment of this diversity is based in a weak scientific edifice. Published research is taxonomically, geographically, and thematically scattered. In our attempts to briefly review what is known, we will emphasize some of the organizing concepts of biodiversity research (Table 1) and then place the extant literature into this framework (Table 2).

Relevant Comparisons

Scattered through the cacao research literature are studies of the numbers of species in various taxa found in particular farms or farming regions. However, because studies have no comparative focus, they often are of limited utility in addressing the core question of how well cacao protects biological diversity and how this protective role varies with different management strategies. Important comparative paradigms in such studies are 1) how do cacao farms compare in diversity and faunal and floral composition to alternative agricultural land uses; 2) how do cacao farms compare in these parameters to comparable natural forest; and 3) how do cacao farms with different management systems compare with each other.

Regional versus Global Diversity

The enhancement of **regional diversity** through protection of tropical forest organism in a particular area may or may not make a significant contribution towards the conservation of **global diversity** by protecting extinction-prone species depending upon the degree that those organisms survive and prosper in plantations, the amount of locally extant natural forest in the area, and the overall degree of faunal and floral endemism in the region. For example, cacao farms may play a more important conservation role in deforested Andean valleys and the Atlantic forests of eastern Brazil than in a heavily forested portion of the Amazon Basin proper.

Planned Versus Unplanned Diversity

The term biological diversity may conger up divergent images to people with different training and interests. Agronomists may think primarily about the diversity that, through planting or selective clearing, the farmer intends to be present in the farm. To a large degree the diversity of the shade trees themselves is often the intended result of farm management. This aspect of diversity is termed **"planned diversity"**. The thousands of other species, from microbes to monkeys, that visit or reside on the farm compose the

"unplanned diversity".

Parameters of Diversity and "Conservation Value"

The simplest parameter to examine is **species richness** (or species diversity which incorporates information on species-abundance patterns). Although species lists are the most readily available statistic, it may be the most misleading and difficult to interpret.

First, a habitat may have a long species lists - most of which involves generalist species or species that adapt easily to human disturbance. In the case of cacao, we should examine any list to determine the degree to which species sensitive to tropical deforestation can occur in cacao farms. So probably a better indicator of the conservation value of cacao farms would be the **forest species richness.**

Species richness and forest species richness are much less straightforward measures than they seem. Unlike abundance estimates, which become more precise with sampling effort, species richness generally increases and it is difficult to extrapolate between two qualitatively or quantitatively different censusing efforts. Species richness can be compared for equivalent efforts or the curves of the species numbers that accumulates with effort or area sampled can be examined. Other more sophisticated estimation procedures (rarefaction) are available. The important consideration is that the survey work needs to be based on a standardized and repeatable protocol. Another key issue when considering raw species numbers is that the biological significance of a habitat is hard to evaluate simply on the basis of a species presence or absence, particularly for mobile organisms where individuals wander out of typical habitat from time to time (Remsen 1994). It is useful to think of **core species richness** to biota — those that either reproduce or occur regularly and predictably in a habitat. Ultimately we wish to know the long-term fate of forest species that reside in cacao plantations, what we might think of as the **sustained diversity**.

Scale: the micro and macro of tropical diversity

Although studies of diversity on cacao farms tend to focus at the level of the farm and farm management, the basis for diversity of any habitat needs to be addressed at various levels of scale. On the micro-scale, tropical forest ecosystems — of which a shaded cacao farm is a highly modified form — consists of a large number of microhabitats, each of which supports a high diversity of specialized organisms. In addition, many organisms depend upon these microhabitats for a critical stage in their life cycle. Management that removes or modifies any of these microhabitats can potentially cause critical changes in overall diversity. Consider the "aerial leaf litter" — an example from my own research on Neotropical lowland forests. A number of birds specialize in foraging from leaves of canopy trees that hang in understory shrubs and vines. If one collects arthropods from these leaves, the collection reveals a community of arthropods that live only, or primarily in this microhabitat as well. Many other arthropods — particularly Orthopterans — rely upon these leaves as diurnal hiding places. Manipulation of understory to remove lianas or dense vegetation will impact this microhabitat and overall diversity in, as yet unknown ways. The same argument can be made for epiphytic plants, various forms of dead wood, etc.

On the macro-scale, the size and configuration of a habitat patch and its spatial distribution with respect to existing forest (and the size and configuration of that habitat as well) exerts tremendous influence on the diversity of the target patch. It is likely that a number of forest organisms can occur in cacao, but require forest for part of their life cycle. In many areas, cacao is grown on tiny parcels mixed in with many other crop types, rather than as contiguous bands of habitat, making it difficult to conduct standard censuses on vertebrates and other taxa with large home ranges.

