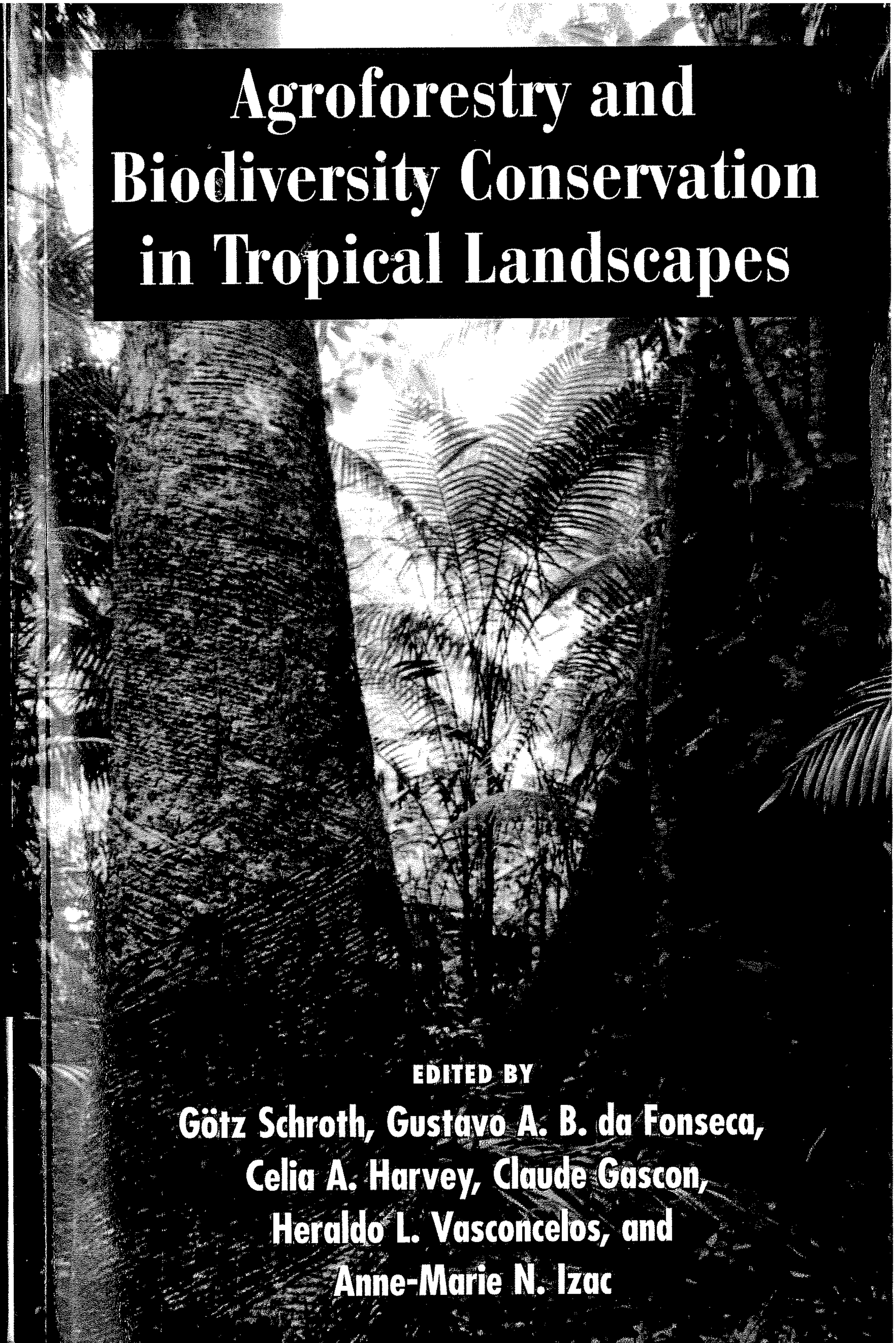
Agroforestry and Biodiversity Conservation in Tropical Landscapes



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Chapter 6

Chocolate Forests and Monocultures: A Historical Review of Cocoa Growing and Its Conflicting Role in Tropical Deforestation and Forest Conservation

François Ruf and Götz Schroth

An American scientist who visited southern Bahia on the southeastern coast of Brazil in the 1950s captured the impression that the cocoa cropping systems of that region, locally known as cabruca cocoa, made on him in the following words: "Only slowly does the initiate become aware that this 'forest,' and the 'forest' that had appeared as formidable to him in the latter stages of his trip into the cacao region is that same huge orchard which he had sought from the air and from the truck window. He learns to recognise the tall trees as jungle trees left during the clearing of the land as shade for the low cocoa trees" (Leeds 1957, 41). These chocolate forests (Johns 1999), created by underplanting selectively thinned natural forest with cocoa trees (*Theobroma cacao*), not only protect the tree crops from climatic hazards and pests and increase their longevity but also conserve some of the characteristics of the original forest, including part of its biodiversity. As agricultural land use, including cocoa cultivation, has transformed the formerly vast and highly diversified Atlantic rainforest into isolated fragments in an agriculturally dominated landscape, the potential role of the cabruca agroforests for the conservation of biodiversity has increasingly attracted the attention of conservationists and natural resource managers: "In Southern Bahia, the merits of the cabruca cacao is that the system allows economical development while maintaining a portion of the original forest diversity and thus preserving wildlife" (Alves 1990, 136).

In 1996, local authorities and the scientific community used the International Cocoa Research Conference at Salvador de Bahia to develop an image of tradition, culture, and environmental protection around the cabruca cocoa farms after the slump in cocoa prices in the late 1980s and the arrival of the

witches' broom disease (*Crinipellis perniciosa*) in 1989 motivated the conversion of some of these traditional systems into pasture (Alger and Caldas 1992; Trevizan 1996). The official recognition of their potential for biodiversity conservation and ecotourism marked a fundamental change in political priorities compared with campaigns of previous decades, in Brazil and in other cocoa-growing regions, to thin these dense canopies of forest remnants in order to increase cocoa yields (Johns 1999). It reflects particularly well the dual nature of the cocoa agroforests as an agent of the conversion of natural forests into agricultural ecosystems in this part of the Brazilian Atlantic forest and as one of the most biodiversity-friendly land use options available to local farmers.

Of course, basically all upland agriculture in the humid tropics has to take place on forestland and therefore ultimately at the expense of the forest. What made the cocoa tree an important agent of the conversion of primary tropical forests over the last four centuries, and especially in the twentieth century, is a history of boom-and-bust cycles, combined with the tendency of the principal cocoa-growing regions to move from one place to another. Where these cycles started, they led to the opening up of new forests, sometimes at a tremendous speed. Where they ended, they left behind, in the best cases, disease-infested groves of low productivity in a secondary forest environment but often only poor fallows and pastures. These cycles were fueled by the access to cheap forestland and often the labor force of immigrants.

In regions such as Bahia, southern Cameroon, southwest Nigeria, eastern Ghana, and initially the Côte d'Ivoire, cocoa was grown in complex agroforests that are among the most diversified and forest-like of all agricultural systems (see Chapter 10, this volume); in other cases, such as most of the Côte d'Ivoire, western Ghana, Malaysia, and Sulawesi in Indonesia, cocoa was grown in plantations with little or no shade, often almost monocultures. It is obviously important for biodiversity, both on the plot and on the landscape scale, whether forest is replaced by a tree crop monoculture or a complex agroforest with an understory of cocoa trees under the shade of old forest trees. Even more important, however, for regional biodiversity is how these land use types affect primary forest cover in the long term. Both the longevity of a tree crop such as cocoa and the ease of replanting it on the same site are system characteristics that are influenced by the degree of shading and may influence, in turn, the long-term forest consumption by cocoa farms, as we shall see.

As attempts increase around the world to change the historical role of the cocoa tree from a consumer of tropical forests into an instrument to improve the livelihoods of tropical farmers and to conserve as much as possible of tropical forests and their biodiversity, it may be instructive to review the factors that have determined whether this crop was grown in complex agroforests or monocultures, whether these systems were sustainable, and how they responded to social, economic, and technological change. Although this chapter focuses on cocoa, some of the conclusions are also valid for other tropical tree crops that are both consumers of tropical forest and potential allies in the search for sustainability in tropical forest regions.

Continental Drifts: How the Cocoa Tree Conquered the Tropics

The center of origin of the cocoa tree probably is on the eastern equatorial slope of the Andes and undoubtedly is in the Amazon basin. The oldest real center of cultivation seems to have been Central America, where the crop has been under cultivation for more than 2,000 years (Cope 1976). Once the Spanish had learned from the Amerindians how to transform it into a palatable drink, cocoa became an economically important commodity. Cocoa trees of the *criollo* variety from Central America were planted in Venezuela and Trinidad in 1525; subsequently Jamaica, Haiti, and the Windward Islands became important producers (Cope 1976).

From this point, world cocoa production increased as new countries adopted the crop while previous production centers collapsed. The continuous increase in world production over the centuries hides a succession of national and regional boom-and-bust cycles. In the sixteenth century, Central America was the first region to develop a cocoa economy before it relinquished the lead position to the Caribbean, especially Jamaica and Venezuela. Venezuela became the world's leader in cocoa production in the eighteenth century before it declined at the beginning of the nineteenth century, when Ecuador took over and its port Guayaquil became the world's capital of cocoa export from the end of the nineteenth century until the 1920s. As cocoa production in Ecuador collapsed, its place was taken by production in Brazil and Ghana. Subsequently, Ilhéus and Salvador de Bahia in Brazil, Accra in Ghana, Lagos in Nigeria, and Abidjan in the Côte d'Ivoire became the leading cocoa export ports of the twentieth century, shipping hundreds of thousands of tons of cocoa to Europe and North America. From 1980 to the early 1990s, Malaysia started to monopolize the New York stock market's fax machines, but its cocoa cycle was one of the shortest in history; Indonesia, especially the island of Sulawesi, took over almost immediately.

These production shifts from one country to the next were reproduced by similar cycles on the subnational scale. The history of cocoa growing in the Côte d'Ivoire, discussed in detail in this chapter, and the more recent one of Sulawesi show cut-and-run cycles in regions of early adoption of the crop that were then abandoned for new pioneer fronts. Descriptions of these shifts of cocoa-growing regions from different continents and separated in time by four centuries sound surprisingly similar, underscoring a feature that characterizes much of cocoa history:

> The Sonocusco province (in Mexico) was famous for its wealth and prosperity, densely populated with Indians and much visited by Spaniard merchants for its abundant cocoa production and its important trade that followed from it. There are now very few Indians. It is said that there are less than two thousand and that cocoa trade is disappearing, moving to another province, farther on the track to Guatemala. (Alonso Ponce, 1586, quoted by Touzard 1993, 53)

> In Côte d'Ivoire, cocoa cultivation is rare today between Abidjan and Abengourou, the region where the cocoa industry was born. In the Abengourou region itself, production has declined for the last 12 years to 6,000 tonnes from approximately 22,000. One can see abandoned farms everywhere. Production is shifting to the interior toward Dimbokro and Gagnoa, where new virgin forest lands are cleared. (FAO 1957, 16–17)

One may add that Dimbokro, the heart of the Ivorian cocoa belt in the 1960s, already ended its cocoa cycle in the early 1980s, when the crop moved further to the west, mostly to Soubré. Cocoa has thus been moving around the world for the last four centuries, in most cases at the expense of tropical forests. What are the factors that drove these cycles?

Cheap Labor and Forestland: Ingredients of Cocoa Booms

Throughout the world, most tree crop booms have been made possible through a combination of migrations and deforestation. Migrations result from the presence of large and mobile populations not too far from sparsely populated forest. Such a mobile work force was available in the savanna zone of West Africa to supply the cocoa booms in the Côte d'Ivoire in the 1960s to 1980s, for example, and on the densely populated southern part of Sulawesi and Bali to supply the cocoa boom in Sulawesi in the 1990s. Cheap land in sparsely populated forest zones provides a strong pull factor to poverty-stricken farmers in the source areas of such migrations; for example, in Indonesia in the 1980s, by selling a quarter of a hectare of paddy terraces in his village in Bali, a migrant could buy at least 10 ha of land suitable for cocoa planting in the forested plains of central Sulawesi.

