Chapter 3
Biodiversity conservation in cacao agroforestry systems
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Introduction

The cacao tree (*Theobroma cacao*) is famous for its beans from which cocoa powder and butter are produced. The tree originates from the Amazon basin, whose cultivation started by the Maya and Aztec culture, which used the beans in a drink. In the 16th century, Spanish explorers were the first to bring cacao beans to Europe. Nowadays, cacao has become one of the most important cash crops and cocoa a key ingredient for many sweets and cosmetics. Since the discovery by Europeans, the tree quickly spread and has become important throughout the humid tropics. In the past 30 years, world production tripled to a record of 3,7 million tonnes of dried cacao beans in 2008 and generated an estimated US$ 7,4 billion of income for millions of smallholder farmers (ICCO, 2008).

The world's cocoa production is characterized by the introduction in new countries and the collapse in previous centers of production. After Venezuela (primary exporting country in the 18th century), Ecuador (19th century) and Brazil (early 20th century) (Ruf and Schroth, 2004), Ivory Coast, Ghana and Indonesia are currently the world's most important cacao bean exporting countries (ICCO, 2008). Almost without exception, each rise and fall in cocoa production was and is driven by comparable cut-and-run production cycles with expansion into previously forested areas and abandonment when soil depletion and pest outbreaks make cocoa production uneconomical.

Such agricultural expansion is the primary cause of deforestation and habitat degradation in the tropics (Achard *et. al.*, 2002) and collides with the world's highest terrestrial biodiversity (Myers *et. al.*, 2000). Because cacao plantations can resemble forests in terms of tree cover, such cacao agroforestry systems have gained interest as tool in tropical biodiversity conservation (Rice and Greenberg, 2000). Heterogeneous agroforestry systems in which tall trees are maintained and planted for shade (agroforestry systems) can act as refuge for tropical biodiversity (Bhagwat *et. al.*, 2008). Because cacao agroforestry systems cover well over 8 million hectares of land worldwide (extrapolated from Urquhart, 1955), they have received increasing attention for their potential of harboring tropical biodiversity. In this chapter we will review biodiversity studies from cacao agroforestry systems in tropical America, West Africa and Asia, to identify management aspects that can enhance (native) biodiversity in such agroecosystems. Possible conservation strategies to promote environmentally sustainable cacao agroforestry in general and biodiversity conservation in particular are discussed, as well as some actual scientific challenges.

Cacao agroforestry systems

The natural habitat of the cacao tree is the understory of humid lowland rainforests in the Amazon basin, which explains the need of shade of cultivated cacao trees at least at a young stage (Urquhart, 1955). Cacao agroforestry systems that have reached the productive stage vary widely in terms of management intensity and the presence, density and composition of shade tree stands (Figure 1).

In all cocoa producing regions, agroforestry systems can be found that have dense shade cover (>60%) provided by a diversity of trees that remains from the previous rainforest cover (*e.g.*, Bos *et. al.*, 2007; Faria *et. al.*, 2007; Sonwa *et. al.*, 2007). Such structurally rich "chocolate forests" are a common pioneer form of agricultural land use after expansion into pristine rainforests. As such, these "rustic" agroforestry systems are a sustainable alternative to slash-and-burn practices in which all forest cover is lost previous to agricultural expansion (Rice and Greenberg, 2000). However, the key reason of expansion into forestland is that it is more lucrative than replanting in existing plantations because of cheaper labour and the presence of soil nutrients (the "forest rent"; Ruf and Schroth, 2004), which makes the expansion of cocoa production one of the causes of ongoing forest degradation.

Cacao trees can very well be intercropped with other cash or food crops, which thus form heterogeneous and biodiverse agroforestry systems. Because it takes 3-6 years before cacao trees become productive, intercropping is an existential necessity for many smallholder farmers to grow food and generate income for the time cacao trees are not yet productive. Examples are vegetables (*e.g.*, cassava), spices (*e.g.*, peppers, vanilla), timber and

Figure 1: Cacao agroforestry systems are characterized by the presence/absence and composition of shade tree stands. A – Agroforestry systems with dense shade cover (>60%) provided by a diversity of trees that remain from the previous rainforest cover. B – Agroforestry systems with a shade tree stand that consists of planted or secondarily grown timber and fruit trees such as teak, avocado and palms. C – Agroforestry systems with shade tree stands planted for various benefits to the cacao crop, such as leguminous tree species for their nitrogen fertilizing effects on soils.

fruit trees (*e.g.*, teak, avocado, sugar palm). This type of cacao agroforests is most common after previous forms of agricultural use (*e.g.*, rice paddies, cornfields, coffee plantations, oil palm plantations).

