Linking Carbon, Biodiversity and Livelihoods Near Forest Margins: The Role of Agroforestry

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Abstract Agroforestry systems distinguish themselves from other forms of agriculture through their ability to store higher amounts of carbon (C) in their biomass, and often also to conserve more biodiversity. However, in both regards they are generally inferior to forests. Therefore, the impact of agroforestry practices on landscape C stocks and biodiversity needs to be analyzed both in terms of the interactions between agroforestry and forest, which may be positive or negative, and in terms of the conservation of C and biodiversity in the farming systems themselves. This paper argues that in forest frontier situations, the most important characteristic of land use systems in terms of C and biodiversity conservation is to be "land-sparing" (i.e. minimizing forest conversion), which requires a certain level of intensification.

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In land use mosaics, on the other hand, where natural habitat has already been reduced to small fragments, land use practices should also be biodiversity-friendly and have high levels of C storage to complement those in natural vegetation. Agroforestry has a role to play in both situations by making land use more sustainable and by making inhabited reserves ecologically and economically more viable. The paper presents three case studies where different sets of incentives are used to provide communities with the means to conserve C and biodiversity on their land and adjacent forest. In the Sierra Madre de Chiapas, Mexico, C trading is combined with shade coffee (*Coffea* sp.) production to conserve and increase tree cover on farm land in biosphere reserves. In North Sumatra, Indonesia, coffee-growing communities receive technical and marketing support and assistance with legalizing their land tenure situation as incentives to stop forest conversion for coffee, with a prospect of adding C trading later. In the central Brazilian Amazon, communities reforest their land in an extractive reserve and offer reforestation credits on a local market while laying the basis for a more tree-based reserve economy. In all three cases, the bundling of various forms of incentives is meant to increase the resilience of the respective approach to market and policy changes. Approaches like these would benefit from a better integration of agricultural and forest policies.

Keywords Amazon • Biosphere reserve • Environmental service rewards • Extractive reserve • North Sumatra • Sierra Madre de Chiapas

Introduction

Agroforestry systems are distinct from other forms of agriculture in their ability to store higher amounts of carbon (C) in the above- and belowground biomass and soils (Montagnini and Nair 2004; Nair et al. 2010). Similar characteristics – substantial and preferably complex and multi-layered canopies formed by native tree species, reduced levels of disturbance, and high levels of litter and soil organic matter – are also basic ingredients of land use systems that harbor elevated levels of biodiversity in vegetation, litter, and soil (McNeely and Schroth 2006; Schroth and Harvey 2007). Therefore, agroforestry systems (AFS) and especially their most complex, forest-like forms termed "agroforests" (Michon and de Foresta 1999; Schroth et al. 2004a) often combine higher C stocks with higher biodiversity compared to simpler-structured land use systems based on annual crops or sole stands of tree crops. However, the C stocks of AFS are generally lower than those of the natural forests of their respective site. For example, C stocks in cacao (*Theobroma cacao* L.) agroforests in southern Cameroon were 62% of those of mature forest at the same site, and were also significantly less than those of old secondary forests (Kotto-Same et al. 1997). The same is true for biodiversity. Although extensively managed agroforests may harbor a large number of native plant and animal species including certain endangered and endemic species, other more strictly forest-dependent and slow-growing species will avoid them or be progressively eliminated through hunting, weeding, and lack of reproduction, ceding their place to more "weedy" and commercially useful species (Siebert 2002; Sonwa et al. 2007; Cassano et al. 2009). Therefore, when reflecting upon the role of agroforestry systems (or land use in general) in conserving C stocks and biodiversity, it is necessary to consider the wider landscape with its dynamic patterns of forest, agroforestry, agriculture, and other land uses, rather than just the (agroforestry) plot or farm.