Seasonality and Phenology

Seasonality is a central issue in the study of most terrestrial habitats — including those located in the humid tropics. Most tropical areas experience a seasonal rhythm in rainfall and those closer to the poles receive weather systems from higher latitudes. This seasonality drives phenological peaks and valleys of leaf flush, flower and fruit production and variation in humidity and soil moisture. Diversity must be assessed throughout the phenological cycles for species with limited activity periods and mobile species (such as nectarivorous birds) that visit plantations in particular seasons. Few studies of cacao have explicitly addressed this issue (but see Gibbs and Leston 1970).

Focal Taxa

Although we bandy about the term "biological diversity," most studies, in fact, have a taxonomic focus or set of foci. Ecologists are becoming increasingly concerned with the concept of indicator taxa. That is simply to say that the response of most disturbance sensitive organism may or may not be extrapolated from data gathered from birds, trees, or whatever happens to be the taxonomic specialty of the investigator. We are grateful for even the sparing literature, so it is hard to second-guess the particular taxonomic focus. On the other hand, as future studies are planned - some time should be invested in selecting representative and important taxa. Criteria for selecting taxa of study include:

- Well-known and well-loved taxa: Birds are a prime example of taxa that is disproportionately the focus of research on biological diversity. In the case of cacao this has two advantages. First, birds ecology and distribution is relatively well known and the census techniques established so that data on birds can be evaluated and placed into a broader ecological context. Second, birds are well known and loved by the chocolate-eating public and hence information about birds may prove useful interesting consumers in issues of biodiversity in cocoa production.
- Taxa most likely to fail: certain groups of animals are, because of their behavior and demography, more extinction-prone than others. Focus on these taxa would provide information on the limits of cacao plantations as a conservation tool.
- Taxa most likely to succeed: Cacao plantations may be particularly important for the conservation of certain taxa with ecological requirements satisfied by small patches of highly modified forest habitat. These taxa would include such groups as bromeliads, sedentary arthropods, and amphibians, where populations can persist in preserved canopy environments of limited extent. Long distance migratory birds is a another group where the forest-dependent species are capable of persisting in relatively small and disturbed forest patches.

- Indicator taxa: a research program on biodiversity may select taxa that are representative of the more complete spectrum of biodiversity. Such a selection should focus on taxa for which the systematic is reasonably well known and taxonomic specialists are available.
- Taxa with specific functional significance: an ecological guild is composed of species that perform a similar ecological function. Such guilds can be based on growth form or trophic relationships or shared dispersal and pollination characteristics. Research that strives to integrate the study of biodiversity and the functioning of the cacao ecosystem should be focused on all taxa that constitute a guild and priority would be set by functional importance. For example, herbivorous arthropods are consumed by birds, bats, lizards, ants, and spiders and parasitized by a number of arthropod groups. Ultimately the diversity of all of these groups should be examined to evaluate the role of unplanned biodiversity in the population dynamics of pest or potential pest insects. However certain groups — such as ants (which make up 10-33% of arthropod biomes of cocoa farms, Majer 1994) and spiders (Robinson and Robinson 1974) because of their abundance, and birds and bats because of their size and high energy demands — would have greater intrinsic functional significance and be a higher priority for research. Add to these, the parasitic and hyperparasitic Hymenoptera that by virtue of their diversity and specialization may play a key role in maintain populations of potential pests in check.
- Keystone taxa: Certain groups of organisms are central to the maintenance of diversity of many other groups. In particular, trees, shrubs and epiphytes provide homes and food for many other taxa that require diversity in these groups to support ecological specializations.

Some Results of Research on Biodiversity in Cacao Farms

1. Trees and shrubs are thinned to 10% of their original abundance and lianas eliminated in the *cabruca* system of Bahia (Aves 1990 for this section). Because of this, plant diversity is substantially reduced and modified by human management. More importantly, regeneration is eliminated and eventually the naturally occurring trees are replaced by those planted. Among mammals, large-bodied terrestrial mammals and larger primates were among the groups underrepresented in the cacao. Cacao plantation bird assemblages lack many of the specialized understory species and supported low abundances of foliage insectivorous birds and high relative high abundances of canopy frugivores and omnivores.