Shade trees can also be maintained for various benefits to the agroecosystem. Leguminous tree species (*e.g.*, *Erythrina* spp, *Gliricidia* spp and *Inga* spp) are widely used for their nitrogen fixation from atmospheric nitrogen. In Indonesia, *Erythrina* and *Gliricidia* trees reportedly resulted in a N-fertilization of soils of up to 69 kg/ha/year (Anhar, 2005). In Perú, shade trees were even successfully used for the rehabilitation of cacao agroforests where production stagnated after soil depletion (Kraus and Soberanis, 2001). In addition, shade tree stands in cacao agroforests have been related to lower pest pressures (Beer *et. al.*, 1998), high carbon storage and sequestration (Verchot *et. al.*, 2007), microclimate stabilization (Sporn *et. al.*, 2009) and soil protection against heavy rainfall (Dietz *et. al.*, 2006).

Alarmingly, shade tree removal is currently inherent to cocoa production cycles. The removal of shade when plantations become productive is predicted to increase productivity in the short term (Zuidema *et. al.*, 2005) and leads to increasingly dominant zero-shade cacao monocultures in all major cocoa producing regions. In the long term, however, shade removal is a recognized threat to the productivity of cacao plantations and is arguably one of the main causal factors underlying the cut-and-run cycles of cacao booms and busts (Ruf and Schroth, 2004).

Biodiversity preserved in cacao agroforests and related agroforestry management

The world's most important cocoa producing regions collide with the world's most important terrestrial biodiversity hotspots (Myers *et. al.*, 2000). These hotspots make up less than 5% of the Earth's land cover, but harbor more than half of all known animal and plant species. In the tropics, these species are mostly confined to rainforests that in the past 50 years lost over half of their land cover (Millennium Ecosystem Assessment, 2005), which poses an unprecedented threat to tropical biodiversity. In landscapes that are dominated by deforestation, agroforestry systems such as shaded cacao plantations may be the major remaining land cover that resembles that of forests in terms of tree cover.

Because of the heterogeneous and forest-like systems in which cacao can be grown, these agroecosystems are recognized by conservation biologists as important element in biodiversity conservation (Rice and Greenberg, 2000; Bhagwat *et. al.*, 2008). Since the 1990s, conservation biologists have assessed the potential role of the different types of cacao agroforests for the conservation of tropical biodiversity in general and for native biodiversity in particular.

Trees

Cacao agroforestry systems are characterized by their tree stands. In the understory, the agroforestry systems are dominated by cacao, but in the higher canopy strata, the stands are represented by a large variety of trees that consist of forest remnants, secondarily grown trees, or planted timber, fruit and nitrogen fixing trees. Depending on management and land-use history, plantations differ greatly in terms of tree species richness and composition. On 0.25 ha study sites in Indonesia, Gradstein *et. al.*, (2007) found a decrease from an average of 21 non-cacao tree species in plantations shaded by forest remnants to less than 10 species in plantations where shade trees were planted. Cacao plantations with a variety of fruit and timber trees inter-cropped, had on average 19 tree species per 0.25 ha.

The proportion of native tree species in shade tree stands generally decreases with increasing age of active plantations, market access and land-use intensity. As soon as farmers put more production pressure on the plantations, native shade trees that remain from previous forest cover are steadily removed or replaced by species for fruit and timber production, which are mostly non-native to the area (Gradstein *et. al.*, 2007; Sonwa *et. al.*, 2007). In Cameroon, Hervé and Vidal (2008) found on average 11 tree species in old growth cacao agroforests, which decreased in tree species richness and diversity with increasing plantation age and management intensity for which they calculated a "management intensity index". Conversely, abandonment can result in a relative increase of native tree species. Sambuichi *et. al.*, (2007) reported a marked increase of total tree species richness up to over 100 species per hectare with increasing time since abandonment of the "cabrucas", the chocolate forests in Bahia, Brazil.