Access for migrants to virgin forest areas (and subsequent transport of agricultural produce to markets) is facilitated when logging companies construct roads and open tracks into the forest, especially if they are subsequently maintained by public investments (lack of these may have saved logged forests in parts of Cameroon from immigration; J. Gockowski, pers. comm., 2003). Government policies also strongly influenced the pace of migration. Before

independence, both the Côte d'Ivoire and Cameroon produced approximat 100,000 metric tons of cocoa per year. After independence, totally oppos migration policies in the two countries were the decisive factor behind t astonishing 1.2 million metric tons reached by the Côte d'Ivoire by the m 1990s and the apparent stagnation around 110,000 metric tons in Camero (Ruf 1985; Losch 1995). In Indonesia, the cocoa boom in Sulawesi of t 1980s and 1990s, which had been launched by spontaneous Bugis migra from the southern part of the South Province of the island, was involunta enhanced by the government's transmigration program: although the progr intended to resettle populations from the densely populated islands of B and Java in irrigated rice production schemes on Sulawesi, it took a new dir tion when the migrants copied the successful experiences of the Bugis a became cocoa planters.

Planting a crop after clearing primary forest can have strong econon advantages over planting it on previously used crop or fallow land, a fac that can be interpreted as a "forest rent" and that has contributed significan to the conversion of tropical forests. This factor is not specific to cocoa b may be more important for it than for other tree crops because of the diffic ties of replanting cocoa in areas where the forest has disappeared. It helps explain why cocoa has shown such a strong tendency to follow the vanishi forest, with new plantations being established on cleared forestland ratl than old and disease-infested plantations being replanted on the same site.

The differential forest rent applied to cocoa is defined as the difference investment and production costs for a metric ton of cocoa between a plan tion that was established after primary forest clearing and one established fallow land or by replanting an older cocoa plantation (Ruf 1987). It turns c that planting on forestland nearly always trumps replanting. The reasons this are related to the different efforts needed for forest clearing and plantati maintenance, especially weeding, differences in soil fertility and microclima conditions between forest and replanted sites, and biological factors such pest and disease pressures, which in concert determine production co: yields, and risks of tree mortality when a new plantation is established.

Planted in virgin forest soil, cocoa benefits from low weed pressure, hi soil fertility, and a microclimate that is conducive to the development of th drought-sensitive understory trees. Replanting fallow land or old plantatic entails more weeding, the growth of the young trees is slower, and mortal may be high, especially in the first dry seasons. In addition, as the forest c appears, timber and game resources become scarce so that housing and liv costs increase.

In the Côte d'Ivoire, attempts to estimate the forest rent show an appr imate doubling of the investment costs for replanting after fallow (now u ally dominated by the aggressive invader *Chromolaena odorata*) or after an c weed-infested cocoa plantation compared with planting after cleared for

Table 6.1. Estimate of cocoa production costs in the hills of Sulawesi.

	After Forest (cents kg⁻¹)	*After Grassland (cents kg⁻¹)*	*Forest Rent (cents kg⁻¹)*
Net input costs	8	16	7
Labor costs	28	31	3
Total	36	46	10

Source: F. Ruf, unpublished data from a survey in 1997.

For the first year, the total effort for clearing, planting, and weed control was 168 working days per hectare for replanting and 86 days per hectare for planting after forest (Ruf and Siswoputranto 1995). Another estimate of all labor investments until the cocoa started to produce put the replanting effort at 260 days per hectare, compared with 74 days per hectare for planting after forest (Oswald 1997).

In the hills of Sulawesi, cocoa planting after fallow instead of forest results in higher labor costs, and most smallholders also believe that cocoa needs more fertilizer when planted on grassland than when planted on forestland, with the total difference in production costs (consisting of net inputs such as fertilizers and labor costs) amounting to approximately US$0.10 per kilogram of cocoa (Table 6.1). This should be considered a conservative estimate because the net input costs are reduced by yields of food crops that are initially associated with the cocoa, which tend to be higher after forest than after grassland. In addition, the depreciation of the labor costs during the juvenile phase of the cocoa trees puts planting after grassland at a further disadvantage because it may delay the first cocoa yields. As a consequence, forest is still sought in the hills and uplands, but farmers in the rich alluvial plains fear the loss of the forest rent less (Ruf 2001).

For centuries, this forest rent and the availability of forestland has discouraged sustainable cocoa growing. For example, MacLeod (1973) described the wasteful use of forest land in Sonocusco, Mexico, in the sixteenth century:

> The heavy cutting and burning of forests and tall grasses caused erosion, leaching of the top soil, and flash flooding. Land was plentiful compared to labor and capital on the cocoa coast, and the Spaniards saw no reason for maintaining its quality and fertility. The restoration of eroded, leached soils for cacao plantations is an extraordinarily long and difficult task even today. The Central Americans of the sixteenth and seventeenth centuries did not have the technology and the patience to attempt it. Cattle or brush often filled the poor pasture lands left behind by the exhausted cacao growers (p. 95).

In the same tone, Delawarde (1935) wrote about Martinique Island in th seventeenth century: "In the mountains, cacao cultures grow to produce mucl profit. However, the factor of success, new soil, is a transitory one. Th colonists did not fertilise the soil, they used it up and then planted elsewher (p. 103)."

As mentioned before, the existence of a forest rent is not specific to coco: Lower labor inputs for planting on virgin forestland compared with replant ing have been reported for rubber trees in Sumatra (Gouyon 1995), and earl colonists of the Atlantic rainforest region of Brazil believed that coffee an even sugarcane find optimum growth conditions only on recently cleare forestland (Dean 1995). The difference is that whereas rubber, coffee, and sug arcane are routinely replanted throughout the tropics today, in many regior replanting of old cocoa remains a difficult task even for modern agronomist This is especially so where during boom times soils unsuitable for the demanc ing cocoa trees have been used for planting, as has occurred in many places i the western Côte d'Ivoire, in Nigeria (Ekanade 1985), and in Sulawesi (Ru and Yoddang 2001).

These technical difficulties of replanting old cocoa are compounded b social and economic factors. For the first generation of cocoa farmers wh have arrived in a region, replanting often turns out not to be economically fe: sible at a time of declining returns and increasing costs caused by the aging (the plantation. Furthermore, the tree life cycle interacts with the life cycle (its owner, his or her family, and the community. Migrants involved in cocc planting often are young, and often all planters in a particular zone hav arrived together during a brief period of time, and so they all age along wi their farms. When replanting time comes, the farmers lack the necessary lab(force, especially if they have sent their children to school. As the yields fro: the aging plantations decline, family size and consumption increase, whic further limits the ability to invest in replanting. Conflicts between potenti inheritors often aggravate the degradation of the farms by postponing inves ment decisions.

These factors can be compounded by ecological change such as the arriv of new diseases and fluctuating climatic conditions. Eastern Ghana was tl main cocoa belt of the country in the 1930s and still an important one in tl 1950s. However, as the region was struck by the swollen shoot virus, s(exhaustion, and declining annual rainfalls, its cocoa economy collapsed, aı the main center of cocoa production shifted into the virgin forests of weste Ghana, whereas the former cocoa belt turned into an oil palm and citrus b((Amanor and Diderutuah 2001).

With this background, we will now discuss in some detail the cocoa h tory of the world's leading cocoa producer, the Côte d'Ivoire, before consid(ing more briefly two regions where particularly complex cocoa agrofore: have developed, Bahia and Cameroon.

A Forest for a Bottle of Gin: Migrants and the Cocoa Boom of the Côte d'Ivoire

The history of cocoa in the Côte d'Ivoire began in the 1890s with a short-lived cocoa boom in the extreme southwest of the country. Although economically without much consequence, this local event is instructive because it proves that early adoption sprang up as an indigenous process, not from colonial policies (Chauveau and Léonard 1996). However, the base of the current Ivorian cocoa economy was built in the eastern region after 1900. From 1910 to the 1950s, cocoa spread in this region and some parts of the center-west, mostly through micro–pioneer fronts. As the local farmers needed workers, these first decades put the structure of migration in place. After 3–10 years of good services as workers, many migrants could obtain land and become cocoa smallholders. In turn, they also called for relatives and workers. Because of the poverty in the neighboring savanna of the Côte d'Ivoire and Burkina Faso, a large and cheap labor force was ready to be exploited.

In 1960 came the independence, with an Ivorian president who fully understood the potential of combining this foreign labor force with the vast Ivorian forest. Migrations and the opening of pioneer fronts were accelerated by policies of declassifying forest reserves, distributing information, and opening the borders for foreign labor. Logging companies and their tracks facilitated the move into the forests. The result was a sweep of the tropical forest from east to west between the mid-1960s and the early 1990s. The migrants' rush to the forest was strongly related to the low prices of forestland. In the southwest of the country, where the last large cocoa pioneer front opened in the late 1970s, some migrants could still obtain 25 or even 50 ha of primary forest for a bottle of gin, 12 bottles of beer, and one piece of cloth. According to a survey in 1998, with 1,000 cocoa farmers in the whole country, one-third were indigenous farmers, one-third Ivorian migrants (coming from the savanna in the center and north of the Côte d'Ivoire), and one-third foreign migrants, mostly from Burkina Faso, with an average cocoa area of about 5.5 ha per household for all three groups (Legrand 1999).This points to the dominating role of migration in the Ivorian cocoa boom and to the resulting potential for conflict that finally erupted in civil war in September 2002.

From Agroforests to Monocultures: Agronomists, Migrants, and Technological Change

The strong migrant component determined not only the speed with which cocoa spread through the forest zone of the Côte d'Ivoire but also the way in which cocoa was grown. Until the 1960s, most cocoa planters did not cut down the biggest forest trees, at least not all of them. The undergrowth was cut and burned, but some of the giant trees were maintained and formed the upper

canopy of cocoa agroforests. Reference to these agroforests in the Côte d'Ivoire, which resembled those of the neighboring Ghana (formerly Gold Coast), can be found in reports from colonial times, along with first hints at their intensification under the influence of the colonists: "Farms in the western cocoa-growing areas are ordinarily well provided with primeval bush shade, as in the Gold Coast; but in the central and eastern districts, where the influence of the European planter is strongest, the shade for cocoa is often provided by bananas and plantains, as is done on plantations" (Schwarz 1931, 6).

Because no chainsaws or even good axes were available, an important motivation of this agroforest strategy of growing cocoa was to save labor by sparing especially trees with very hard wood or large buttresses, as described decades later for indigenous cocoa farmers in the western Côte d'Ivoire (de Rouw 1987). Of course, these forest people also knew about the different uses of their trees and retained certain useful species (again for the western Côte d'Ivoire, de Rouw mentions the edible seed–producing *Irvingia gabonensis, Ricinodendron heudelotii,* and *Coula edulis,* among others). Such heavily shaded cocoa agroforests can still be found in the eastern Côte d'Ivoire, and pockets of this agroforest tradition have also survived in the center-west, in the region of Gagnoa, where a rebellion of local residents against the government's policy of encouraging immigrants in the 1970s deterred further immigration (Figure 6.1).

Figure 6.1. Forest? No: one of the few surviving cocoa agroforests in the center-west of the Côte d'Ivoire.

An inconvenience of the traditional agroforest method is delayed returns, as heavy shade slows down the growth of the tree crops. On the other hand, shading prolongs the useful life of the cocoa farm. Also, that shading protects cocoa trees from insect pests has been known in West Africa at least since the early twentieth century, when on the islands of Fernando Pó and São Tomé attempts to increase cocoa yields by drastically thinning the shade canopy resulted in complete crop failure (Gordon 1976, cited in Johns 1999). Furthermore, the almost intact root systems of the forest trees allowed the eventual regrowth of the forest. Thirty years after the establishment of the cocoa trees, this system favored a strategy of abandoning the farm and leaving shade trees and forest regrowth to develop freely. The old cocoa farm then became a secondary forest where successful replanting was almost guaranteed. As already understood by Blankenbourg in the 1960s (cited in Ruthenberg 1980), this was nothing else than the shifting cultivation principle applied to a perennial crop. Initially it consumed forest, but once it was established for a given population, it could theoretically rotate on its own tree crop-fallow land without affecting surrounding forest. Had this type of rotational agroforest practice caught on throughout the forest belt of the Côte d'Ivoire, its landscape would now be different. Why did this not happen?