Per-area yields of agricultural crops, including tree crops, are generally highest in intensively managed, simply structured (e.g. little or unshaded) production systems, although the life cycle of tree crops is often shorter under such conditions (Beer et al. 1998). Biodiversity and C stocks in production systems, on the other hand, are generally higher in complex structured, diversified, and less intensively managed systems, including complex agroforests (Michon and de Foresta 1999; Rice and Greenberg 2000; Schroth et al. 2004a). It has therefore been asked under what conditions either "wildlife-friendly" but less productive land use practices (such as complex agroforests) or more intensive practices whose higher per-area yields make it easier to "spare" land for habitat conservation would lead to higher overall biodiversity in a given landscape (Green et al. 2005). These authors suggested that if intensification of land use would lead to proportionally greater biodiversity loss than yield increase, it would be more efficient to practice agriculture and biodiversity conservation in separate areas, i.e. follow a "land-sparing" agricultural strategy. If, on the other hand, yield increase through intensification would lead to proportionally smaller losses of biodiversity, then a "wildlife-friendly" agricultural strategy where production and conservation are integrated in the same area (as is the case in complex agroforests) would lead to an overall better conservation outcome for the landscape as a whole. The same principles can be readily applied to C stocks. Although this approach is theoretically appealing, in practice the situation rarely presents itself in such a clear-cut manner, because some wildlife and plant species that are sensitive to even small levels of disturbance require forest habitat, while other species (including certain rare and endemic species) may even do better in somewhat disturbed areas including agroforests (Cassano et al. 2009; Oliveira et al. 2011).

Another way to consider the relative importance that should be given to biodiversity and C conservation either on-farm (i.e. "wildlife-friendly farming") or off-farm (i.e. through "land-sparing" agriculture combined with forest set-asides) within a landscape-wide conservation and development strategy is to distinguish between two types of landscapes: (1) areas where agriculture advances into a forest frontier (e.g. the Amazon, Central Africa or parts of Indonesia), and (2) the more "advanced" stage of landscape transformation of agriculture-forest mosaics where the frontier has "closed" and the landscape is composed of interspersed patches of agriculture or agroforestry with some remnants of natural forest (Chomitz et al. 2006). In the "frontier" case, a primary goal of a "biodiversity and climate-friendly" agricultural development strategy must be to minimize forest conversion, therefore "land-sparing" technologies that generate high yields and farmer incomes in a sustainable manner from a relatively small area of land, combined with effective forest conservation policies should be prioritized (Ewers et al. 2009). This requires agricultural intensification, e.g., through productive planting material and inputs to maintain soil fertility, and may include the use of agroforestry practices for income diversification and increased soil conservation (Schroth and da Mota 2007). Gockowski and Sonwa (2011) analyzed land use scenarios based on different cacao production technologies in West Africa where much forest has been lost to low-producing cacao production systems over the last half-century (Ruf and Schroth 2004). They estimated that, had intensification technologies, including intensively managed cacao-timber agroforests, supported by effective forest conservation policies, legislative reforms, and functioning input and credit markets been systematically pursued from the outset, the same total amount of cacao could have been produced (and income generated) on a smaller area of land. Consequently, over 21,000 km² of deforestation and 1.4 billion Mg CO_2 emissions could have been avoided, while at the same time preserving these countries' valuable timber and non-timber forest resources.

In mosaic landscapes, on the other hand, the size and number of forest fragments may already be too much reduced to conserve healthy populations and assemblages of the regional fauna and flora, especially of naturally rare and wide-ranging species. Therefore, in addition to the need to conserve the remaining patches of forest habitat, relatively more emphasis should be placed on creating or maintaining on-farm habitat and corridors compared to agricultural frontier situations, i.e., a "wildlife-friendly" strategy should be pursued. For example, in southern Bahia, Brazil, shade cacao systems, locally called *cabruca*, play an important role in the conservation of substantial C stocks (Gama-Rodrigues et al. 2011) as well as a large number of endemic plant and animal species in a landscape where natural forest cover has been reduced to less than 10% of its original extent (Faria et al. 2007; Cassano et al. 2009; Oliveira et al. 2011). In both phases of landscape transformation through agricultural expansion, therefore, agroforestry can play an important role in maximizing biodiversity and C conservation, as will be illustrated in the case studies later in this chapter.

Unfortunately, a common situation in tropical land use is quite the opposite of what was outlined above. In frontier situations, where land prices are low and prices of agricultural inputs needed for intensification are high, land use is often wasteful in terms of land and forest consumption rather than "land-sparing" (Barbier 2005). Once the frontier has closed, land becomes more expensive and agrochemical inputs cheaper, and so a greater emphasis is placed on intensification precisely when "wildlife-friendly" land uses are most needed to complement the dwindling natural habitat. There is, however, some reason for hope that this situation could change in the future. As the case studies below will show, C and biodiversity conservation are locally already becoming sources of income for tropical farmers, complementing income from agricultural production itself, and such opportunities could expand through several mechanisms:

1. A number of certification systems recognize practices that correlate with biodiversity conservation both at the farm level (e.g., shade use in tree crops, maintenance of riparian buffer strips, and on-farm forest reserves) and to some extent at the landscape level (e.g., prohibition of deforestation). Although not specifically designed for that purpose, these practices also impact favorably on C stocks.