Shade removal is common practice when cacao trees reach the mature stage. Shade tree stands diminish by natural processes (lack of tree recruitment) as well as active removal by cutting, burning and girdling (removing a complete strip of bark). Tree biodiversity decreases when shade thinning proceeds. Shade tree stands could gain complexity by replanting and by assuring sufficient recruitment of saplings as older trees fall out. Such shade tree planting programmes can be part of sustainable cacao programmes to avert deforestation into reforestation through cacao agroforestry (Ruf, 2001).

Herb layer

In cacao agroforestry systems, herbaceous vegetation mostly consists of weeds and weeding is a common practice by cacao farmers. Multi-taxa comparisons of flora and fauna revealed no relation of the herb layer vegetation to overall diversity or species composition of other groups (Clough *et. al.*, 2009; Kessler *et. al.*, 2009), except for conservation of native amphibians and reptiles in the leaf litter layer (Wanger *et. al.*, 2009).

Ramadhanil *et. al.*, (2008) compared the herb layer of shaded cacao agroforestry systems with that of forest sites in Indonesia. Herb species richness in the cacao agroforestry systems was about three times as high in cacao agroforests (35 species per 40 m^2) than in the nearby undisturbed rainforest sites, most likely due to the thinner canopy cover that allows more sunlight to reach lower vegetation layers. Interestingly, cacao agroforests with shade tree stands that remained from previous forest cover had herb layers that showed most similarity with that of the rainforest sites. Species composition changed drastically from plant communities dominated by various families in the forest sites to communities predominantly consisting of Asteraceae, Poaceae and several invasive species in the cacao agroforestry systems with planted shade trees.

Epiphytes

With thousands of species worldwide, epiphytes are the most diverse group of plants in tropical rainforests (Kress, 1986; Gentry and Dodson, 1987; Kelly *et. al.*, 2004). In response mechanisms to environmental change, non-vascular epiphytes (lichens, bryophytes), due to the lack of a protective cuticle, are highly sensitive to changes in the microclimate compared to vascular epiphytes (*e.g.*, ferns, bromeliads). For example, Andersson and Gradstein (2005) found a decrease in richness and diversity of non-vascular epiphytes along a gradient of increasing management intensity in Ecuadorian cacao agroforestry systems. Ariyanti *et. al.*, (2008) found that the species composition of non-vascular epiphytes on tree trunks in rainforests and nearby cacao agroforests differed greatly as richness of true mosses decreased, whereas lichens showed no response. On the island of Sulawesi, Indonesia, Sporn *et. al.*, (2009) found that changes in species composition of non-vascular epiphytes in cacao agroforestry systems were driven by changes in humidity and temperature that in turn resulted from shade tree thinning and removal. Species composition changed in that specialist species native to or even endemic for the rainforests of Sulawesi decreased, whereas pantropic moss species increased.

While vascular epiphytes on tree trunks seem to cope better with changes related to land use intensification, richness and diversity of vascular epiphytes can decrease dramatically when old and tall shade trees are removed (Haro-Carrión *et. al.*, 2009). If shade trees are removed, agroforests can not provide a substitute habitat for these specialist species. Thus, the suitability of cacao agroforests for local non-vascular and vascular epiphytic flora strongly depends on the type of shade management (Zotz and Bader, 2009).

Cacao trees can be richly covered with epiphytes and damage to host trees ("epiphtosis") has been reported, although for epiphytic flora dominated by mosses, no negative effect on cacao tree functioning has been detected (Sporn *et. al.*, 2009). Nevertheless, cacao farmers are trained to remove the often dense layers of non-vascular epiphytes, which may thus pose a threat to this important aspect of native tropical flora in cacao plantations. Moreover, Sporn *et. al.*, (2009) even detected a slight positive effect of epiphyte layers on the fruit-set of cacao, which might point at the benevolent microclimate around epiphytes for cacao's primary pollinators. Bromeliads are vascular epiphytes that store water and have been proved to provide a nesting site for the ceratopogonid midges that pollinate cacao (Fish and Soria, 1978).