In the subsequent transformation of the cocoa-growing method, the research and extension services that favored zero-shading from the early 1970s until the late 1990s in the Côte d'Ivoire, as in most other countries (but see Cameroon later in this chapter), played a significant role. A contributing factor in this philosophy was the replacement since the early to mid-1970s of the old amelonado cocoa varieties, locally known as cacao français, by a new planting material, the upper amazons and hybrids of upper amazons, locally called cacao Ghana. The vigor of the new varieties seemed to be better expressed with little or no shade.

However, the most important driver of the changing cocoa-growing practices was the demographic and social change. Up to the mid-1960s, most cocoa farmers were indigenous forest people who applied the type of forest clearing that they knew from shifting cultivation to their tree crops. There were very few migrants in the forest zone before that time. In the 1970s and 1980s, however, rural populations in the parts of the forest zone where actual booms were taking place kept growing at rates of 10–20 percent per year through immigration (Direction des Grands Travaux 1992). This social landslide was followed by a technical one, a simultaneous adoption of a labor-saving technology to remove forest trees.

The Baoulé migrants, the most dynamic of the savanna people streaming into the forest, introduced a technique of killing big trees by gathering undergrowth around them and keeping it ablaze over a few days; the trees then fell apart over the next few years. This was much more labor efficient and far less dangerous than cutting them with axes, often from a platform

Figure 6.2. Young cocoa farm established after killing most of the forest trees in the southwest of the Côte d'Ivoire.

that allowed them to attack the stem above the buttresses, as had been don previously. Along with the cocoa trees the migrants planted their staple foo crop, yams, which necessitated intensive soil tillage and further reduced th chance of the forest to regenerate, instead of upland rice, which was grow by the locals and entailed little disturbance of the forest soil (de Rou 1987).

The new technique of forest conversion served a strategy of rapidly plant ing cocoa trees to mark land ownership instead of spending a lot of time cu ting the forest trees and clearing the plot (Figure 6.2). The intensive burnin of biomass, soil tillage, and opening of the canopy also accelerated the initi growth of the cocoa trees and provided rapid financial returns: whereas th indigenous method took 5 years until the first cocoa yield and produced 50 kg of cocoa per hectare after 10 years, with the no-shade system the tree cro started to produce within 3 years and yielded close to 1 metric ton of coco per hectare at 6–7 years. The migrants thought in terms of quick planting an quick returns. Also, the social and demographic pressure brought by th immigrations rapidly erased any chance of implementing the traditiona extensive tree crop–fallow rotation. Where cocoa was booming, there was n space for cocoa fallows, and abandoning a farm for 5–10 years would hav provoked claims on the land by indigenous people. These factors explain wh complex agroforests were not an option for the migrants in the Côte d'Ivoi when they started the cocoa cycle and also helps to explain the low adoptio

rates of agroforest practices in most other regions where migrants dominate the cocoa sector.

The End of the Cycle

The problem of the "Baoulé method" of forest conversion was that at the end of the first cocoa cycle the forest rent had been consumed. When a cocoa farm came to the end of its life cycle, which occurred more rapidly under unshaded conditions, it was difficult to implement the shifting cultivation principle to allow the establishment of a forest vegetation where, after some time, cocoa could be conveniently replanted. Fewer forest trees could regenerate and grow again. With or without the influence of droughts and accidental fires, these old cocoa farms often turned into fallows dominated by the invasive shrub *Chromolaena odorata,* where replanting of cocoa was difficult and mortality high.

Case studies of Baoulé villages in the center-west of the country in the 1990s illustrate the end of a cocoa cycle. In this region around the town of Gagnoa, the cocoa boom started in the mid- to late 1960s. In the 1970s and early 1980s, the Baoulé migrants coming from the savanna areas in the center-north were rightly considered the winners of the race for land and forest. In a village of Baoulé migrants, Petit Toumoudi, interviews with 10 farmers in 1995 show a picture that is representative of the region. Most of the farmers had arrived just before 1970. On the average, they received 9.7 ha of forest and planted more than 90 percent of it (8.9 ha) with cocoa associated with plantains. Severe mortality of the cocoa trees began in the drought year 1983 and continued in the following years. They tried to replant an average of 1.5 ha, half of which did not survive. In 1995, 25 years after their arrival, they ended up with 5.3 ha of low-yielding cocoa. Their comments turned around the exhaustion of soils, indicated by the mortality of plantains, which announced the upcoming mortality of the cocoa trees. They also mentioned reduced and irregular rainfall, reflecting an increased duration of the dry season rather than a decrease in total annual rainfall but certainly also the drier microclimate in the increasingly deforested region (Schroth et al. 1992; Ruf 1995; Léonard and Oswald 1996). They also complained about invasion of weeds and epiphytes, and termites were destroying the cocoa trees. Although they did not mention their age, all were older than 55 years and lacked the labor force for successful replanting.

They also lacked the technique. Techniques that were extremely efficient at forest times had become obsolete in the postforest era. Instead of efficient ways to clear forest, a technique to get rid of the weed shrub *Chromolaena odorata,* which had increasingly taken over the former space of the forest, was needed. It was also increasingly difficult to control the weed pressure in young and old plantations. Furthermore, fire had increasingly become a threat to the

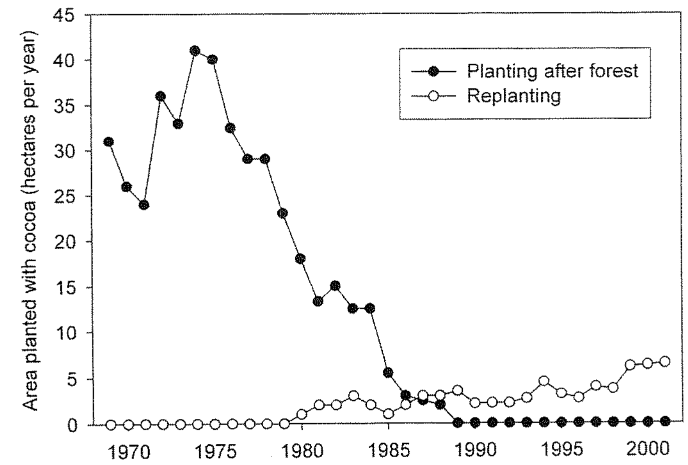

Figure 6.3. Planting and replanting of cocoa by Baoulé migrants in Konankouassikro, center-west of the Côte d'Ivoire (F. Ruf, unpublished survey results, 2001).

plantations in some regions of the country, such as the former cocoa regio of Tanda and M'Bahiakro, which had almost turned into savanna. Data fro the Baoulé village of Konankouassikro, also in the Gagnoa area, show th rates of successful replanting in the 1990s remained extremely low compar with planting rates after forest in the 1970s (Figure 6.3).

Technological Innovations in the Postforest Era

The described system of cocoa growing was highly consumptive of forest. old cocoa plantations needed to be replanted and more migrants arrived, tec nological innovations developed in response to the postforest conditions. T following three examples are particularly instructive in the present conte because, theoretically, they offered opportunities to adopt more sustainab practices, including agroforestry, and perhaps avoid some of the difficult described earlier. However, because extension services lacked the training a financial means to engage in the necessary dialog with the farmers and p mote more sustainable practices, the opportunities were missed and farm had to rely mostly on their own innovation and channels of information.

In the 1980s, primary forests for cocoa planting became increasingly sca in the east and center-west regions of the Côte d'Ivoire. Both established a recently arrived migrant farmers therefore looked for alternative sites wh cocoa could be planted conveniently. In the 1960s most farmers in the for zone of the Côte d'Ivoire were still oriented toward robusta coffee, and a seve volume report from that time treated the difficulties of rehabilitating a

replanting old and degraded coffee farms in the region (Bureau pour le Développement de la Production Agricole 1963). A decade or so later, the farmers found their own way to solve the "coffee crisis" by using the mostly old and abandoned, generally shaded coffee groves as alternative sites for planting cocoa, whose price was much more attractive than that of coffee (this technique had already been mentioned in colonial reports from the Congo in the 1950s). The common practice was to cut down most of the spontaneous forest trees that had grown in the abandoned farms, rehabilitate the coffee, and then plant cocoa seedlings the following years below the coffee shade. Once these were established, the conversion was completed by cutting down the coffee trees. The first clear reports of the use of this technique in the Côte d'Ivoire date from the late 1970s to early 1980s. In the 1980s, thousands of old and abandoned coffee farms that had effectively turned into secondary forests were converted into cocoa plantations. At that time, it had become clear that the forest would not last forever and that cocoa was very difficult to replant on deforested sites. This could have inspired the farmers to develop a more permanent cocoa culture on these old plantation sites by keeping some of the shade trees and spontaneous regrowth, which could later be turned into secondary forest and then replanted, thereby avoiding the replanting difficulties in the monoculture system. Instead, with the cocoa sector dominated by recently arrived migrants, increasing population pressure, and an active land market, the conversion technique, once proven successful, was adopted on a large scale by migrants, who bought abandoned, forested coffee farms from the indigenous farmers and transformed them into mostly unshaded cocoa plantations (Ruf 1981).

The second innovation occurred in the 1990s, when the Baoulé almost stopped their migrations to the forest zone once there was little forest left for planting, and replanting proved so difficult. However, young Burkinabé kept coming in numbers. Hardly surviving in their own country, they accepted to work at any cost. At that time it became increasingly clear that the future of cocoa in the Côte d'Ivoire would depend on the smallholders' ability to control the invasive shrub *Chromolaena odorata,* which invaded the plantations and dominated the fallows generated by forest clearing and cocoa aging (Ruf 1992). In this situation, many Burkinabé bought 1–2 ha of shrub fallows from indigenous people and replanted them working three times as many hours per hectare as during the previous forest time. The most successful in replanting fallows with cocoa were the recently arrived young Burkinabé migrants, who concentrated their energy on a small area rather than spreading it over a larger farm, as the indigenous farmers and the migrants who had come earlier did (Figure 6.4). Almost for the first time in the history of cocoa growing in the Côte d'Ivoire, thousands of hectares of cocoa were no longer planted after primary and secondary forests but after shrub fallows (Table 6.2). The farmers used simple associations of cocoa trees and plantains. Another possibility,

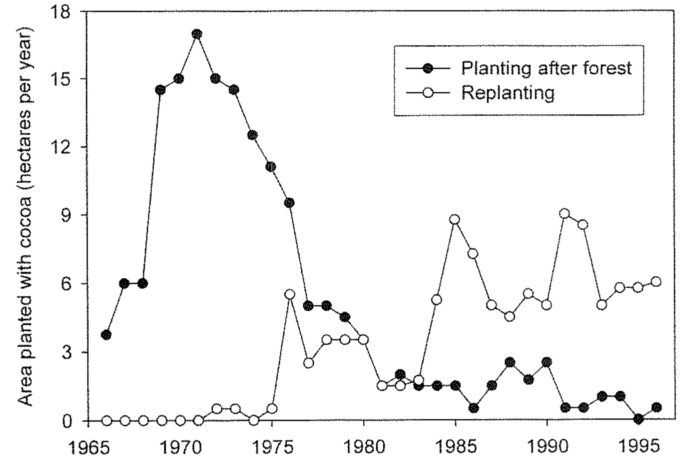

Figure 6.4. Planting and replanting of cocoa by Burkinabé migrants in the center-west of the Côte d'Ivoire (F. Ruf, unpublished survey results, 1997).

Table 6.2. Contribution of cocoa plots planted after forest or replanted to th cocoa production of farms in the center-west of the Côte d'Ivoire.

	Planted after Forest (%)	*Replanted after (Mostly Shaded) Coffee and Cocoa (%)*	*Replanted after Shrub Fallow (%)*[a]	*To Produc Farm (*
Indigenous Bété (64 farmers)	75	0	25	1,1
Baoulé and other Ivorian migrants (44 farmers)	78	3	19	3,8
Burkinabé and other foreign migrants (46 farmers)	53	11	36	2,3
TOTAL (154 farmers)	71	3	26	2,2

Source: CIRAD (F. Ruf, unpublished data from a 2001 survey).