2. The Smithsonian Migratory Bird Center has been surveying the composition and diversity of birds in both natural and anthropogenic systems in Southeastern Mexico for the past decade. We have worked in cacao plantations in two distinct landscapes using very different farm management strategies. The first are small rustic plantations in the buffer zone of the Montes Azules Biosphere Reserve in the Selva Lacandona of eastern Chiapas. The second is the planted shade of the more extensive cacao zone of the lowlands of Tabasco on the southern Gulf Coast of Mexico. The species richness of the Selva Lacandona cacao plantation (142 species in 20 transect survey weeks) was most similar to forest or disturbed forest habitats (118-149) and considerably lower than pasture/open agricultural habitats (20 - 100 species). A high proportion of the common species — both resident and migratory -- were shared with undisturbed tropical forest (36 forest breeding species) The planted shade farms of Tabasco supported a considerably lower numbers of bird species than rustic cacao (84

species found in 220 point census a comparable census effort to the above transect data) — with virtually no forest breeding species (5 species of vanishingly low abundances). Migratory species fare better than ecologically similar residents. Some forest-dependent migratory species — such as Wood Thrush, Kentucky Warbler, male Hooded Warbler and American Redstart were common. These results with migatory birds support the conclusions of a ground-level mist-netting study of cacao grown under *Erythrina* in Belize (Robbins et al. 1992). In this study, the cacao had the most similar migrant assemblage to natural forest of several crop types. In the Mexican study, we cannot easily tease apart to landscape and management effects, but we can present the information on the avifauna of these systems as best and worst case scenarios for the value of cacao in tropical forest bird conservation.

3. A small amount of data (Alves 1990 Parrish and Reitsma unpubl.), supports the concept that cacao grown close to natural forest — particularly large tracts of forest — support a greater diversity of forest birds and mammals than those that are isolated from natural habitats. Young (1994) has made a similar argument for invertebrates — including some of the pollinators for cacao. In fact, the endemic vertebrates mentioned in the introduction (furnariid and tamarin) seem also require forest patches and can only use cacao as a secondary habitat (Alves 1994, Pacheco et al. 1996).

4. The ant assemblages of cacao farms comprise a complex three dimensional mosaic of dominant territorial species each with a distinct set of associated subordinate species (Room 1971, Leston 1973, Majer 1993, 1994). This pattern of community organization is similar to that found in natural forest (where it has been compared). There is some suggestion that in plantations of structurally simple shade, fewer ants are able to more thoroughly dominate the habitat.

5. Bats, non-volant mammals and birds were compared between isolated rustic cacao plantation, other agricultural habitats (shaded and non-shaded) and forest patches in Las Tuxtlas, Veracruz, Mexico (Estrada et al. 1993a, 1993b, 1994, 1997). Cacao supported high abundances and relatively high numbers of species in these different groups. For some taxa, cacao supported the second highest species richness — behind natural forest fragments. Overall, plantations had higher diversity where they were closer to natural forest patches.

The importance of specific microhabitats (mistletoe, epiphytes etc.) has been underscored by research of Room (1971, 1972) and Young (1994 and ref. therein).

6. We were able to locate few systematic survey of biodiversity comparing cacao plantations and forest or other habitats in Africa or Asia. Room (1975) compared terrestrial ant assemblages across habitats in Papua, New Guinea and reported that cacao and rubber plantations most closely approached forest in species richness. Room noted that the high diversity in the tree plantations is comprised of early and late successional species. Room (1973) speculated that the above-ground ant diversity of Ghanaian cocoa farms was substantially greater than those of New Guinea, because the former are small rustic plantations and the latter larger planted shade farms. Leston (1970) cites several studies suggesting high diversity insects in cacao plantation including Lepidoptera (174 species in Ghanaian plantations) and Coleoptera (56 genera of beetles in West African), also noting that the high diversity results from a mixture of species characteristic of forest and open farmland. Room (1971) found an ant fauna in the cocoa farms of Ghana that approached natural forest in its diversity. T. Smith (pers. comm.) has a large database from mist-netting birds in plantations of Cameroon and notes that the diversity and abundance of forest birds is relatively high. Latinos and Smith (1992) found that although some endemic

species occurred in cacao plantations of Book and Cameroon, the most common species in the former site were characteristic of disturbed habitats.

Overview

The most striking feature of the published research so far is its paucity. Systematic studies of otherwise well-studied taxa are all but lacking from Africa and Asia (regions of origin of over 80% of the world's cocoa). Some quantitative and a fair amount of qualitative information supports that idea that rustic cacao supports a modified forest flora and fauna — combining forest and open country species. A very small amount of data — and a lot of common sense -- suggests that planted systems using a few species of dominant shade tree support far less diversity than rustic systems. However, the comparative study of different management systems is wide-open fields for future research. Furthermore, outside of a few studies primarily on invertebrates, the evaluation of the contribution of specific microhabitats and tree species has not been accomplished. These are the sorts of studies that will be most useful for making concrete recommendations on the effect of shade management on biodiversity.