Mammals

Protected mammal species are often considered "flagship species" of which the presence is a conservation priority. Based on animal tracks, Harvey *et. al.*, (2005) found that mammal abundance in cacao agroforests can remain as high as in rainforests. However, species richness did decline in agroforests, most likely due to a combination of lacking food resources and higher hunting pressures. The latter may in part can be an effect from farmers' suspicion that mammals, such as monkeys and rats, are primary cacao pests (Arlet and Molleman, 2010).

Cacao agroforests can harbor significant mammal populations, which has been illustrated by Muñoz *et. al.*, (2006) who studied a group of howler monkeys (*Alouatta palliata*) in a Mexican cacao plantation. For decades, these monkeys lived solely from 16 out of 32 shade tree species in the 8 ha plantation. Their presence was not associated with reduced productivity of the cacao trees as the monkeys primarily fed on shade tree foliage. Similarly, Cassano *et. al.*, 2011 reported the Brazilian "cabrucas" as a preferred habitat of the endangered maned sloth (*Bradypus torquatus*), primarily due to the diverse and dense shade tree stands that included forest tree species.

The protection of single "flagship" mammal species necessitates the conservation of other important biodiversity for resources and shelter. For example, Vaughan *et. al.*, (2007) identified over 100 tree species that were used by only two protected sloth species in Costa Rican cacao agroforests, indicating that in order to preserve these two species, a high amount and diversity of trees has to be maintained as well, which in turn may provide habitat to high numbers of other species.

Only few mammal groups inhabiting cacao agroforests, such as bats and other small mammals, have high enough numbers of species to be included in biodiversity research on this type of land-use. Therefore, mammalian biodiversity research in cacao agroforests has concentrated on these animal groups. In cacao agroforests on the island of Sulawesi, Indonesia, Weist *et. al.*, (2009) recorded eight species of rats, four of which were endemic to Sulawesi. Interestingly, the native rat species tended to decline with increasing forest distance, whereas occurrence of introduced species was not related to forest distance. In a selection of Brazilian "cabruca" cacao agroforests, Faria *et. al.*, (2006, 2007) observed 44 species of bats, with richness declining with fragmentation of the forest-agroforest mosaic.

Because mammals in cacao agroforests (particularly rodents) can consume fruits of the cacao tree as well, some native and even endemic species are considered as cacao pests (Entwistle, 1972; Bhat *et. al.*, 1981). Conversely, mammals that primarily feed on the leaves of shade trees can be beneficiary to the agroecosystem in their "pruning" effect on the shade cover and the soil fertilizing effects of their excrements (Muñoz *et. al.*, 2006).

Birds

Dense and diverse shade tree stands in cacao agroforests can harbor high bird species richness. Particularly canopy roaming and frugivorous species can very well cope with cacao agroforests. In a survey by van Bael *et. al.*, (2007) in Panamá, densely shaded cacao agroforests harbored 188 bird species, whereas in the same survey only 148 species were recorded in nearby forest sites. This is in support of results from the Brazilian "cabruca" cacao plantations, where the dense and diverse shade tree stands harbored more birds and bird species than the canopies of nearby natural forest sites (Faria *et. al.*, 2006).

Estrada and Coates-Estrada (2005) compared agroforestry systems (including dense shade cacao agroforests) with forests and zero-shade pastures and found that agroforestry systems indeed preserve levels of species richness that resemble and even exceed that of natural forests, but that species richness declines drastically in other, less shaded forms of agriculture. This key-role of shade trees in the conservation of tropical birds has also been shown on the island of Sulawesi, Indonesia, where bird species richness declined with 80% from forests to cacao agroforests with few planted leguminous trees (Waltert *et. al.*, 2004).