[a]Often where a previous plantation was destroyed by fire.

more difficult but potentially leading to more permanent, shaded cocoa systems, would have been the use of tree fallows to suppress the *C. odorata* thickets, later to be underplanted with cocoa trees (Schroth et al. 1992). Whethe the resulting delay in cocoa planting would have been acceptable to recentl arrived immigrants is an open question; efforts to promote the principle to replant fallow lands have been initiated in the Côte d'Ivoire (N'Goran 1998)

The third technological innovation that changed the traditional ways o cocoa growing was the spontaneous adoption of mineral fertilizers by immigran

farmers in the Soubré region in the center-west of the Côte d'Ivoire in the 1990s. Already in the 1960s, agronomists had classified this region as unsuitable for cocoa because of its stony soils. Migrants did not know that and would not have cared. In the 1970s and 1980s, they rushed into the region by the tens of thousands, and in the late 1980s it became the new cocoa belt of the country, taking over from the Dimbokro-Bonguanou region further to the east. In the early 1990s, a huge number of farmers rediscovered what agronomists had said earlier: they started suffering yield declines and sharp increases in tree mortality. Poor soils in combination with strict monoculture accelerated the local cocoa cycle, and 15-year-old cocoa trees looked like trees of twice that age in the eastern region. In the mid-1990s, many cocoa plots had already disappeared. The migrants had only two alternatives: move to new forests further to the west or find a solution on site to slow down the death of their cocoa farms. It is well established that shading reduces nutritional stress in cocoa trees, so one could have again imagined the adoption of shade trees to improve the nutritional status of the cocoa trees and a gradual transition to agroforestry practices. Instead, at a time when extension services had largely disappeared, the farmers found mineral fertilizers. Although the use of fertilizers did not sustain individual farms over decades, it increased yields (possibly doubled them) and thereby gave the farmers an incentive to stay on their farms rather than move into new forests. This temporary solution to the local cocoa crisis may seem less satisfactory in environmental terms than the adoption of agroforestry practices. However, it played a decisive role in delaying a further shift of the cocoa production areas and thereby helped to increase the sustainability of cocoa growing on a regional scale.

Present Trends: Are Ivorian Cocoa Farmers Prepared to Adopt Agroforest Practices?

A trip through the former forest zone of the Côte d'Ivoire with some attention paid to landscapes shows a trend of decreasing shade density in cocoa from east to west. Preliminary survey results at the farm plot level in three villages indicate that large forest trees are present in cocoa plots at a density of about five trees per hectare in the east, two trees per hectare in the center-west, and less than one tree per hectare in the southwest (Delerue 2003). This decrease in the use of shade from east to west reflects the increasing dominance of the cocoa sector by migrants, who tend to use less shade than indigenous farmers (Table 6.3). In the east, indigenous farmers kept immigration under control, whereas in the western region migrants locally represent 80–99 percent of the farmer population.

For both indigenous farmers and migrants, most of the noncocoa trees in the farm plots are planted or spontaneous fruit trees rather than forest trees (Table 6.3), mainly oil palms, cola, orange, and avocado trees, around 20 trees

Table 6.3. Density of noncocoa trees and annual revenues in 15 cocoa farm in the eastern, center-west, and western regions of the Côte d'Ivoire in 2002

	Number of Noncocoa Trees per Hectare	*Number of Fruit Trees per Hectare*	*Number of Forest Trees per Hectare*	*Estimated Noncocoa Revenues per Farm*[a]	*Esti C Gross per*
Indigenous farmers	37	23	3.7	70,000	1,06
Migrants	21	15	1.8	125,000	1,40

Source: CIRAD-TERA survey (Delerue 2003).

[a]In African Financial Community francs.

per hectare (compared with about 1,500 cocoa trees per hectare). For bo indigenous farmers and migrants in the survey, the revenues obtained fro these fruit trees were only 5–10 percent of those obtained from cocoa. Th slightly higher noncocoa revenues of the migrants could be explained by be ter access to the cola trade networks in their home countries, Burkina Faso an Mali, and more commercially oriented selection of noncocoa trees.

In ecological terms these fruit trees are no substitutes for the giant fore remnant trees that constituted the overstory of the traditional cocoa agr forests. However, today most Ivorian cocoa farmers, and especially the youn generation, seem to have a negative perception of permanent shade fro forest trees. In a 2002 survey of 65 farms focusing on the center-east and cen ter-west regions, 70 percent of the respondents found shade from forest tre useless to cocoa, and 20 percent found it useful only as temporary shade f plantation establishment, for which (at least on suitable soils) most farme preferred plantains. About 90 percent believed that shade trees increased n only diseases but also pest problems of the cocoa, because they allowed insec to hide in the canopies and escape insecticides, and reduce their cocoa rev enues (F. Ruf, unpublished data). Although the farmers acknowledge th shade prolongs the life of their cocoa farms, this is not sufficient to preve zero-shade plantations from spreading.

This trend tends to be reinforced by a generational change of the far owners: when a recently arrived migrant buys an old shaded cocoa farm fro an indigenous farmer, the first decision often is to eliminate the shade tree In the indigenous population, an intergeneration transfer often provokes th same behavior. Many young cocoa farmers want immediate revenues, irrespe tive of the long-term impact on the cocoa farm. Because chainsaw teams a readily available, it is easy to turn the shade trees into cash. This type of beha ior is even more likely if a cocoa farm is inherited by several family membe together and final ownership is uncertain. Even in the most remote migra villages close to the border of the largest forest reserve in the country, the T National Park, it has become very common to cut down the giant trees tha

are said to provide habitat to insect pests (mirids) and are considered globally harmful to cocoa (Ruf 1996).

Although more complete studies of the attitudes toward shade among Ivorian cocoa farmers and the factors that influence them are needed, evidence suggests that from an incipient tradition of cocoa growing in potentially sustainable but low-yielding rotational agroforests, with a 35-year longevity of the cocoa trees and a fair chance of successful replanting after a forest-fallow period, little has survived after four decades of dominance of the sector by migrants who had neither the tradition nor the incentives and technical assistance to adopt this type of extensive agriculture. Agricultural science and extension have also played a major part in this development by favoring low-shade systems over much of the past three decades, in the Côte d'Ivoire as elsewhere.

This history has brought the Côte d'Ivoire to the top of the list of cocoa-exporting countries in the world but has cost it not only most of its forest but also its former tradition of more conservative use of forest resources. As international efforts increase to compensate tropical countries and their inhabitants for their environmental services, such as the conservation of biodiversity and the carbon stocks of their standing forests (see Chapter 4, this volume), the farmers of the Côte d'Ivoire may find themselves at a disadvantage to their counterparts in other tropical regions, where cocoa-growing practices have been more conservative. Any efforts to move the Ivorian cocoa economy toward more sustainable practices must take into account the experiences of other countries. This brings us back to the chocolate forests of Bahia with which this chapter began and to those of southern Cameroon.

Cocoa Agroforest Traditions: Remnants of the Past or Examples for the Future?

Readers of historical descriptions of regions that are now reputed for their shaded cocoa systems, such as Grenada (Knapp 1923; Preuss 1901), Bahia in Brazil (van Hall 1914), and the eastern region of Ghana (Knapp 1923; Revue Générale de Botanique 1924), may be surprised to learn that in the early twentieth century most cocoa farms in these regions were unshaded. In countries such as São Tomé, attempts to increase cocoa yields by removing shade date back to the 1920s (Navel 1921). These cases deserve the attention of historians and agronomists because the fact that farmers in East Ghana and Bahia apparently realized benefits of shaded systems may bear lessons for the present. However, globally speaking, these cases of increased shade adoption in the twentieth century seem to be exceptions. Until the 1960s most cocoa was grown under shade, and since the mid-1970s most cocoa has been grown unshaded. Bahia, southern Cameroon, and southwest Nigeria stand out as regions where complex and seemingly sustainable cocoa agroforests have

evolved and been well conserved into the twenty-first century. Why has thi happened, and what are their chances of surviving into the future? Are ther lessons to be learned for the introduction of more sustainable cocoa-growin practices in other tropical regions?

Agroforest Estates in Bahia, Brazil

Bahia is exceptional in the cocoa world for a second reason: most of its coco is grown on large estates (Ramos 1976; Alger and Caldas 1992; Greenhil 1996). This makes it difficult to apply lessons from this case study directly t the smallholder farms that dominate the cocoa sector in most other countries Nevertheless, it is instructive to see that the attitudes toward shade in thi region, though insufficiently researched, oppose to some extent those of th Côte d'Ivoire.

Historical evidence suggests that in the nineteenth century cocoa growin in Bahia was associated with the familiar shifts in local production zones. Martius (cited by Monbeig 1937) writes:

> In 1820, the grains (beans) were spread over the hot banks of fine sand to dry, then taken down on pirogues to the maritime ports, Ilhéos, Belmonte, Caravellas etc., a journey of three to four days. This traffic has considerably diminished, firstly due to the construction of the railway, but also because of the progressive shift away from the river, which has led to the abandonment of the old fazendas; near Itabuna, all the way along the river, one often sees the now deserted buildings of these fazendas. (p. 210)

In the early twentieth century, a structure of large estates was built in Bahi (Mahony 1996), and the practices of cocoa growing on these estates wer described by James (1942, cited by Leeds 1957) as follows:

> Plantation practices in Bahia are notably extensive and exploitative. . . . Once planted, the young trees are given almost no attention until they come of bearing age. . . . Thereafter, instead of clearing away the brush and weeds each year, this kind of work is done only every four or five years. When yields decline, the older plantations are abandoned and new ones are set out on virgin soils. . . . Here is speculative and destructive economy at its worst; one that is bringing temporary and unstable activity to Ilhéus and Salvador. . . . In short, the land, for the cacao zone capitalist class, is to be raped like a woman of easy life, rather than cherished like a wife. (p. 400)

Ironically, the structure of large estates where these "notably extensiv and exploitative" practices were observed was also a key factor favoring th

development of the cabruca system. As Alger and Caldas (1992) note, farmers on large estates tended to plant cocoa under native tree shade (i.e., in the cabruca system) and to invest in only part of their holdings, leaving more under forest, whereas small farmers were more likely to clearcut the forest on a larger part of their property and use bananas and other planted shade instead of native trees for their cocoa crop. Planting cocoa in the cabruca system took smaller investments per unit area than the clearcut system and was more amenable to the minimal management system practiced by absentee owners of large estates (Hill 1999). The cabruca system also gave them the flexibility to hire workers and intensify plantation management when the cocoa prices were high and to fire the workers when the prices fell. Under the sociopolitical and legal conditions of the late twentieth century, with improved workers' rights, and since the outbreak of the witches' broom fungus, which necessitates continuous efforts to keep the disease in check, these former advantages (from the perspective of estate owners) of the cabruca system have to some extent been lost.

In the late 1980s and 1990s, low cocoa prices coincided with the spread of the witches' broom disease in Bahia, encouraging some planters to (illegally) sell timber from their residual forests that had been reserved for future plantations and the cocoa agroforests themselves to compensate for low cocoa revenues. Moreover, some cocoa agroforests were abandoned, but others were converted into pasture (Alger and Chaldas 1992; Trevizan 1996; Johns 1999). In a November 1996 survey, 30 farmers declared an average loss of 70 percent of their labor force and a similar drop in production. All planters mentioned tree felling and timber selling by neighbors, and several planters anticipated a large-scale conversion of cocoa farms into other land uses, including pasture.

In 2003, however, the picture looks different. According to Brazilian agronomists and private cocoa pod counters and forecasters, the rate of tree felling and transformation of cabruca cocoa into pastures in the mid- to late 1990s, though higher than before, did not exceed 10 percent in the last 10 years (P. Petersen, pers. comm., 2003). Most of it occurred in drier parts of the region where the cocoa trees had also been affected by an increased frequency of droughts and inconsistency of rainfalls since 1982 (Carzola et al. 1995). These climatic events appear to have increased the sensibility of the Bahian cocoa planters to the ecological functions of shade trees, especially the retention of soil moisture and the microclimatic protection of the cocoa trees. In the mid-1990s, a study highlighted the importance of ecological functions of the shade canopy in the farmers' perception: protection from the sun and conservation of soil moisture and soil fertility (Johns 1999). In the same period, many farmers accused the extension service of having misled them in the 1980s by promoting shade removal in old farms and the establishment of new farms with little or no shade and expressed their worries about the climate change, especially more frequent drought, some giving drought the same

importance as the witches' broom disease in reducing cocoa yields (F. Ru unpublished survey data, 1996). In 2003, protection of the cocoa trees fron drought is the very first function of shade trees that Bahian cocoa farmer mention (P. Petersen, pers. comm.).