Furthermore, some certifiers (such as the Rainforest Alliance: www.ra.org) are working to integrate C sequestration explicitly into their standards. Since the demand for certified agricultural commodities is increasing rapidly on the global markets, environmental certification is a way through which farmers may benefit from biodiversity and C conservation through increased market access, price premiums and also the technical support that often comes with certification programs.

2. While environmental certification of smallholder tropical farmers is well established in Latin America and rapidly advancing in Africa and Asia (Neilson 2008), access for smallholder farmers to markets for C credits from afforestation/reforestation projects that reward high C and biodiversity agroforestry practices has advanced more slowly. This is due to the significant technical and administrative obstacles and transaction costs that are inherent in the development of C projects (Torres et al. 2010; Brown et al. 2011). Examples of agroforestry projects where these obstacles have to some extent been overcome are presented below and in other chapters of this volume.
3. High C and biodiversity production systems may also be rewarded indirectly by opening additional market opportunities for farm timber and non-timber products for local, national, and potentially international markets (Sonwa et al. 2007; Gockowski et al. 2010).

A well established approach to the simultaneous pursuit of livelihood development and the conservation of biodiversity and ecosystem services, including C stocks, is the creation of specifically managed areas such as sustainable use reserves, including biosphere reserves, where land use options are regulated by management plans distinguishing various use and non-use zones and prohibiting deforestation and certain forms of land use that are considered unsustainable or destructive. In return, the traditional, legal inhabitants have access to certain forms of government support such as secure land tenure, housing, and special government or externally funded projects. This type of legally inhabited, sustainably managed areas is particularly well established in Latin America. Despite land use restrictions and their (partial) focus on forest conservation, some reserves produce significant amounts of agricultural commodities. For example, the biosphere reserves of the Sierra Madre de Chiapas in southern Mexico that are discussed in the first case study are one of the most important production areas of Arabica coffee in Mexico, while the Tapajós-Arapiuns Extractive Reserve that is presented in the third case study hosts substantial areas of community rubber agroforests (Schroth et al. 2003) although many of these are now temporarily abandoned awaiting an increase in rubber prices and better market access. The role that agroforestry can play in the conservation of biodiversity and C stocks at a landscape scale by increasing the economic and ecological viability of biosphere and sustainable use reserves has not received much attention, although these reserves offer a unique institutional framework for integrating conservation and development objectives and could offer relatively easy opportunities for the labeling of “sustainable landscapes” as a form of distinguishing their products on regional and global markets (Ghazoul et al. 2009).

In the following, we present case studies from ongoing projects from a mosaic landscape in Mexico and forest frontier landscapes in Sumatra and the Brazilian Amazon where agroforestry practices contribute to preserving the biodiversity, C stocks and other ecosystem services both directly on farms and indirectly through their interaction with natural forest and their contribution to the sustainable livelihoods of their inhabitants.

Case Study 1 – Sierra Madre de Chiapas, Mexico

In the first case study, we discuss a project that uses agroforestry practices to connect smallholder farmers in several biosphere reserves in southern Mexico to voluntary C markets, thereby reinforcing and complementing existing incentives to use sustainable and biodiversity-friendly land use methods and helping to protect the integrity of the reserves. The Sierra Madre de Chiapas is a mountain chain covering about 1.8 million ha in southern Mexico that runs parallel to the Pacific coast (Fig. 1). The region is recognized for its biodiversity and provides important watershed services to the surrounding lowlands, especially the narrow but agriculturally important coastal plain and the central valley with the state capital Tuxtla Gutierrez. The higher elevations of the Sierra Madre are included in a system of biosphere and forest reserves that host over 27,000 inhabitants (Schroth et al. 2009).