Nevertheless, transition from forest to cacao agroforests does result in changes in species composition. In Panamá, the transition was particularly caused by a decline of understory bird species and favored migratory bird species (van Bael *et. al.*, 2007). In Brazil, the transition caused a shift in bird species assemblages from habitat specialists to habitat generalists (Faria *et. al.*, 2006), which have lower priority from a conservation point of view. Similarly, Clough *et. al.*, (2009) showed a decline in forest specialists in response to increasing distance from forests on Sulawesi. In that study, granivorous bird species were the only group that increased in abundance and richness in cacao agroforests that were more isolated from natural forest sites.

Most bird species in cacao agroforests are insectivores and frugivores (Waltert *et. al.*, 2004, Faria *et. al.*, 2006; Clough *et. al.*, 2009) but there are no known records of birds feeding on cacao itself. In cacao agroforests, birds have even been linked to lower densities of herbivorous invertebrates on cacao trees and were therefore accredited pest reducing properties (van Bael *et. al.*, 2007).

Amphibians and reptiles

Only few biodiversity studies have been carried out in cacao agroforests that included amphibians and reptiles, despite the endangered status of particularly amphibian species (Stuart *et. al.*, 2004). For example, after 35 years of observations, Whitfield *et. al.*, (2007) reported a 75% decline of leaf-litter dwelling amphibians and reptiles in Costa Rican rainforests.

Parallel to the sharp declines in Costa Rican rainforests, Whitfield *et. al.*, (2007) reported a remarkably constant richness and even a slight increase of amphibians and reptiles in nearby abandoned cacao plantations. Although these plantations were abandoned for at least two decades, the contrasting trends could be explained by the fact that cacao trees have several leaf flushing events each year, contributing to a greater leaf litter accumulation while litter accumulation in the natural forest sites decreased, possibly due to effects of climate change (Whitfield *et. al.*, 2007).

Other factors that stimulate the herpetofauna in cacao agroforestry systems are the presence of branch piles, a thick cover of shrubs (Wanger *et. al.*, 2009) as well as ponds and streamlets, and food resources as lepidopteran larvae, beetles and spiders (Solé *et. al.*, 2009).

In their comprehensive field observations on the island of Sulawesi, Indonesia, Wanger *et. al.*, (2009) recorded six amphibian and 17 reptile species in 43 plantations. Habitat variation is required to accommodate the different life histories of the herpetofauna, hence they stressed the importance of a landscape-level, integrative management approach with maintenance of thick leaf litter layers, dense shrub cover and branch piles in cacao agroforestry systems.

For the conservation of native forest herpetofauna, the presence of nearby forest sites is of key importance. Faria *et. al.*, (2007) reported high proportions of native forest lizards and frogs in the Brazilian "cabruca" cacao agroforests, but the amount of forest species declined in landscapes where such "cabrucas" dominated above rainforests.

Insects

With estimated millions of species of which the majority still has to be described, tropical insects make up the most species rich component of the world's biodiversity (Novotny *et. al.*, 2002). This unequalled richness is reflected in the fauna of cacao agroforestry systems as well. Room (1971) observed no less than 240 species of litter and tree dwelling ants in an acre of a Ghanaian cacao agroforestry system. On the island of Sulawesi, over hundred ant species and hundreds of beetle species were found dwelling the canopy of cacao trees in a single valley (Bos *et. al.*, 2007, 2009). In comparison with other forms of land-use, such as annual crops and oil palm plantations, richness of cacao agroforestry systems is high (Bos *et. al.*, 2006) and can be comparable with that of rainforests (Bos *et. al.*, 2007).

Insects provide several key functions in tropical agroecosystems. High numbers of insect species feed on cacao trees, but their most important natural enemies are insects as well (Entwistle, 1972) and they are an important food resource for animals higher up the foodweb (Van Bael *et. al.*, 2007; Solé *et. al.*, 2009). Cacao is pollinated by tiny midges (Entwistle, 1972) and also intercropped fruit crops are primarily pollinated by insects that naturally occur in the agroecosystem or its surroundings (Hoehn *et. al.*, 2008).

Several management aspects have an impact on insect richness directly by affecting resources or indirectly through microclimatic changes and changes in species assemblages. The ceratopogonid midges that pollinate cacao depend on moist habitats rich of rotting plant material, where they breed, feed and remain during the day (Entwistle, 1972). Such substrates are compared to less intensified shaded agroforestry systems and lowland rainforests rare in cacao mocultures that are frequently cleaned. This could explain pollinator deficits on cacao plantations. Management that controls the availability of nesting habitats for midges can play an important role in local increases of pollinator abundances (Young, 1982).