Why this emphasis on the ecological functions of shade trees is found i Bahia but not in some other regions that have also experienced droughts, suc as the Côte d'Ivoire, is an open question in need of research. It may be relate to shallow soils (P. Alvim, pers. comm., 1996), but this hypothesis must b tested. One way to explore how the experiences of Bahian cocoa growers ca provide lessons for their counterparts in other cocoa-growing regions woul be to promote the exchange of experiences between farmers from these region and joint visits of their respective plantations.

Cocoa Agroforests in Southern Cameroon

Similar to the cabruca cocoa in Brazil, the 50-year-old cocoa agroforests unde heavy shade formed by natural forest trees in southern Cameroon are amon the best examples in Africa of seemingly permanent agriculture that preserve a forest environment and some of its biodiversity. Satellite imagery is unabl to distinguish these cocoa agroforests from closed canopy forest. That comple agroforests have developed in this region as the predominant form of coco growing, in contrast to most of the Côte d'Ivoire, is best explained by the pre dominance of indigenous farmers among the cocoa growers of souther Cameroon. Other cocoa-producing regions in Cameroon, such as the M'Ban region and the southwest region, received more immigrants and followe more monocultural trends of cocoa growing, comparable to those in the Côt d'Ivoire (Losch et al. 1991). Furthermore, research and extension services i Cameroon favored shade both before and after independence, and coco farms established under forest tree shade in the 1950s have now turned int huge chocolate forests as the forest trees have also aged by 50 years.

A disadvantage of heavy shading in these cocoa agroforests is low yields, o the order of 300 kg of cocoa per hectare per year (Arditi et al. 1989; Losch e al. 1991). Where shading is too intense, it may also increase pod rot (*Phytoph thora megakarya*), the most serious cocoa disease in this country, so reducin shade intensity may be a component of integrated disease managemen schemes (Berry 2001). However, it is difficult to regulate the shade provide by such giant trees, except by cutting them down and making planks (Kaise 1987; Ruf and Zadi 1998). The heavy, permanent shade of the forest trees als raises its own type of replanting difficulties: farmers trying to regenerate thei cocoa farms by underplanting the agroforests with cocoa seedlings often fin that in the dense shade the trees become tall and thin in their search for ligh and form their pods 2–3 m high, where they are difficult to harvest (and dis eased pods are difficult to remove). Therefore, farmers may choose to establis

new cocoa plots at another site, outside the plantation, where the shade intensity is easier to regulate. Ideally, this would be a previously planted area under secondary forest, as in the old rotational system, but in practice farmers often use primary forest if available.

Production shifts at village and regional scales provide historical evidence of this process. Between 1960 and 1963, the East province and the department of Dja et Lobo, where cocoa is grown mainly in agroforests, produced a yearly average of 8,000 and 9,000 metric tons of cocoa, respectively. Until 1984, annual production had fallen to 5,300 metric tons per year, while cocoa production in the southwest province jumped from 7,300 to 27,000 metric tons per year and that in the M'Bam department from 6,200 to 10,900 metric tons per year (Losch et al. 1991). In the latter regions, cocoa is produced mainly by migrants in lightly shaded systems. Production shifts also occurred within the departments: in the Nyong et M'foumou department, where cocoa is produced in ancient chocolate forests, the main cocoa production centers in the 1970s were the road from Akonolinga to Yaoundé and Endom in the south; by the late 1980s, cocoa production had moved to other districts such as Nwane Soo and Ayos Fang Biloun in the north of the department (F. Ruf, unpublished survey data, 1990).

Available data suggest that noncocoa revenues from these agroforests usually are insufficient to compensate the farmers for reduced cocoa revenues at times of low cocoa prices. Therefore, when the cocoa price collapsed in the 1990s, farmers resorted to new forest clearing oriented toward food crop production as a survival strategy (J. Gockowski, pers. comm., 1998). However, during this time of economic crisis cocoa farmers close to the urban market of Yaoundé were successful at diversifying their farms by planting mandarin orange trees, often in places where cocoa trees had died and were difficult to replant (Aulong et al. 1999; Gockowski and Dury 1999), and this could indicate a way to further commercially oriented diversification of the cocoa farms in other regions. In the 1980s, farmers in the Nyong et M'foumou department mentioned the tree *Voacanga africana* (Obahtoan) as a source of an exportable medicinal product, but this export trade has ceased, probably because of a lack of certification and nonconformity to the legislation of the European market (Arditi et al. 1989). An interesting species is the African plum tree (*Dacryodes edulis*), which according to a survey of 300 farmers in southern Cameroon was planted by 83 percent of the respondents in their cocoa farms (Sonwa et al. 2000).

In conclusion, although cocoa agroforests have successfully conserved part of the forest environment of southern Cameroon, they have not been able to sustain farm revenues at times of crisis, although examples of successful economic diversification of cocoa farms are emerging. Replanting problems in agroforests are different from those in no-shade systems, but they do exist and may have contributed, together with immigrations into the southwest and

M'Bam regions, to historic shifts in cocoa production at department an province levels. As long as the demographic pressure remains low in souther Cameroon and migrants do not enter the region through a potential land ma ket, the cocoa agroforests have a good chance to survive. However, the mod may be difficult to reproduce if demographic pressure increases rapidly, unle cocoa and noncocoa revenues from these agroforests can be increased.

Conclusions

Historically, cocoa has been an important source of tropical deforestation, an it is still a nonnegligible one today. At the same time, it is a crop on whic many conservationists and natural resource managers base their hopes for a agriculture that not only provides a living for tropical farmers but also hel to conserve a degree of biodiversity in tropical forest landscapes. A critic question is whether agroforestry practices can help stabilize cocoa growing sy tems and prevent the further move of this crop to new forest frontiers whi providing sustainable income to successive generations of tropical farmers.

In all three countries discussed in this chapter—the Côte d'Ivoire, Brazi and Cameroon—there are or were traditions of growing cocoa in agroforest Obviously, this fact did not prevent deforestation by cocoa farmers, but helped to slow down the process, at least in certain parts of these countries an during certain periods, by extending the useful life of the cocoa tree and, cri ically, providing a basis for the replanting of cocoa after a period of forest fa low and thereby for more permanent cocoa systems. This basis was serious compromised when cocoa was cultivated in strict monoculture using mo destructive techniques of forest conversion, as in the case of the Côte d'Ivoir What is the future of the existing agroforests, and what are the chances of suc techniques being adopted in regions where cocoa is grown in monocultur Only preliminary answers can be given to these questions.

Complex cocoa agroforests have evolved under specific technological, ec nomic, social, and historical contexts. When these contexts change, as throug immigration, such traditional systems may become unstable. As we have see in the case study of the Côte d'Ivoire, several such changes may occur simu taneously. An important factor that has historically favored the developme of complex agroforests worldwide was the need to reduce labor costs whe establishing new plantations against a background of a low level of technolog and abundant land. By maintaining a large part of the forest trees, farme saved time for forest clearing and weed control. As land became less abunda through immigration and more effective techniques of forest clearing becam available, important premises of complex cocoa agroforestry were lost. A important factor in the move of the Ivorian and part of the Ghanaian coc economies toward zero-shade systems and monocultures was the introductio of new cocoa varieties that needed less shade and had a more rapid initi

development, thereby reducing the attractiveness of extensive and labor-saving agroforestry practices during the long investment phase. Furthermore, the use of insecticides and later of mineral fertilizers gave an immediate advantage to the monoculture system, and once these innovations had been adopted there was even less incentive to adopt (or keep) agroforestry practices.

Despite the advantages of cocoa agroforests in terms of longevity of the tree crops and ease of replanting, the chances of the traditional agroforestry practices using primary forest trees as shade and forest fallows to facilitate replanting probably are low in most regions, especially where demographic pressure increases, unless strong incentives develop or are created for the maintenance or adoption of such systems (e.g., markets for the timber from forest fallows, certification schemes). In many regions, the most promising option to promote cocoa agroforestry probably is not so much to try to save the old forest trees in the remaining agroforests as to rebuild a new agroforestry tradition based on the planting of valuable timber or other useful trees together with cocoa.

The chance that these new agroforests will be adopted will increase with their ability to provide higher and more stable income to farmers from both cocoa and noncocoa products. Cocoa revenues from agroforests may increase with the introduction of clonal materials resistant to major cocoa diseases, as has recently started in Bahia (witches' broom disease) and West Africa (*Phytophthora* pod rot). Stable revenues cannot be obtained under conditions of fluctuating cocoa prices without markets for noncocoa products, like those in the Yaoundé area in southern Cameroon, leading to the diversification of cocoa farms with fruit trees. In all tropical countries, the development of urban markets will encourage this type of diversification on the plot and farm scale.

Specifically in the Côte d'Ivoire, a hope for cocoa agroforestry is the opening of the timber market to farmers in 1999, which legalizes the commercialization of timber and makes it less subject to informal taxation. Once the information about their new rights has reached the cocoa smallholders, which is not the case yet, it should increase the attractiveness of managing trees in cocoa farms. Whether this potential can be used to help establish more diversified and potentially more sustainable cocoa systems will be highly instructive for other African cocoa growing regions. The key factor in cocoa sustainability is not necessarily longevity of the tree crop but successful replanting. Replanting is costly, so it is important that at the end of the cocoa trees' life cycle there is capital that can be used to finance replanting, and this could be provided by the trees. This idea is nothing new: "As cocoa plantations should not live more than some twenty years, native people should be encouraged to intercrop cocoa with other trees, every 15 meters, for instance with oil palms, colas and avocados which provide them with valuable produce when the main crop disappears" (Vuillet 1925, 5).

Whereas intercropping with oil palms and fruit trees can help diversify the revenues from productive cocoa groves, timber trees may accumulate the capital needed for replanting during the life of a plantation. Imagine a couple of Côte d'Ivoire migrants who started clearing forest and planting cocoa in 1968 when they were in their twenties. Between 1989 and 1993, at the height of the cocoa crisis, suppose they sold a few iroko (*Milicia excelsa*) or frake (*Terminalia superba*) trees, or perhaps even a sipo (*Entandrophragma utile*). They could use the timber money to replant their cocoa grove, which was facilitated by still some large trees and enough trees of intermediate size to provide the necessary shade. They could retain and tend these trees in the plantation as retirement capital and as an inheritance for their sons and daughters to finance the next replanting. Perhaps they even planted some tree seedlings that they had collected in a nearby forest or received from the extension service. Their maintenance in the cocoa farm, along with the cocoa crop, would be almost cost-free.

Ways to trigger such investments in sustainability through contracts and institutional arrangements between farmers and forestry services or wood processing companies should be explored. They need to be backed up by measures to protect remaining forests, signaling to the farmers that further shifts to the forest frontier are not an option. Whether the diversification of cocoa farms relies on timber, fruits, medicinal products, ecotourism, carbon credits, or payments for conserving biodiversity in the buffer zone of a forest park, what is most needed to make cocoa agroforests more sustainable is access to reliable and diversified markets for their products and services.

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Chapter 7

Achieving Biodiversity Conservation Using Conservation Concessions to Complement Agroforestry

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Throughout the tropics, cultivation of agricultural commodities drives habi tat conversion and biodiversity loss (McNeely and Scherr 2001). A role clearl exists for targeted interventions to decelerate and mitigate the impacts of thi process, and in many cases agroforestry presents an alternative that is prefer able to clearcuts and monocultures. However, from a strict conservatio perspective, agroforestry systems are a compromise rather than a solutio (Terborgh and van Schaik 1997). Although agroforestry initiatives can creat corridors or buffer zones in a patchwork of forest and production areas, the nevertheless impose a disturbance on the ecosystem; given a choice, biodiver sity protection is better served by continuous intact habitat than by th fragmentation inherent in a patchwork (Laurance and Bierregaard 1997) Moreover, agroforestry systems may or may not be sustainable in the mediur to long term and therefore offer uncertain outcomes even where adopted as conservation strategy.