Lessons from the coffee ecosystem

Insights into the management of Cacao plantations need not be restricted to the sparse information garnered from cacao plantations. Other shade grown crops, particularly coffee, share many of the same management patterns and are often times simply replacement habitats on an elevation gradient. Interpreted with some caution, the somewhat greater volume of research on the effects of different shade management systems in coffee should be consulted in designing research and management for cacao. Based on a review research on biodiversity and shade management of coffee (mainly Perfecto et al. 1996), we can garner the following insights — which have been used to develop specific field criteria for ecologically sustainable coffee:

- Diverse shade coffee plantations support a relatively high diversity of birds, mammals, reptiles, insects, epiphytes etc. In part, this diversity is a unique combination of early succesional and forest species. However, shade plantations, to varying degrees, do protect forest species.
- Bird diversity, epiphyte diversity and presumable the diversity of other groups and the relative representation of forest species increases with the increased vertical stratification of arboreal vegetation. In particular, the presence of even a small number of tall trees (>15 m) greatly increased diversity.
- Planted (*Inga* spp.) and rustic plantations of similar stature supported similar levels of avian diversity — but the rustic had a higher proportion of specialized forest species.
- Diversity of frugivores and nectarivores increases with the diversity of flowering and fruiting trees — vertebrates that do particularly well include hummingbirds, tanagers, and fruit and flower feeding bats. Plantations may be important to migratory organisms (both long distance and altitudinal) by providing a habitat with an abundance of fruit and flowers in the canopy during the tropical dry season.
- Greater floristic diversity provides more diverse and seasonally available floral and fruit resources. In this regard, trees with long or year round fruiting and flowering (such as *Ficus*) maybe particularly important.

- Shade trees with perennial foliage supports greater bird abundance and diversity, particularly during the critical dry season months.
- The presence of dead and rotting wood in trees and on the ground contributes considerably to diversity, particularly invertebrates.
- The presence of parasitic plants (mistletoes) and epiphytes contributes substantially to diversity by providing shelter, nest sites, flower and fruit resources.
- Terrestrial arthropods — particularly ants — are much more diverse in the presence of shade, presumably due to climatic buffering and the presence of leaf litter.
- Large bodied vertebrates and species dependent upon viny vegetation and undisturbed understory do no persist well in even rustic plantations.
- Parasitic and hyperparasitic Hymenoptera retain a disproportionately high level of diversity in shaded versus monocultural coffee plantations.
- The presence of weedy and shrubby areas contributes substantially to avian diversity and presumably to the diversity of other groups as well.
- Plantations located closer to extant forest support a high diversity of forest birds than more isolated plantations.

The Value of Biological Diversity in the Production of Cacao

Up to this point we have been discussing ways in which cacao farms can promote biological diversity. To what degree can we argue that managing for biological diversity in general and specific types of organisms in particular can enhance the functioning of a cacao farm? It is fashionable to call such relationships between the natural world and our own economic interests "**ecological services**". If we can be allowed a bit of characterization, we would like to contrast three views of how to treat ecological services or more generally the role of nature itself in the production of crops:

- Replace nature. Certainly a dominant viewpoint of the latter part of this century, ecosystem functions — such as the regulation of populations of pest and disease organisms — are replaced by human technological approaches.
- Selective use of nature. The viewpoint underpinning Integrated Pest Management, the natural system is studied and particular biological control agents introduced or encouraged to control specific problems.
- Holistic ecological (organic) management of nature. Management of ecosystem so that trophic structure and mutualistic relationships are kept as intact (similar to natural forest) as possible — resorting to specific control strategies as a last resort. The pests and pestilence would come indirectly through the management of vegetation.

The following is a cogent description of a more holistic ecological view of disease control:

"Many of the pods of cacao forest were stained with the handiwork of *Monilia* and *Phytophthora* diseases. Abandoned cacao plantations are reservoirs for fungal organisms that attack cacao pods. In the pristine rainforest, the fungi would just be a small part of a complex balancing act imposed by networks of specialized predator-prey associations, which dampen the tendency for most species to proliferate. But vast monocultures of cacao are sitting ducks for sweeping infestations of such organisms." (Young 1994:136).