Although cacao agroforests can easily be as rich in insect species as nearby natural forest sites (Bos *et. al.*, 2007, Delabie *et. al.*, 2007), species assemblages have been found to differ between natural forests and cacao agroforests and between differently shaded cacao agroforests. On Sulawesi, Indonesia, Bos *et. al.*, (2007) found changes in beetle species compositions from cacao agroforests with shade tree stands that consisted of trees remaining from the previous forest cover towards agroforests with planted shade tree stands. The difference was primarily caused by an increase in abundance of herbivore and xylobiont beetle species in the agroforests with planted shade (Bos MM and B Büche, unpublished data). This is in support of Klein *et. al.*, (2002) reporting that predator-prey ratios in the entomofauna changed with intensifying land-use, where herbivores increased and entomophagous species decreased.

Bos *et. al.*, (2007) found an almost complete species turnover from nearby natural forests to the cacao agroforests. This, and the fact that information on the distribution of the vast majority of tropical beetles is still lacking, makes it difficult to evaluate the true value of the cacao agroforests for preserving locally native beetle fauna.

Ants are a species rich and ecologically important group of insects that are directly affected by changes in agroforestry management, for example by altered resource and nest site availability (Armbrecht *et. al.*, 2004), but also indirectly through a complex interplay between the microclimate and subsequent changes in the species composition (the "ant mosaic"). Delabie *et. al.*, (2007) found that a Brazilian cacao agroforest with a species poor stand of shade trees harbored a high proportion of forest ants when compared with other tropical agroecosystems and urban habitats. Similarly, Bos *et. al.*, (2007) found that about half of the ant species in Indonesian cacao agroforests also occurred in nearby forest sites, but its proportion decreased with decreasing shade cover.

Shade management affects the microclimate (light, temperature, humidity) in that shade thinning leads to increased light throughfall in the understory, increased temperatures and decreased humidity (Dietz *et. al.*, 2006). Ant species differ greatly in their response to changes in the microclimate after shade tree removal. Some ant species cope better with these altered microclimate than others (Bos *et. al.*, 2008; Wielgoss *et. al.*, 2010), for example by increasing reproduction rates, territorial activity and foraging. Ant species that cope well with such habitat changes are generally common in antropogenically disturbed habitats ("tramp ant species" *e.g.*; Rizali *et. al.*, 2009). Bos *et. al.*, (2008) recorded the yellow crazy ant (*Anoplolepis gracilipes*) in Indonesian cacao plantations, which is one of the most widespread invasive tramp ant species, its introduction linked to significant ecosystem changes and local extinctions of ants, birds and reptiles (Hill *et. al.*, 2003; O'Dowd *et. al.*, 2003). Its presence was stimulated by lower shade tree density and was related to decreases in the number of forest ant species in cacao canopies (Bos *et. al.*, 2009).

Soil fauna

Soil fauna has reached little attention in biodiversity research as it has received little conservation priority. However, functioning soil ecosystems are crucial for proper functioning of the agroecosystem, eventually resulting in sustainable crop productivity. For the cocoa production cycle, soil quality and soil fertility may well be the most important environmental factor facilitating productivity, even more effective and certainly more sustainable than removal of shade trees.

In an experimental approach, Molina-Murguía *et. al.*, (2009) improved the quality of top soil in cacao agroforestry systems by applying several earthworm species and composted organic waste from cocoa production. Such functions of soil biodiversity are particularly important for the many smallholder farmers that do not have the means to invest in agrochemicals and productivity depends solely on the natural processes that affect soil quality and fertility.

Da Silva Moço *et. al.*, (2009) investigated the soil and litter fauna of the Brazilian "cabrucas" and found a positive relation between the thickness of the litter layer and the amount of soil fauna. In Cameroon, Norgrove *et. al.*, (2009) found that the use of fungicides, which are used against some common cacao diseases, negatively affected the earthworm populations. Earthworm densities were comparable in rainforests and in cacao agroforests (81 and 80 m^{-2} respectively) without the use of pesticides, whereas density decreased in agroforests where fungicides were used.