Agroforestry rests on the premise that forests and the natural resource bas must generate income from a flow of products to benefit farmers. Confinin income to that which can be generated from flows of physical output limi the scope for action by conservation interests and income opportunities fc local stakeholders. The danger of exclusively linking income to production i particularly well illustrated in areas with deteriorating economic prospects fc

or maintaining tree cover, agroforestry provides habitat, may leave land better suited to future conversion to natural habitat, creates a microclimate suitable for many plant and animal species, and may provide food sources outside reserves for many seed dispersers and pollinators (Lord et al. 1997). These elements are in turn important in providing source populations, transitional habitat, seed dispersal to new areas, and destination habitat for species moving because of climate change.

Agroforestry may play a role in broader regional climate maintenance as well. Forest denuded to grassland may warm rapidly, causing hot updrafts that lead to convective rainfall. At a medium scale, this effect results in increased rainfall intensity. Over larger areas, it is believed to lead to regional drying (Pitman et al. 2000). Either effect can compound climate change–related increases in storm frequency or drying. By providing a landscape with substantial tree cover, agroforestry in conjunction with major protected areas under natural forest cover may help moderate rainfall disruptions and regional drying. This in turn reduces regional climatic changes that may affect species' ranges and abundance through changes in food resource availability, reproductive timing, or survival (especially during drought or fire).

Habitat provided by agroforestry is important for some species. For example, shade coffee has been shown to provide habitat to bird species that unshaded coffee (or "sun coffee") does not (see Chapter 9, this volume). If the ranges of these species shift because of climate change, shade coffee plantations provide a semipermeable matrix land use that may facilitate natural movements. Shade coffee often is practiced by smallholders with low capital inputs, meaning that the marginal cost of maintaining these conservation values is low. In contrast, intensive coffee culture offers little alternative habitat, may pollute the soil with pesticides, and has high cost of conversion to conservation set-asides, if such conversion is even biologically possible.

Agroforestry can help provide food sources outside reserves that maintain populations of large seed-dispersing birds and some mammals that facilitate range shifts. It can also facilitate long-distance foraging when food is less plentiful in nature reserves. The importance of providing food sources to seed dispersers is illustrated by the brown-cheeked hornbills (*C. cylindricus*) of the Dja Reserve in Central Africa (Whitney et al. 1998). These birds are resident in the largest park in Cameroon and one of the largest in Africa yet depend on food sources outside the park in certain seasons. Radio tracking in small planes has shown that they move hundreds of kilometers and across international borders in search of off-season food, despite the fact that the Dja Reserve is half the size of Belgium (Figure 20.3). Movements such as these can be critically important to forest plant species whose ranges are shifting because of climate change. Hornbills are important seed dispersers, and in times of rapidly changing climate, getting seeds to areas with newly suitable climates is critical to the ability of forest

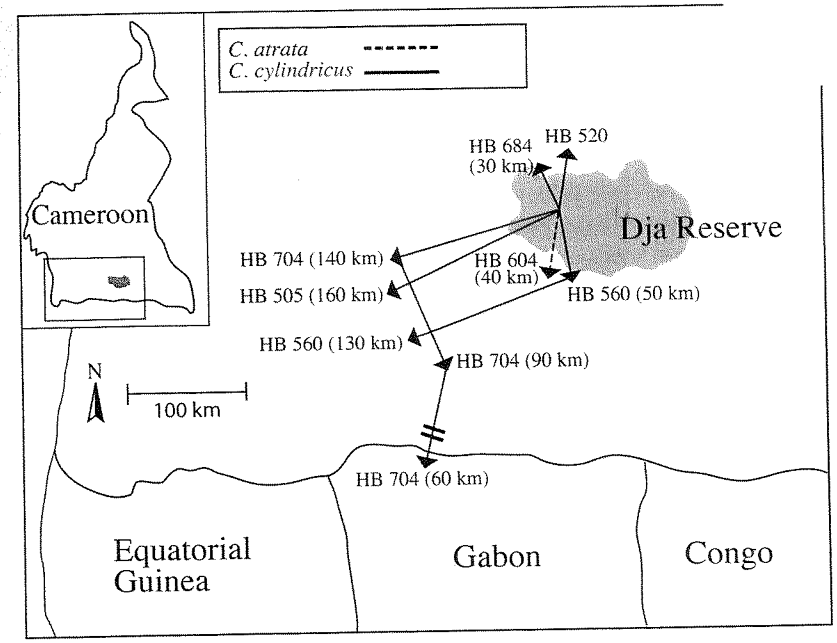

Figure 20.3. Foraging by *Certogymna cylindricus* in the Dja Region, Central Africa, as determined by radiotelemetry. (Figure courtesy of Thomas B. Smith.)

tree species to shift their ranges. Without food sources outside reserves, these movements would be reduced, greatly decreasing the chance of long-distance dispersal for some forest plants. In landscapes in which forest is being increasingly converted to agriculture, agroforestry can therefore play a pivotal role in maintaining trees that provide off-season food resources for large dispersers such as hornbills.

A final example illustrates the potential of agroforestry to foster forest regeneration. Cocoa is an agroforestry crop often favored by smallholders. Cocoa must be replanted periodically to maintain productivity, providing an economic window in which conversion to conservation set-asides could take place. Apart from the habitat value of native plants, the cocoa and associated trees maintain many soil components and understory microclimate conditions necessary for forest regeneration (see Chapter 10, this volume). Restoring forest on denuded land can be extremely difficult and slow because of the changes in soil and the light and moisture regime that occur with total clearing. Cocoa, though in no way comparable to natural forest, does provide conditions for forest regeneration far superior to those of cleared land. If intentionally managed as part of a CCS, these attributes may help maintain future options for biodiversity management.

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Conclusion: Agroforestry and Biodiversity Conservation in Tropical Landscapes

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Following the World Agroforestry Center, in this book we define agroforestry as a dynamic, ecologically based natural resource management practice that, through the integration of trees and other tall woody plants on farms and in the agricultural landscape, diversifies production for increased social, economic, and environmental benefits. The 20 chapters in this book analyzed ways in which agroforestry could best contribute to one particular group of environmental benefits, namely the conservation of tropical biodiversity. In the Introduction we proposed three hypotheses on how agroforestry could help conserve tropical biodiversity: by reducing the pressure to deforest remaining forestland and degrade forest through the unsustainable extraction of its resources, by providing suitable habitat for forest-dependent plant and animal species, and by creating a biodiversity-friendly matrix to facilitate movements between existing patches of natural habitat and buffer them against more hostile land uses. In this Conclusion, we briefly review these three hypotheses in light of the contributions in this volume, identify opportunities where existing knowledge can be applied, and pinpoint knowledge gaps where further research is needed. We conclude with a list of the most immediate research needs.

Agroforestry as a Means of Protecting Natural Forest

> Agroforestry can help reduce pressure to deforest additional land for agriculture if adopted as an alternative to more extensive and less sustainable land use practices, or it can help the local population cope with limited availability of forestland and resources, such as near effectively protected parks (the agroforestry-deforestation hypothesis).

This hypothesis should not be misunderstood to suggest that the promotion of agroforestry in forest frontier areas as such would have a general forest-conserving effect. Both historical and economic arguments reviewed in this book show that this is not a simple causal relationship. A key argument in the early discussion of the effects of agroforestry on deforestation was that by being more sustainable than alternative land use practices, agroforestry may reduce deforestation as a means to create new fertile crop lands to substitute for degraded agricultural lands (Chapter 5). However, although it is true that agroforestry often is more sustainable than alternative agricultural land uses, this does not necessarily lead to less deforestation, for two reasons. First, even potentially sustainable land use practices can be used in an unsustainable manner if the prevailing socioeconomic conditions favor the occupation of new land rather than investments in sustaining the productivity of existing fields, pastures, and plantations. For example, converting new forest areas for agriculture may be a way for farmers (e.g., immigrants) to establish use rights, defend traditional use rights against other land users or the government, or simply expand their farmed land. Furthermore, the profitability of tree crops such as cocoa and rubber usually is highest if they are grown in newly deforested areas, which provides a further incentive for farmers to establish new plantations in primary forest rather than replant already cultivated land as long as forestland is readily available (Chapter 6). Second, if agroforestry land use, such as growing commercial tree crops, is more profitable than alternative activities in the same or nearby regions, such as slash-and-burn agriculture with subsistence crops, there will be a tendency for agroforestry to expand, including into forested areas, if socioeconomic factors (access to land, labor, and capital) or biophysical factors (soil conditions and pest and disease pressures) do not pose obstacles to such expansion (Chapter 5).

In combination, these two factors explain why some perennial crops, which form the basis of the most biodiversity-rich agroforests, have also contributed significantly to the expansion of the agricultural frontier into primary forest. Chapter 6 demonstrates this for cocoa; other examples include rubber in lowland Sumatra (Chapter 5) and coffee in Colombia (Chapter 7) and elsewhere. Global markets for these commodities, their (former) profitability, and an abundant labor force of immigrants, for example in Sumatra and the West African rainforest zone, are among the factors that have permitted this expansion of tree crops, sometimes grown in agroforests, into primary forest areas (Chapters 5 and 6).

On the other hand, there are combinations of farmer characteristics, types of agroforestry practices, and market and tenure conditions under which agroforestry is likely to pull labor and capital resources away from the forest frontiers and thereby help to reduce deforestation. In particular, techniques that necessitate long-term investments in the land (e.g., through the planting of trees with a long productive life), that are labor or capital intensive, and that reduce production risks and thus the need to clear excessive land as a form of insurance are likely to have this effect. Cases in which agroforestry adoption has helped to stabilize the forest frontier include the introduction of coffee in slash-and-burn systems in Nicaragua (Chapter 5). Also, in some regions traditional shaded cocoa systems reduced forest conversion compared with modern monoculture cocoa by extending the useful life of the cocoa tree and, critically, facilitating replanting on the same site (Chapter 6).

However, as Angelsen and Kaimowitz (Chapter 5) point out, it will often be difficult to promote the techniques that have the highest forest-saving potential in a forest frontier situation. Because farmers tend to prefer technologies that increase rather than limit their options (including the option to move into new forest areas if this appears advantageous), they will often be reluctant to adopt labor- or capital-intensive agroforestry technologies when these factors are scarce but land is abundant, as is typically the case at open forest frontiers, especially where these frontiers are continuously being opened up by road construction and logging development (Chapter 2). Therefore, rather ironically, agroforestry practices or technologies that have the highest forest-saving potential are more likely to be adopted once the forest is gone (Chapter 5) or has become inaccessible to farmers.

In isolation, promoting agroforestry therefore will not usually be an effective means of reducing deforestation. Rather, the evidence and experiences reviewed in this book suggest that agroforestry can make its greatest contribution to forest conservation when it is combined with other, more direct forest-conserving measures, such as the declaration and enforcement of protected areas and other environmental legislation, or approaches that provide farmers with net benefits from forest conservation, such as conservation concessions (Chapter 7), access to special markets, ecotourism revenues, payments for watershed functions, or perhaps carbon credits (Chapter 4).

Agroforestry can complement such direct forest conservation measures in several ways. Agroforestry practices that allow the sustainable intensification of land use in deforested areas and increase the profitability per unit area, such as through the introduction of tree crops in pasture or slash-and-burn areas or valuable secondary crops and timber trees in tree crop systems, can help populations cope with reduced land availability in a closed-frontier situation, such as the buffer zone of a park. Under such conditions of limited land availability,

the potential for sustainability of agroforestry practices is more likely to be realized and labor-intensive practices more likely to be adopted. By providing timber and nontimber products that would otherwise be taken from the forest, agroforestry in buffer zones can also help reduce pressure on forest resources and make legal restrictions on their extraction from the forest more acceptable to the local population (Chapter 10). Where populations live within the limits of less strictly protected areas, tree-dominated land uses such as complex agroforests may be the land use option that is most acceptable to both farmers and park managers and thereby help avoid conflict (Chapter 13).