We believe that more emphasis should be placed on the third view of nature on cacao farms. It should also be noted that the holistic ecological view is philosophically similar to the underpinnings of the organic agriculture movement. However, the concept that the cacao ecosystem should be managed for biological diversity should not be based simply on some philosophical love of nature but on evidence garnered from scientific research. Here we discuss several areas of promising research:

Pollination

Probably the best worked-out example of indirect effects of ecosystem-level management on cacao production is in the area of pollinator diversity. The work of Young (1994) and others suggest that the natural pollinators (Ceratopogonid midges) require microhabitats for breeding — including rotting cacao fruit -- that are often removed from highly-managed Cacao plantations. Pollination may actually be highest when cacao is grown adjacent to natural forest vegetation.

Pest Control

Probably the most obvious ecological service provided to the cacao farms is the possible biological regulation of pest or potential pest insects. The general hypothesis that we put forth is that populations of organisms are less likely to reach pest or epidemic proportions in the presence of high levels of biological diversity. Rather than manipulate specific predator-prey or other relationship, the manipulation of the cacao habitat to retain the coevolved ecological relationships characteristic of natural forest is the first approach to be taken to prevent disease or pest problems. Although natural predators, such as the Black Cocoa Ant (*Dolichoderus thoracicus*) of Southeast Asia, are often used in specific Biological Control programs (Khoo and Ho 1992), it has also been suggested that the natural "ant mosaic" is generally effective at reducing pest problems (Room 1971, Leston 1973, Majer 1994). Outside of the work on ant mosaics there seems to have been little research conducted on the interaction between the assemblage of natural predators and symbionts with pests and disease organisms — real or potential.

Most studies of the impact of natural predators on arthropods in agroecosystems have focused on the control of particular pest species (Kirk ET al., 1997). For cacao, major pests would include Cocoa Pod Borer (*Conopomorpha cramerella*), Mealybugs (*Planococcus* spp.), Mirids, and the Cocoa Beetle *(Steirastoma breve*) and each region has a host of minor pest as well. Minor pests reach epidemic population levels much less often than do the major pests. Controlling pest insects has been the focus for research on predator- insect interaction in forest ecosystems*.* However, recent work on the impact of bird predation on the herbivorous insect community as a whole has suggested that birds play an important role in preventing non-outbreak populations and species from substantially reducing the growth rate of forest trees (Marquis and

Whelan 1994). Furthermore, predators — including not just birds, but bats, spiders, ants, parasitic wasps and many other groups -- may be much more important than previously thought in preventing species from achieving pest status to begin with. If a diverse web of predators does confer stability on herbivore populations, then some management issues become important. 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 (Leston 1970, Wood and Lass 1985). Shade removal has been shown to have a direct impact on capsids, but the presence of canopy vegetation may have an indirect effect as well. Both shade removal and application of chemicals probably reduce the abundance and diversity of potential predators and parasitoids and provide prima facie evidence supporting the ecological view of population regulation. In many ways, the management of biodiversity through shade management is analogous to the use of natural buffer vegetation for field and orchard crops (see Altieria and Letourneau 1982*).*

Nutrient Cycling and Disease Control

The impact shade on leaf litter and soil components of the cacao agroecosystem provides some exciting possibilities. The leaf litter and the climatic protection of the shade trees create an environment that may support a greater diversity of natural predators as well. McVean (1992) has suggested that natural predators of nematodes, which damage plant roots, is housed in the leaf litter created by shade trees in coffee farms. Of course, the diversity of soil and litter organisms is critical in nutrient breakdown and cycling. In particular, fungal symbionts such as vesicular-arbuscular micorrhizae (VAM) play a key role in the nutrient budget of moist forest understory plants (Janos 1980) and cacao has long been known to harbor such fungae (Laycock 1945). Micorrhizae and endophytic fungi may play an unrecognized role in conferring disease resistance (Herre pers. comm.), certainly a central issue for economically sustainable cacao production. Factors that effect fungal and microbial diversity are poorly known. The study of the role of these naturally occurring organism can take the more focused approach, searching for specific species or groups of species that effect particular disease organisms, and at the same time a more holistic ecological approach of examining how the entire community functions and in what ways we can manage the system to maintain the original forest-like diversity.

Research and Management Recommendations.

An assessment of what is known and not known concerning shade management and biodiversity of cacao farms is presented in Table 1. The following are major recommendations that follow from this analysis:

Management

(assuming that natural or "unplanned" biodiversity needs to be optimized)

- Use structurally and taxonomically diverse shade of native species.
- Leave buffer zones along streams and property boundaries of native vegetation.
- Leave epiphytes, lianas and parasitic plants in shade tree canopies.
- Retain standing dead wood.
- Weed in a manner to protect some forest tree regeneration.