Discussion

Tropical landscapes are dominated by decades of rapid deforestation and are still undergoing further habitat degradation (Millennium Ecosystem Assessment, 2005), which poses a major threat to the immense biodiversity to tropical rainforests (*e.g.*, Sodhi *et. al.*, 2004). In such landscapes, agroforestry systems can be of importance for providing habitat to flora and fauna that are characteristic to the regional forest biodiversity (Bhagwat *et. al.*, 2008). Since the 1990s, a still increasing body of scientific literature has illustrated that for all major plant and animal groups, cacao agroforestry systems indeed harbor levels of species richness that resemble that of primary rainforests, as long as dense and diverse stands of shade trees are maintained that include native tree species.

As any introduction of an agroecosystem into previously undisturbed natural areas, also conversion of natural forests into cacao agroforestry systems causes high species turnover. However, compared with more drastic conversions into, for example, oil palm plantations (see Bhagwat *et. al.*, this volume) and annual crops and pastures, still considerable proportions of native flora and fauna can persist in cacao agroforestry systems. This is underlined by the observations of endangered mammal species that were still supported in cacao agroforestry systems with dense and diverse shade tree stands. For most groups such as mammals, birds, and epiphytes, habitat generalists were less affected and even supported by habitat changes, than habitat specialists that are predominatly found in undisturbed forests. Similarly, native and endemic species have shown high sensitivity to forest conversion into cacao agroforests and subsequent agricultural intensification whereas non-native species tended to profit from these habitat modifications. Invasive, non-native species were even implied as driver of further changes in the supported biodiversity (Bos *et. al.*, 2009). Furthermore, trophic groups can differ in their response to the introduction of cacao agroforestry and related changes in management. For example, frugivorous and nectarivorous bird species were particularly sensitive to decreasing shade tree diversity and density in Indonesian cacao agroforestry systems (Clough *et. al.*, 2009).

However, reports on shifts in species compositions are limited to relatively well-known animal groups or single invasive species of which their natural habitat and distribution are known. From species rich groups, such as beetles and non-vascular epiphytes, too little is known of the natural habitat and distribution of the majority of species, which complicates the evaluation of the conservation potential of cacao agroforestry systems for native biodiversity.

Management implications

Dense shade tree stands that consist at least in part of native tree species or trees that remain from the previous forest cover are the basis of agroforestry management aimed at supporting the highest species richness as well as high proportions of native flora and fauna. Shade trees do not only support high levels of biodiversity, but are as well beneficiary to the overall sustainability of the agroecosystem. Shade removal does increase photosynthetic activity of cacao trees, thereby increasing its productivity, but shade trees also affect nutrient cycles positively to assure longer term availability of minerals to the cacao tree (Beer, 1988). Additionally, shade trees have been related, directly or indirectly, to the natural control of pest outbreaks (Beer *et. al.*, 1998) and to the adaptability of agroecosystems to the adverse effects of climate changes (Verchot *et. al.*, 2007). Besides the benefits to the farmers, shade trees provide environmental services, such as carbon storage and sequestration, which in addition to biodiversity conservation are appreciated particularly by consumers in western countries.

Other local management aspects that facilitate the support of native biodiversity in general and that of local species in particular are those that affect the leaf litter and herb layer, the presence of ponds and streamlets, and piles of dead wood and branches. In general, intensive management includes the regular removal of weeds and leaf litter, which should be discouraged in order to stimulate the conservation of leaf litter fauna that harbors native amphibians and reptiles. The maintenance of ponds, streamlets and piles of dead wood is of importance for amphibians and reptiles, as well as their prey (primarily invertebrates).

Cacao agroforestry management aimed at (native) biodiversity, calls for approaches at the landscape level. Mosaics of forest patches and cacao agroforests were found to harbor higher amounts of native biodiversity than larger scale cacao agroforestry landscapes without undisturbed forest patches. Moreover, particularly groups such as birds and mammals depend on the proximity of natural forests, which further argues for a landscape level approach in which sustainable agroforestry management is combined with the preservation of natural forests and undisturbed (secondary) forest patches.