The Sierra Madre is an important production area of high-quality Arabica coffee and many of its inhabitants make a living as coffee growers, especially at elevations upward of 600 m and in the southern and more humid parts of the mountains, while cattle and annual crops such as maize (*Zea mays* L.), cultivated in slash-and-burn systems, are more important in the drier north and at lower elevations. Since the mid 1990s, the US-based non-profit organization Conservation International (www.conservation.org) had been working with coffee farmers especially in the buffer zone of El Triunfo Biosphere Reserve, providing technical assistance in agricultural best practices, such as the use of diversified coffee shade and the conservation of forest, with the objective of harmonizing farming and biodiversity conservation. While initially working with several private sector partners, the program received a significant boost in the late 1990s through a partnership with Starbucks Coffee Company which sourced coffee from participating farmers and created its Organic Shade Grown Mexico brand (Perez-Aleman and Sandilands 2008). By the mid-2000s the program involved about 900 farmers and had some notable successes: participating farmers "earned 20% more per ha [compared to non-participants]; nine out of ten families were able to make improvements to their homes; 72% reported being able to consume meat more than once every 10 days, compared to only 50% for non-participants" (Perez-Aleman and Sandilands 2008). However, the cost of the technical assistance to the farmers and the dependency on external funding made it difficult to sustain and further scale up the program, therefore additional incentive and funding mechanisms were needed.

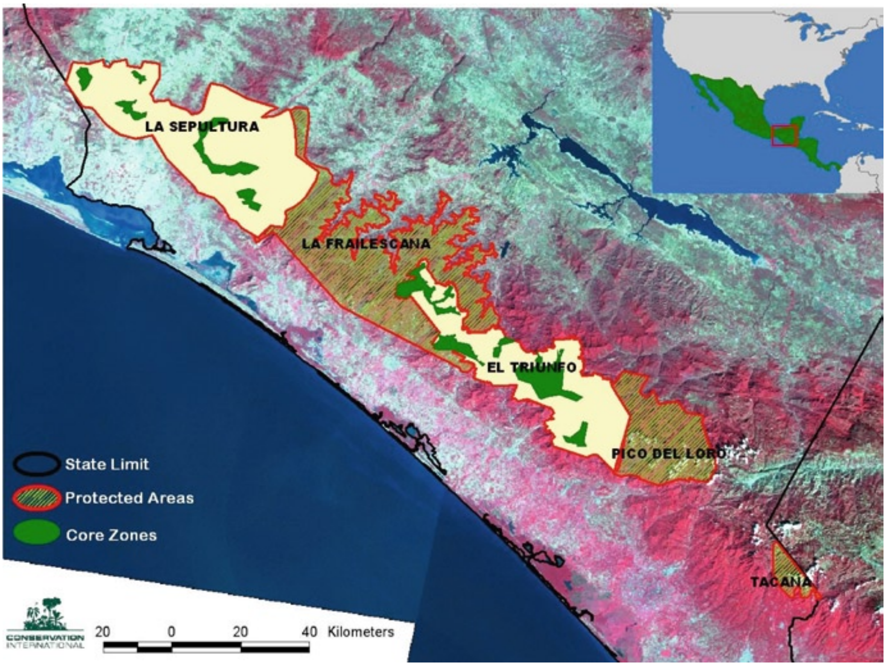

Fig. 1 The protected areas system of the Sierra Madre de Chiapas, Mexico (From Schroth et al. 2009)

Practices such as the use of complex shade canopies in coffee and the conservation of forest, beside protecting biodiversity, also increase (or maintain) the C stocks of farms and landscapes. Therefore, in the mid 2000s, when C markets were slowly emerging as an option to generate additional farmer income, it seemed logical to pursue the integration of the coffee program with C sequestration, thereby diversifying the incentives offered to farmers for C and biodiversity friendly land use practices. A second reason for pursuing this integration was that coffee growing, although a very important land use in the higher parts of the Sierra Madre, is by no means the only one. Highland farmers also grow annual crops such as maize and beans (*Phaseolus* sp.) in fallow rotations, raise small numbers of cattle, and extract forest products such as *xate* palm leaves (*Chamaedorea* sp.) that are used in decoration. These other land uses, which become relatively more important towards the lower and northern parts of the Sierra Madre, were practically not affected by the coffee program, and this reduced its potential to impact the landscape as a whole. For example, conservation and C benefits obtained in the coffee farms could partly be offset by fire use in pasture areas or clearing of secondary forest for food crops by non-participating farmers. This was particularly evident in the drought year 1998 when a total area of 37,336 ha or 22% of La Sepultura Biosphere Reserve was affected by wildfires, including 20% crown fires, that destroyed forest and coffee farms (Schroth et al. 2009).