Agroforestry is a suitable land use option not only in areas surrounding legally protected forests but also where land users voluntarily opt for conservation set-asides in exchange for direct payments, investments in health or educational infrastructure, or other benefits, as in the conservation concession approach (Chapter 7). In the long term, the protected status of conservation set-asides will depend on the sustainable use of the remaining agricultural land, or at least the cost of setting aside land will increase if unsustainable land use in the surroundings increases the pressure on the forest protected by a concession. Therefore, sustainable agroforestry practices that also reduce farmers' dependency on forest products probably can contribute to the long-term viability of conservation set-asides. As Hannah (Chapter 20) suggests, the greater flexibility of agroforestry compared with other land uses for eventual future conversion into natural habitat, which results from native tree cover, soil conservation, and extensive management of agroforestry areas, is an added advantage in the proximity of conservation set-asides and legally protected areas (by contrast, agroforestry practices using exotic tree species can be a serious threat to such areas, as discussed later).

Including agroforestry land uses in conservation concession agreements could sometimes make a critical difference in farmers' decision to adopt agroforestry in exchange for simpler agricultural practices. Transition to agroforestry often entails long-term investments (e.g., in tree planting), or agroforestry may be more sustainable but produce lower yields than nonagroforestry alternatives, at least in the short term, as is often the case with shaded compared with unshaded tree crops (Chapters 6 and 9). Consequently, by adopting agroforestry, farmers often incur immediate additional costs for which they may be rewarded only in the longer term. Some biodiversity-friendly agroforestry practices may even necessitate permanent subsidies to be competitive with conventional agricultural land uses. Through conservation concessions, land users can be compensated for such investments in biodiversity and sustainability in return for conserving additional forest or retiring agricultural land, thereby increasing the opportunities for integrated land use planning (Chapters 7 and 20). In a similar way, farmers could be rewarded for conserving forest and managing agricultural land sustainably through revenues from ecotourism, access to specialty markets (ecolabeling), payments for maintaining watershed functions, or carbon trading (Chapter 4).

As mentioned earlier, agroforestry may help maintain the integrity of forests by providing timber and nontimber forest products that would otherwise be collected from forests, often in an unsustainable manner. Empirical evidence is emerging that farmers who possess agroforests are less dependent on forest resources in general (Chapter 10). Whether this also applies to hunting is less clear, however. Tropical farmers commonly hunt in agroforests, where wildlife may be attracted by fruits and seeds and where hunting may serve the purpose of crop protection and subsistence (Chapter 13). In some cases, farmers even conserve tree species in cultivated areas specifically to attract wildlife (Chapter 8). In principle, hunting in agroforestry buffers could reduce hunting pressure in primary habitat; however, the extent to which this is the case and how source populations in primary habitat are affected by possibly high hunting pressure in cultivated areas, which could act as population sinks, have not been studied adequately.

In summary, although it would be naive to expect that promoting agroforestry as such would lead to reduced forest clearing, agroforestry can make significant contributions to the political acceptability and long-term stability of forest frontiers if they are imposed or protected by other, more direct mechanisms and may reduce pressures on forest resources. Forest conservation in parks or conservation concessions and the promotion of agroforestry land uses in the surroundings are likely to have synergistic effects. The development of such synergies depends to a large extent on good governance, especially sound environmental legislation and its effective enforcement, and institutions that allow and engage in integrated approaches to conservation and rural development planning. Thus, under particular scenarios and in combination with other measures, the agroforestry-deforestation hypothesis appears to be valid, although more empirical work is needed to clarify the range of social and economic conditions under which its validity is maintained.

Agroforestry as Habitat for Native Plant and Animal Species

> Agroforestry systems can provide habitat and resources for partially forest-dependent native plant and animal species that would not be able to survive in a purely agricultural landscape (the agroforestry-habitat hypothesis).

As several contributions to this volume have shown, tropical agroforestry systems such as shifting cultivation, shaded tree crops, and complex agroforests contain or contribute to supporting many species and varieties of plants and

animals that are not present in agricultural monocrops and pastures. Some of these species and varieties belong to the planned components of a system, especially crops, planted shade trees or tree crops, and domestic animals; others are remnants from prior plant and animal communities or are present as populations or metapopulations distributed over, or using, both natural and agroforestry-based patch types in the landscape (unplanned components). Both groups may contain species or varieties that are threatened and in need of conservation and others that have low conservation priority but may contribute to the productivity and stability of the land use system.

Some of the planned components of an agroforestry system may be widespread and often exotic crop and tree species, whereas others may be of native origin, including threatened crop species and varieties (Chapter 8). Although not usually considered in biodiversity conservation projects, the active conservation of such local crop species and varieties may be important for many reasons, including site adaptation and use in future breeding programs, but also as insurance of cropping systems against yield failure, especially under changing climatic conditions, which could force impoverished farmers to clear more forest or migrate to new forest frontiers (Chapter 20). Among the wild species present in a system, some common, disturbance-adapted species, including weeds, may contribute to ecosystem processes such as nutrient retention, pollination, and biological pest control but have low conservation value, whereas others may be rare forest species. Of the latter, some may be actively managed to fulfill essential functions, for example as shade trees, whereas others may be exploited occasionally for timber or nontimber products, and yet others may be merely tolerated or not noticed at all. Some common weedy species may also provide important food resources and habitat for other species more in need of conservation (Chapter 19).

As land use systems are intensified, wild species tend to be increasingly suppressed (e.g., by weeding and application of pesticides with cascading effects on higher trophic levels) or be replaced by a smaller number of planned species (e.g., forest remnant trees by planted, often exotic shade trees and tree crops, spontaneous weed communities by introduced cover crops, or diversified native by monospecific planted fallows; Chapters 8 and 9). Consequently, where high diversity of wild plant and animal species occurs in agroforestry systems or landscapes, this is usually the result of extensive management or even temporary abandonment of cultivated areas, that is, a result of the tolerance or unintentional maintenance (as in fallows) of biodiversity in production systems rather than specific management to promote its persistence.

This is most obvious in shifting cultivation, the most widespread and among the oldest forms of agroforestry. As Finegan and Nasi (Chapter 8) point out, the length of the fallow period (i.e., the time during which land is not managed or is managed only very extensively to enable it to recover from previous cropping) is a key factor determining the accumulation of wild species both at the plot and

at the landscape scales. Consequently, the widespread phenomenon of shortening fallow periods in the tropics as a result of increasing land use intensity and the concomitant increase of disturbance through vegetation cutting and burning threatens not only the sustainability of these systems but also their potential to conserve native forest species. This is particularly true for forest plants, which tend to be excluded from short-rotation fallows through burning and weeding during the cropping phase and perhaps through competition from pioneers during the fallow phase. Forest animals, on the other hand, are often able to move between different habitat patches in shifting cultivation landscapes and tend to be less affected, although they will suffer if shortening of fallow periods leads to smaller areas of older fallows, or primary vegetation, in the landscape. Some groups may even be more abundant or diverse in structurally heterogeneous fallow landscapes than in more homogeneous primary forest, as has been shown for some raptors, certain primates, and small to medium-sized mammals, whereas other groups such as terrestrial and understory insectivorous forest birds generally are less abundant (Chapter 8).

Extensive management is also a key factor influencing the habitat value of more permanent agroforestry practices, including shaded tree crop systems and complex agroforests. Shaded, and especially extensively managed, rustic coffee plantations have been shown to provide habitat for numerous species of mammals and birds that are absent from intensively managed sun coffee or other treeless areas and also to provide critical overwintering sites for migrant birds (Chapter 9). Complex agroforests, such as jungle rubber in Indonesia or shaded cocoa systems in Africa and Latin America, are the most forest-like of all agricultural systems and have been shown to provide at least temporary habitat to many forest species, including some threatened cat, primate, and bird species. Extensive management of the whole system or of certain sections or vegetation strata, or even abandonment of the system during certain phases (e.g., at times of low commodity prices), often allow the persistence or recolonization by native plant and animal species (Chapter 10). However, even such extensively managed, forest-like systems are no substitutes for native habitat because certain species groups tend to be underrepresented or absent. This is particularly true for forest interior species, large herbivores, and top predators (high hunting pressure clearly contributes to the declines especially of larger animals; Chapter 14). Furthermore, many forest animals that are observed in agroforestry systems or fallows may depend on the existence of nearby native habitat and use these managed systems only sporadically or as stepping stones between patches of natural vegetation (Chapter 10). The degree to which some threatened species depend on the presence of natural forest in agroforestry landscapes is a key question for future research because it will influence the rates of depletion of local populations as natural forest is replaced by even the most forest-like agricultural systems.

Although the same biodiversity benefits arising from rustic coffee systems

or complex cocoa or rubber agroforests cannot be expected from isolated trees, windbreaks, or hedgerows, such agroforestry elements in managed landscapes have been shown to permit the presence of several species of birds, bats, and small mammals that would not be present in treeless fields or pastures, including occasional forest interior species (Chapter 11). Woodlots of native trees in pasture areas have been shown not only to provide supplementary fodder resources for livestock and increase their carrying capacity during periods of low forage availability but also to provide crucial habitat for insects and migratory birds (Chapter 19). In wider wooded corridors connected to native forest, substantial colonization by forest plant, bird, and mammal communities has occurred within a few years of establishment, suggesting rapid development of suitable habitat conditions (Chapter 18).

Whether agroforestry systems provide habitat for forest species depends to a large degree on their management, especially whether they are managed on a short rotational or semipermanent basis, the structural complexity and diversity of their shade canopy and understory, and the degree of weeding, pollarding, and pesticide use. In addition, the size and location of the system within the landscape, particularly its proximity and degree of connectivity to remaining forest cover, strongly influence the abundance and diversity of plant and animal species present (Chapters 10 and 11).

Another key factor that acts directly on the animal diversity and abundance of agroforestry landscapes is hunting pressure. Wildlife is hunted in most tropical regions for food, income, medicine, and trophies, to control crop pests and predators of domestic livestock, and to reduce threats to human safety (Chapter 14). Although as a result of moderate levels of disturbance agroforestry landscapes tend to be more productive for certain wildlife species than undisturbed forest, present levels of wildlife consumption in many tropical regions are unsustainable and risk driving many species to extinction, particularly large and slowly reproducing species. In more densely populated tropical regions, the potential of agroforestry landscapes to serve as habitat for forest wildlife therefore also depends on changes in local consumption preferences and attitudes toward wildlife (Chapter 14). Furthermore, wildlife species that pose threats to crops or the safety of humans or domestic livestock are unlikely to be tolerated in inhabited areas (Chapter 13), stressing again the need for large and undisturbed areas of natural habitat even in regions where agroforestry is a dominant land use.

In summary, certain agroforestry practices have a significant potential to provide habitat for many species of forest-dependent flora and fauna and can probably play a crucial role in reducing species extinctions in regions where the area of remnant native habitat has been greatly reduced. However, because even in the most diversified and extensively managed agroforests certain groups of forest species are missing or underrepresented, agroforestry systems cannot be seen as a substitute but only as a complement to areas of natural habitat. Furthermore, increasing intensification of land use practices in tropical regions, such as shortening of fallow periods or reduction and simplification of shade canopies in tree crop plantations, reduces the habitat value of these systems for native species (Chapters 8 and Chapter 9). Therefore, it will be increasingly important to find ways to increase the profitability of traditional agroforestry systems while maintaining as much as possible of their biodiversity benefits.

Agroforestry as a Benign Matrix Land Use for Fragmented Landscapes

> In landscapes that are mosaics of agricultural areas and natural vegetation, the conservation value of the natural vegetation remnants (which may or may not be protected) is greater if they are embedded in a landscape dominated by agroforestry elements than if the surrounding matrix consists of crop fields and pastures largely devoid of tree cover (the agroforestry-matrix hypothesis).

It has been suggested that the type of land cover and land use in the matrix of managed areas around and between remnant forests and parks has an important influence on ecosystem processes and population dynamics within these patches; therefore, matrix management has become an emergent topic in the design and implementation of biodiversity conservation strategies (Chapter 1). Key functions of the matrix that were identified in this book include providing a smooth transition between open agricultural areas and forest boundaries that reduces edge effects and the incursion of fire into forest areas (Chapter 2), providing connectivity between patches of primary habitat (Chapter 3), and providing alternative or supplementary habitat and resources for forest species (Chapter 8). Agroforestry systems may also provide a supply of timber and nontimber forest products that reduces the dependency of the local population from forest resources, as discussed earlier. Evidence supporting the hypothesis that the conservation value of habitat fragments is greater if they are embedded in a matrix of agroforestry than in less diversified and structurally simpler agricultural land uses is still mainly indirect, although direct evidence is slowly accumulating.