Although some leguminous shade tree species are purposefully planted for their fertilizing properties, the wide variety of other management tools that benefit biodiversity and the agroecosystem as a whole are rarely applied in cacao extension programmes and mostly depend on extra revenues generated by the cocoa supply chain ("payments for environmental services"; Wunder, 2007). To date, the existence of heterogeneous and biodiverse agroecosystems primarily depends on extensive management that results from, for example, poor market access (Sonwa *et. al.*, 2007), young plantation age (Bos *et. al.*, 2007) or abandonment after pest outbreaks (Sambuichi and Haridasan, 2007). As such, these valuable "chocolate forests" are temporary and condemned to change into less diverse systems as long as farmers are not able to fully profit from the ecological or economic benefits through extra revenues.

Research challenges

In the scientific literature, there is consensus that cacao agroforestry systems with dense and diverse shade tree stands do harbor high levels of species richness. However, particularly for species rich animal and plant groups, such as insects and non-vascular epiphytes, the lack of taxonomic and ecological information at the species level makes it challenging to assess the true value of such agroecosystems for native and endemic flora and fauna. For example, numerous tropical insect and epiphyte species are to date only known from biodiversity studies in cacao agroforests, their natural habitat and distribution unlikely to ever be disclosed. Taxonomic work and tropical biodiversity inventories should include pristine habitats as well as cacao agroforests in order to build upon the knowledge base of the immense tropical biodiversity, which is currently still lacking for the majority of flora and fauna.

Alternatively, indicator species or groups of species may be used to predict patterns in other elements of the local and regional biodiversity that are, for example, less easy or more expensive to investigate. Because the costs of biodiversity research varies greatly between animal and plant groups (Kessler *et. al.*, 2011), several biodiversity studies have used multi-taxa approaches to assess the extent to which patterns in one group can predict those in others (Kessler *et. al.*, 2009 and references therein). Despite the evident importance of shade tree stands for almost all plant and animal groups, few direct relationships have been found between shade tree species richness and, for example, birds and bats (Faria *et. al.*, 2006; Clough *et. al.*, 2009). Relationships appear to be more complex within animal, plant groups and characteristics of the microhabitat, which to date are rarely included in studies. More research is needed on the dependence of animal and plant groups on aspects of the agroecosystem in order to identify the links between indicator groups and their dependence on habitat qualities at the micro- to macro-scale (Kessler *et. al.*, 2009). For example, for the extremely species rich beetles, relationships with shade tree stands is complex as it largely depends on the resources provided by microhabitats within those trees, such as dead wood (MM Bos and B Büche, personal observations).

Despite the detailed knowledge available on shade tree properties (*e.g.*, Asare, 2006) and the benefits for agroforestry systems, shade tree management still tends to tree removal rather than shade maintenance. Shade removal leads to increased photosynthetic activity, thus increasing productivity (Zuidema *et. al.*, 2005), but the more complex interplay between shade trees, environmental factors and, ultimately, the productivity of cacao tree still remains poorly understood.

A major impediment to the conservation of biodiversity in cacao agroforestry systems is the complexity of the cocoa supply chain. The millions of farmers that grow cacao throughout the humid tropics are poorly organized and most live in poverty. Besides soil depletion and pest outbreaks, socio-economic developments are the major driver of the cut-and-run cocoa production cycles that drive land-use intensification and agricultural expansion into natural habitats. Organizing smallholder farmers is complex but possible (Elzakker and Eyhorn, 2010), and certainly necessary for conservation strategies to succeed. Regional smallholder farmer organisations can allow better access to new market developments such as payments for environmental services (Wunder, 2007) and other developments of sustainable agroforestry.

Where cacao agroforestry is introduced into pristine habitats, it is an important driver of forest degradation and deforestation, but the introduction of sustainable shade tree management can make cacao agroforestry an important agent of reforestation. The positive effects of shade tree management on soil fertility and pest outbreaks may hold the key to break the current cocoa production cycles and facilitate the conservation of valuable tropical biodiversity in agroforestry systems.

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