- Encourage shade cacao farms as a buffer zone crop adjacent to forest reserves.
- Form corridors of habitat — particularly on mountain slopes — consisting of forest patches, cacao farms (lower elevation) and coffee farms (higher elevation).
- Encourage cacao farming with native forest trees in regions lacking protected forest. Development of a full range of incentives for farmers to grow cacao in a biodiversity friendly manner including fair-trade practices, access to pre-harvest credit, carbon sequestration credits, avitourism, and environmental funds based on taxing agrochemical inputs.

Research

- Establish of the value of traditional cacao as a conservation tool. The geographic and taxonomic scope of biodiversity surveys needs to be greatly expanded and conducted in a systematically comparative fashion — comparing cacao farms to other agricultural habitats, comparing among different management schemes of cacao, with the emphasis on the ability of cacao to harbor forest-dependent flora and fauna.
- Assess of the long-term stability of populations of forest trees and other organisms (birds, epiphytes, and fungi) in traditional cacao plantations.
- Evaluate the selection of shade tree species and the mode of shade management to optimize farm productivity and biological diversity. Research would include a detailed region by region assessment of the use of shade trees by forest organisms of selected major taxa overlaid on information garnered on the silvicultural and agronomic properties of the same tree species, as well as the use and value of tree products.
- Continue to test the concept that the greater unplanned diversity of traditional farms will dampen the population outbreaks of pest and disease organisms and improve pollination levels.

References

Altieri, M. A., Letourneau, D. K. Vegetation diversity and insect pest outbreaks. CRC Critical Reviews in Plant Sciences 2:131-169.

Alves, M. C. 1990. The role of cocoa plantations in the conservation of the Atlantic forests of southern Bahia, Brazil. M. S. thesis. Univ. of Florida. Gainseville, Florida.

Estrada, A., R. Coates-Estrada and D. Merritt, Jr. 1993. Bat species richness and abundance in tropical rain forest garments and in agricultural habitats at Las Tuxtlas, Mexico. Ecography 16:309-318.

Estrada, A., R. Coates-Estrada, and D. Meritt Jr. 1994. Non flying mammals and landscape changes in the tropical rain forest region of Los Tuxtlas, Mexico. Ecography 17: 229-241.

Estrada, A., R. Coates-Estrada, and D. A. Merritt., Jr. 1997. Anthropogenic landscape changes and avian diversity at Los Tuxtlas, Mexico. Biodiversity and Conservation 6: 19-43.

Estrada, A., R. Coates-Estrada, D. Meritt Jr., S. Montiel, and D. Curiel. 1993. Pattern of frugivore species richness and abundance in forest islands and in agricultural habitats at Los Tuxtlas, Mexico. In: T.H. Fleming and A. Estrada (eds.): Frugivores and Seed Dispersal: ecological and evolutionary aspects. Kluwer Academic Publ. Dordretch, The Netherlands, pp. 245-257.

Gibbs, D.G. and D. Leston. 1970. Insect phenology in a forest cocoa-farm locality in West Africa. Journal of Applied Ecology 7: 519-548.

Greenberg, R., P. Bichier, A Cruz, etc. MS. The impact of bird insectivory on herbivorous arthropods and leaf damage in some Guatemalan coffee plantations.

Greenberg, R., J. Salgado, I. Warkentin, and P. Bichier. 1995. Managed forest patches and the conservation of migratory birds in Chiapas, Mexico. In: Conservation of Neotropical Migratory Birds in Mexico, Symposium - Workshop Proceedings. Wilson, M.H. and S.A. Sader, eds.. Maine Agricultural and Forest Experiment Station Misc. Publication 727. pp. 178 - 189.

Heinen, J.T. 1992. Comparisons of the leaf litter herpetofauna in abandoned cacao plantations and primary rain forest in Costa Rica: Some implications for faunal restoration. Biotropica 24(3): 431-439.

Janos, D. P. 1980. Vesicular-arbuscular mycorrhizae affect lowland tropical rain forest plant growth. Ecology 61: 151-162.

Khoo, K. C. 1192. The influence of *Dolichoderus thoracicus* (Hymenoptera: Formicidae) on losses due to *Helopeltis theivora* (Heteroptera: Miridae), black pod disease, and mammalian pests of cocoa in Malaysia. Bull. Entom. Res. 82:485-491.

Kirk, D. A., M. D. Evenden, Pierre Mineau. 1997. Past and current attempts to evaluate the role of birds as predators of insect pests in temperate agriculture. Current Ornithology 13, 175-269.

Larison, B. and T. B. Smith. 1996. A survey of montane and lowland birds from three sites on the island of Bioko, Equatorial Guinea. Report to the government of Equatorial Guinea.