In 2007, Conservation International therefore partnered with a local NGO, Ambio, which managed the *Scolel Té* (Tzeltal-Mayan for “The growing tree”) program in other parts of Chiapas and Oaxaca, already benefiting several hundred families. This program, which is described in detail in this volume by Ruiz-De-Oña-Plaza et al. (2011), connects small farmers to voluntary C markets through a participatory, community based land use planning process where farmers can choose among a number of “modules” (such as planting additional shade trees in coffee, establishing live fences, reforestation of pasture, fire damaged or landslide areas, etc.) that generate C benefits and implement them with the help and under the monitoring of the program (Torres et al. 2010; Zepeda et al. 2010). The *Scolel Té* program began in 1994 as an academic project by the research and higher education institution *El Colegio de la Frontera Sur* (ECOSUR) in San Cristobal de las Casas, in partnership with the University of Edinburgh and Pajal Yakaktic, a farmer organization based in Chiapas. At that time, a participatory diagnosis and design study was carried out to select the main technical interventions and determine the associated costs as well as the social organization required for their implementation. As a result, the cooperative Ambio was created. Starting in 1997, Ambio negotiated C credits from the project on the voluntary market using the “Plan Vivo” standard (www.planvivo.org) that had been developed for *Scolel Té* but is now being used globally (Torres et al. 2010).

The *Scolel Té* approach is flexible. The land use “modules” that are offered to the communities are treated as initial suggestions and are later often modified and adapted to the farmers’ specific needs, for example by maintaining colonizer trees among planted trees or grazing cattle under trees. Another important advantage of the approach is that it leads to early payments to farmers, with installments in years 1, 2, 3, 5 and 8 subject to the results of a continuous monitoring and technical support program, while other methodologies often involve a delay of many years between project design and implementation, credit sales, and actual payments to the land users which is a disincentive to small farmers (Torres et al. 2010; Ruiz-De-Oña-Plaza et al. 2011).

For the pilot project integrating Conservation International’s coffee program with the *Scolel Té* C sequestration program, initially eight coffee communities were chosen. Although costly in logistical terms, the eight pilot communities were widely spread across the Sierra Madre so that the approach could be tested under a range of biophysical and socioeconomic site conditions. Areas where the reserve administration (the National Commission of Protected Areas) perceived a high risk of land use change either from forest to agriculture or from coffee to annual food crops were prioritized. Through a participatory process, the communities were familiarized with the Plan Vivo methodology and the various land use modules that would generate C credits. Within the first 2 years of the project, 144 farmers participated in the capacity building process of which finally 54 planted trees on a total of 57.25 ha of land, opting mostly (83% of the area) for live fences in pastures or sometimes in coffee. Live fences are an agroforestry technique that can easily be integrated into the local farming systems without negatively affecting crop or pasture yields, thus presenting low opportunity costs, but can sequester non-negligible amounts of C

(28–54 Mg per ha depending on the site; Torres et al. 2010) and generate significant positive impacts in terms of biodiversity conservation (Harvey et al. 2004). On the other hand, and in line with expectation, farmers opted less frequently (14.8% of the area) for increasing the shade canopies in their coffee farms because they already used very dense shade and further increasing it could have augmented disease pressure and compromised the coffee yields. The remaining 2.2% of the area were used for improved fallow plantings. Based on these choices and estimated growth rates, the C income of the participating farmers was estimated at USD 295 over the next 5 years. In 2009, the program forward-sold the first C credits.

Building on this initial pilot phase, the project is now being scaled up to 19 communities in the Sierra Madre, while more farmers are joining in already participating communities. By end 2010, an additional 176 farmers had committed to planting 376 ha, with an even stronger preference for live fences (90% of the committed area). With the expansion of the program, it is hoped that eventually a critical mass will be reached where further growth will be less dependent on external funding. This scaling-up in the field needs to go hand in hand with scaling-up of marketing efforts for the C credits, as well as the sustainably produced coffee, to avoid future bottlenecks. Experience will show if there are synergies on the market in advertising both sustainably grown commodities and C credits with a strong social component from the same landscape, and if this will eventually lead to the recognition of the Sierra Madre as a “sustainable origin” or “sustainable landscape” to help distinguish its products in an increasingly crowded marketplace for certified or otherwise “special” products.