In several tropical regions, complex agroforests form the transition between human settlements and intensively used agricultural areas on one hand and natural forest on the other (Chapter 10). In this situation, depending on the height, structure, and extension of such agroforests, their buffering effect on microclimate and wind can be expected to result in lower edge-related mortality of forest trees than in unprotected forest, as has been shown for buffers of tall secondary forest; however, empirical evidence that such an effect also occurs with agroforests is lacking. Similarly, it is very likely but has not yet been demonstrated that forests buffered in this way are less affected by fire incursions

because farmers will attempt to avoid damage to their tree crops. Despite the lack of proof of such effects, pioneer projects have started to implement agroforestry buffers around forest fragments (Chapter 17), which will in due course also serve as an empirical test of their basic hypotheses.

Some direct and substantial indirect evidence exists for the role of different types of agroforestry in increasing the connectivity of landscape mosaics for forest species. Shaded coffee ecosystems and pastures invaded by native legume tree species in Central America regularly host migrant birds arriving from North America, thereby providing a terminus to migrations as well as stopovers and, in a sense, ensuring connectivity on a continental scale (Chapters 9 and 19). Species of large cats that are known to use large territories, such as tiger and puma, have been seen in damar agroforests in Sumatra and cocoa agroforests in Costa Rica, respectively, although the degree to which such forested habitat in the agricultural landscape is necessary to ensure connectivity remains to be established. In Bahia, Brazil, lion tamarins (an endangered primate species) have been recorded in cocoa agroforests but are believed to be dependent on primary forest and to use the agroforests only as temporary habitat (Chapter 10). Remnant trees and windbreaks in fields and pastures often are used as stepping stones and dispersion paths for birds and flying mammals and may occasionally allow the passage of howler monkeys or other larger fauna (Chapters 11 and 17). In wider agroforestry corridors, such as 100-m-wide wooded strips connecting forest fragments, forest species have become established within only a few years, providing direct evidence of the value of such corridors as dispersion paths (Chapters 3 and 18).

Recent research has also shown a surprising degree of connectivity on a landscape scale for trees in forest fragments that were previously assumed to be "living dead" for lack of nearby mating partners. Agroforestry trees in the matrix may cross-pollinate with trees of the same species in forest fragments or may facilitate movements of pollinators and seed dispersers across the landscape. Consequently, such fragments are genetically less isolated than previously expected. However, the possibility that a few highly productive remnant trees ("superadults") in the open landscape dominate the pollen pool in habitat fragments and reduce effective population sizes warrants further consideration (Chapter 12).

However, there are further risks associated with the use of agroforestry in the matrix around natural habitat. One of these is the use of invasive alien tree species. Many species of timber, fruit, and service trees that are commonly used in agroforestry outside their native home range have occasionally been found to invade natural habitat, often after disturbance (Chapter 15). Because forests bordering on agricultural areas are particularly prone to disturbance, for example through logging and fire, the chances of invasion by agroforestry trees grown in the matrix may be greater. Mutualists such as pollinators, seed dispersers, mycorrhizal fungi, and nitrogen-fixing bacteria (also often aliens) in and around agroforestry systems may also facilitate invasions. In some genera, introduced species may also hybridize with native species, thereby threatening native gene pools (Chapter 12), or exotic species may hybridize with each other, thereby increasing their invasiveness (Chapter 15). Nonnative trees (and crops) may also host exotic pests and diseases to which the natural vegetation is not adapted, resulting in severe epidemics that may fundamentally alter the composition of natural communities or may be susceptible to native pests and diseases to which they have no tolerance or resistance (Chapter 16). Although these risks can be avoided by using native tree species, this may not be without cost and additional effort for the land user, who may forgo income opportunities from faster-growing, more valuable, or simply more available and better-known exotic species, which are often promoted by "diversification projects" using "promising" exotic species (Chapters 15 and 16).

For farmers, growing agroforestry crops in buffer zones and mosaic landscapes may involve both opportunities and risks, and the perception of these will influence their attitudes toward the conservation of primary habitat and wildlife. As the agricultural matrix becomes more hospitable and permeable to wildlife, there will also be greater risks of wildlife damaging crops and threatening domestic livestock or even humans (Chapter 13). For some farmers living close to the forest boundary and possessing the ecological knowledge to hunt larger fauna, benefits from the presence of wildlife may exceed crop losses, but for others it may not. To avoid conflict, land managers could help farmers plant unpalatable crops such as tea or coffee along park boundaries, thereby repelling wildlife from crop fields and channeling it into less sensitive corridors, or develop schemes through which farmers are compensated for crop losses to wildlife (e.g., from tourism revenues). Open communication between stakeholders about their respective objectives is clearly a condition for such integrated, landscape-scale planning and management (Chapter 13).

Although crop damage by wildlife generally is higher in proximity to primary habitat, little is known about how the exposure of crops to pests and diseases is affected by mosaic landscapes compared with more open and homogeneous areas. Although examples of both positive and negative effects exist, there is evidence of greater potential for biological pest and disease control in mosaic landscapes, which adds to the value of natural vegetation for the in situ conservation of resistance genes. However, where agricultural areas are taken out of production as part of conservation set-asides, they may turn into sources of disease inoculum, and intervention may be needed to avoid damage (Chapter 16).

In summary, the available evidence suggests that managing the agricultural matrix for soft transitions between cultivated and protected areas and increased connectivity through a diversified, structurally heterogeneous, and interconnected network of agroforestry elements, preferentially dominated by trees from the regional species pool, could make a substantial contribution to the

long-term viability of plant and animal populations in tropical mosaic landscapes. Whether and at what cost this type of matrix management can be implemented in real tropical landscapes depend critically on the perceptions of farmers who live in such biodiverse landscapes and who will experience both the synergies and the trade-offs between their private goals and the objective of biodiversity conservation. The benefits of greater access to forest products and ecosystem services, such as water supply, pollination, and biological pest and disease control, and the costs of not planting exotic and potentially invasive crop and tree species, of tolerating wildlife on one's farmland, and possibly of coping with pests and diseases that cross-infect between native vegetation and agricultural crops and trees are all parts of an equation that determines whether farmers will perceive the biodiversity of tropical mosaic landscapes as an asset or a liability for which they need to be compensated by those who value this biodiversity and the ecosystem services connected to it.

Outlook and Research Needs

This book provides evidence in support of all three mechanisms through which agroforestry can help conserve tropical biodiversity:

- By helping to reduce deforestation and pressure on forest resources through synergies between agroforestry land use and direct measures of forest protection
- By increasing habitat for native species in cultivated areas, which is most important where natural habitat has been severely reduced
- By providing a more benign and permeable matrix for patches of primary habitat in land use mosaics

This suggests that agroforestry has an important role to play in biodiversity conservation strategies for the tropics, complementing and supporting the essential role of natural habitat within and outside parks and other protected areas. In conservation strategies that integrate agroforestry with other conservation measures, the relative importance of these three mechanisms depends on the specific situation of an area, particularly the degree of human colonization of a landscape and the availability of native habitat. In largely forested wilderness areas, biodiversity will be most effectively conserved by maintaining a maximum of forest cover; consequently, the most important role of agroforestry will be to help reduce the pressure on forestland and forest resources, and the direct habitat role of agroforestry areas will be of secondary importance. In areas where natural habitat has already become fragmented through human colonization, this role will be complemented by the creation of a matrix that maintains connectivity and softens transitions between forest and agricultural areas. The direct habitat role of agroforestry areas will be most important in regions where natural habitat has been greatly reduced so that

agroforestry areas provide some of the last remaining habitat for those forest-dependent species that tolerate a certain level of disturbance.

The effective integration of agroforestry into conservation strategies is a major policy and institutional challenge that necessitates integrated approaches to natural resource management and rural development across traditional disciplinary, ministerial, and departmental divisions. It will also take substantial research and development efforts on biological, agronomic, socioeconomic, institutional, and political levels to close critical knowledge gaps, as well as substantial efforts on the part of scientists to communicate more effectively with decision makers and policymakers.

We conclude with a list of some of the most immediate research needs (in no particular order of priorities), hoping to inspire increased research efforts that may help develop agroforestry into an effective tool to complement ongoing conservation efforts in tropical landscapes.

- Develop, in a participatory manner, indicators and effective monitoring systems to assess the ecological services fulfilled by agroforestry systems, especially in mosaic landscapes comprising both agroforestry and natural forest areas, as both a guide for decision making in land management and a basis for valuing these services and creating political support for biodiversity-friendly land uses.
- Determine the degree to which threatened forest species present in agroforestry systems depend on natural forest within the landscape because this will determine which species will be able to maintain viable populations in agroforestry landscapes in the absence of natural habitat.
- Determine the ecological, social, economic, and political conditions under which shifting cultivation is a stable land use form in biodiversity-rich forested areas; in research on improved fallows include analyses of biodiversity values of longer, extensively managed tree-based fallows and their often substantial use values to local people.
- Assess the ability of different agroforestry types, when planted along forest boundaries, to reduce forest degradation through edge effects, including wind and microclimatic disturbance, invasions by weedy plant and animal species, and fire incursions, as a basis for the strategic use of such systems in buffer zones and mosaic landscapes.
- Determine the effectiveness of different types of agroforestry systems as biological corridors or stepping stones for wildlife (particularly fragmentation-sensitive or edge-avoiding species), the influence of species composition, structure, size, landscape position, and management of these systems, and their associated costs and benefits for farmers and society at large.
- Assess the conditions for hunting sustainability (ecological and economic) in mosaic landscapes, including source-sink dynamics of wildlife populations between agroforestry areas and natural habitat from where overhunted

populations may be replenished; in particular, study the effect of hunting in agroforestry buffer zones on wildlife populations in protected areas, both as it reduces hunting pressure in core areas and as it creates a drain on source populations of hunted wildlife.

- Develop methods of increasing the productivity of traditional diversified agroforestry systems while maintaining biodiversity benefits, and quantify trade-offs between productivity and biodiversity as a basis for designing incentives for farmers to maintain or adopt practices that optimize these trade-offs.
- Design agroforestry systems that optimize trade-offs between biological control of pests and diseases (e.g., through the right species combinations, degree of shade, and structural complexity) and profitability. At the landscape scale, study the effect of diversified mosaic landscapes on the dynamics and interactions of pests, diseases, and their natural enemies and the associated costs and benefits for farmers.
- Identify more indigenous tree species suitable for shading tree crops such as coffee and cocoa that optimize agronomic (labor needs, establishment, growth), economic (e.g., fruits, timber), and ecological benefits (habitat for wild species, nutrient cycling); currently an insufficient number of species (mostly exotics) are used in shaded plantations worldwide.
- Formulate robust strategies to avoid tree invasions and introduction of exotic pests and diseases arising from agroforestry where the use of alien species cannot be avoided, including improved screening and quarantine procedures for alien species and management options for reducing invasiveness.
- Determine the properties of agroforestry systems that increase the acceptance of restricted access to forest resources in protected areas by the local population (e.g., range of products provided by agroforestry, labor, and capital inputs).
- Determine which agroforestry practices, under which circumstances, necessitate initial or even permanent compensations or subsidies to be economically viable for tropical farmers; research the kinds of incentives (e.g., carbon credits, ecotourism, payments for watershed services) that could lead land users to adopt sustainable and biodiversity-friendly land uses and the institutional mechanisms that would ensure that those who fulfill the environmental services of these land uses also benefit from the rewards.
- Develop marketing channels for products from biodiversity-friendly land use systems that ensure that tropical farmers benefit from increased prices of such products in developed countries, including certification systems that are transparent to consumers and that the farmers can afford.
- Use participatory methods to devise effective ways of undertaking land use planning by integrating disciplines that are traditionally spread over several government departments and ministries, such as agriculture, forestry, infrastructure development, tourism, and biodiversity conservation, taking into account current trends toward decentralization of natural resource management in many tropical countries and empowerment of local authorities and civil society.