Laycock, D. H. 1945. Preliminary investigations into the functions of the endotrophic mycorrhiza of *Theobroma cacao* L. Tropical Agriculture, Trinidad 22:77-80.

Leston, D. 1970. Entomology of the cocoa farm. Annual Review of Entomology 273-294.

Leston, D. 1973. The ant-mosaic-tropical tree crops and the limiting of pests and diseases. Pest Articles and News Summaries 19, 311-341.

MacVean, C. 1992. Causas y naturaleza del mal de viñas en cafetos de Guatemala. Publ. Instituto de Investigaciones, Universidad de Guatemala.

Majer, J. D. 1993. Comparison of the arboreal ant mosaic in Ghana, Brazil, Papua New Guinea and Australia -- its structure and influence on arthropod diversity. Pp. 115-141 in J. LaSalle and I. Gould (Eds.). Hymenoptera and biodiversity. CAB International. Wallingford, Majer, J. D. 1994. Arboreal ant community patterns in Brazilian cocoa farms. Biotropica 26:73-83.

Marquis, R. J., Whelan, C. J. 1994. Insectivorous birds increase growth of white oaks through consumption of leaf-chewing insects. Ecology 75, 2007-2014.

Pacheco, J. F., B. M. Whitney, and L. P. Gonzaga. 1996. A new genus and species of furnariid (Aves: Furnariidae) from the cocoa-growing region of southeastern Bahia, Brazil. Wilson Bulletin 108: 397-606.

Petit, D.R., Lynch, J.F., Hutto, R.L., Blake, J.G., and Waide, R.B. 1993. Habitat use and conservation in the Neotropics. Pp. 145-197 *in* Martin, T.E. and Finch, D.M. (eds.). Ecology and management of Neotropical migratory birds: A synthesis and review of critical issues. Oxford Univ. Press.

Perfecto, I., Rice, R.A., Greenberg, R., Van der Voort, M. 1996. Shade coffee: A disappearing refuge for biodiversity. Bioscience 46:598-608.

Remsen, J.V., Jr. 1994. Use and misuse of bird lists in community ecology and conservation. Auk 111: 225-227.

Robbins, C.S., Dowell, B.A., Dawson, D.K., Colon, J.S., Estrada, E., Sutton, A., Sutton, R, and Weyer, D. 1992. Comparison of Neotropical migrant landbird populations wintering in tropical forest, isolated forest fragments, and agricultural habitats. Pp. 207-220. In Hagan, J.M. III, and Johnston, D.W. (eds). Ecology and conservaton of Neotropical migrant landbirds. Smithsonian Inst. Press.

Robinson, M., Robinson, B. 1974. A census of web-building spiders in coffee plantations at Wau, New Guinea, and an assessment of their insecticidal effects. Tropical Ecology 15:95-107.

Room, P.M. 1971. The relative abundance of ant species in Ghana's cocoa farms. J. Anim. Ecol. 40:735-751

Room, P. M. 1972. The constitution and natural history of the fauna of the mistletoe *Tapinathus bangwensis* (Eng. and Krause) growing on cocoa in Ghana. J. Anim. Ecol. 41:519-535.

Room, P. M. 1975. Diversity and organization of the ground foraging ant faunas of forest, grassland and tree crops in Papua, New Guinea. Aust. J. Zool. 23:71-89.

Wood, G. A. R. and R.A. Lass. 1985. Cocoa. Longman. London and New York.

Young, A. 1994. The chocolate tree. Smithsonian Institution Press. Washington, DC.

Table 1. Recommendation Matrix for Shade Management and Shade Management Research

	Bird Diversity and Overall Biodiversity
I. Presence of Shade Trees	1. **We know** — based mostly on studies of coffee —that for a number of taxonomic groups, diversity increases with the presence of shade trees. The proportion of forest or woodland species also increases with the presence of a shade canopy. The reason for these increases is the presence of new habitat structures, as well as the amelioration of microclimate and the presence of more, different food sources to support greater diversity at low trophic levels (which in turn supports greater diversity at higher trophic levels). In birds and ants, low structural diversity many allow few aggressive species to dominate. 2. **We suspect** that the diversity and composition of the associated flora and fauna increases in predictable ways with increases in the structural and floristic diversity of the plantations and (up to a point) with total canopy cover. 3. **It is possible** that increased complexity of trophic and other ecological relationships dampens the occurrence of pathogen or pest outbreaks. 4. **We recommend** that in order to support higher levels of biological diversity, cocoa be grown under a shade canopy. We further recommend that this canopy be as floristically diverse as practical. Research is required in different regions to establish the relationship between shade levels and tree composition to the diversity of some selected taxa (i.e., epiphytic plants, Lepidoptera, birds) that represent different levels of vagility, forest dependence etc. We further recommend that the efficacy of natural predation and disease resistance on pests and pathogens be studied under different shade regimes.
II. Forest (Rustic) Shade Canopy	1. **We know** from studies of both coffee and cocoa that a shade management system with thinned forest trees resembles a degraded form of natural forest, with a higher level of diversity of birds, trees, epiphytes etc. than any other shade management system. 2. **We suspect**, based on some narrower studies, that (1) is also true for cacao. We further suspect that a canopy of thinned primary forest supports more of the local forest specialist species than managed secondary forest. 3. **We do not know** the influence of different levels and strategies of tree thinning on diversity. Further, there have been no studies of the long-term equilibrium diversity under different landscapes and cacao plantation size (assuming there is an equilibrium). Because of poor reproduction (due in part to weeding in the case of trees) species populations may not be self-replacing. We do not know under what circumstances the management of forest for cacao is the ultimate cause of habitat degradation or is an alternative to destruction. 4. **We recommend** that cocoa be grown under managed natural forest whenever feasible. However, we do not recommend that new large tracts of forest be managed for cocoa production until further study - on a region by region basis - of how cocoa growing impacts forest protection. We recommend long-term and experimental studies on the stability of rustic cocoa farms as ecological systems.
III. Floristic Diversity of Planted Shade Canopy	1. **We know** that based on few empirical studies and ecological principles, there is a positive relationship between the diversity of shade trees and bird diversity. We suspect that many groups will show enhanced diversity as well. 2. **We suspect** that this is partly due to increased structural diversity, diversity of chemical defenses, and reduction of phenological gaps In leaf, fruit and flower production. We suspect that dominant shade trees that are native, perennial, and with heavy foliage cover support greater bird diversity, as well as greater diversity in most other taxonomic groups. 3. **We do not know** what mix of common shade trees, such as *Inga, Erithryna* and other trees optimizes cacao production and biological diversity. 4. **We recommend** that cocoa be planted under as taxonomically diverse a canopy as possible. We advocate the establishment of a program of interdisciplinary research on the

degree to which particular trees support biological diversity throughout the year along with the ease with which the trees are propagated and the degree to which the tree competes with or provides refuge for pathogens and pests of cocoa.

IV. Structural Diversity of Shade Tree Canopy

1. **We know**, based on studies in coffee and ecological principle, that the greater the foliage height diversity (presence of plant canopies at different strata) the higher the overall diversity for birds and most other taxonomic groups. Further, the higher absolute amount of foliage at all levels the greater the amount of refuge of prey from predators. We know that the greater abundance (and diversity?) of epiphytic and parasitic plants, as well as liana the greater the diversity of birds.

2. **We suspect** that the greater the number of tall trees, even at lower overall levels of canopy cover, the greater the bird diversity as well as the representation of a number of forest taxa. We suspect that the greater the abundance of standing dead wood, the greater the diversity of arthropods, birds and many other taxonomic groups.

3. **We know little about** the specific relationship between shade tree composition and the abundance and diversity of secondary structures (epiphytes etc.).

4. **We recommend** that shade trees and secondary trees be selected, in part, to maximize structural diversity. We further suggest that trimming be done in such a way as to allow a portion of the shade trees to reach natural heights and that minimal pruning of epiphytes and parasitic plants on shade trees be carried out. We suggest that interdisciplinary research with agronomists and ecologists be conducted to determine what is an optimal level of shade tree pruning.

V. Cacao Farms in the Landscape

1. **We know** that forest patches that are larger and closer to tracts of forest support a greater diversity of forest forms than smaller and more isolated patches. We also know that forest patches located along altitudinal gradients with intact habitat supports higher diversity — particularly of mobile organisms than those in an area of uniform topography.

2. **We suspect** that shade plantations connected to forest by corridors of shade plantation, forest, or riparian growth; will sustain higher levels of forest diversity and provide habitat for mobile forms as well.

3. **We do not know** quantitative effects of surrounding landscape on the composition of any shaded cacao system for any taxa.

4. **We recommend** that, wherever possible, cacao farms be clumped to form larger habitat tracts. Cacao farms should be connected to remnant forest tracts through corridors of habitat — ideally forest, but also other shaded plantation (coffee at higher elevations, for example), and gallery vegetation. We recommend that the development of cacao as a shade crop be institutionally linked to regional programs of forest protection.