The design process of this project integrating conservation agriculture with C trading also revealed strong links between climate change mitigation and adaptation and the role that agroforestry practices can play in both (Schroth et al. 2009). Beside the predicted increase in temperatures, which may negatively affect coffee quality and thus its value on the market, the increasing risk of extreme climate events, including rainstorms as well as droughts, is a particular concern for a region that has been severely affected in the past by hurricanes and wildfires (Schroth et al. 2009). Significantly, recent research has shown that complex vegetation, such as forest and shade coffee, reduces the vulnerability of farmland to landslides (Philpott et al. 2008). On the other hand, fire management plans and reforestation of pasture land, where many wildfires originate, increase C sequestration and reduce the risk of accidental C losses during drought years (Schroth et al. 2009).

Case Study 2 – North Sumatra, Indonesia

This case study is focused on illustrating the practical role of agroforestry in improving livelihoods and reducing deforestation in the context of the Indonesian coffee sector. The study is being undertaken in the highlands of North Sumatra, Indonesia. Sumatra is the third largest island in Indonesia, measuring 1,800 by 400 km. It contains an extraordinary wealth of natural resources and habitat diversity (Whitten et al. 2000), which are crucial for maintaining the welfare of the island's 50 million people. Dairi district with its capital Sidikalang is one of the key coffee growing areas of North Sumatra, with an annual production of 9,300 Mg on about 20,000 ha, out of about 80,000 ha under coffee for all of North Sumatra. It is situated adjacent to Lake Toba, the largest volcanic lake on earth, location of two hydropower plants (Asahan and Lae Renum) that are critical for Sumatra's power supply, and a key freshwater biodiversity area (Fig. 2).

The margins of Lake Toba are largely deforested and sedimentation and agricultural runoff are impacting the ecology of the lake. The sedimentation rates are estimated at 1–3 cm per year according to the Indonesian Environment Ministry.[1] Only the western margin is still under protection forest, most of which is in Dairi district (Fig. 2). According to the district administration, Dairi has lost 60% of the vegetation of its water catchments due to deforestation. This often involved the encroachment of protection forests, including for coffee farming. In quantitative terms, this deforestation is relatively insignificant compared to the deforestation that has affected Sumatra's lowlands over the past 15 years. However, considering the already small remaining area and ecologically sensitive role of the protection forest in the Lake Toba watershed, further forest loss in this area is clearly a concern. Furthermore, although the conversion of production or protection forest into agricultural land often happened many years ago, the production of coffee (and other agricultural products) on encroached land is formally illegal and, according to field interviews, subjects the farmers to occasional fines. With an increasing emphasis on traceability in the global (and Indonesian) coffee industry, it also complicates the access to higher-paying specialty coffee markets for these communities (Arifin et al. 2008; Neilson 2008). In fact, the project presented here was partly motivated by the concerns of Starbucks coffee buyers who had witnessed forest conversion for coffee farms in this important coffee supplying region (C. Jordan, 2005, personal communication to G.S.).

Based on field surveys in 2005 in communities along the forest boundary and interviews with government officials in Dairi district by Conservation International and its local partner, the fair-trade company ForesTrade-Indonesia, the project focused on four coffee communities, Barisan Nauli, Sileu-leu Parsaroan, Pagambiran, and Perjuangan (Fig. 2). As in other similar studies of the causes of forest encroachment and seemingly unsustainable use of forest resources in Sumatra (Arifin et al. 2008; McCarthy 2006), the interviews revealed a complex set of factors driving the encroachment. These included an influx of migrants, their allocation of land at the forest boundary by resident relatives possibly with the intention of expanding the agricultural area of the communities, lack of clarity about the exact location of the legal boundary between agricultural and protection forest land among the communities, and lack of enforcement of forest protection laws by the authorities. They also included lack of technical support and agrochemical inputs to help farmers establish coffee farms on degraded grassland – of which large areas are available – instead of

[1] Jakarta Post, 15 May 2010.

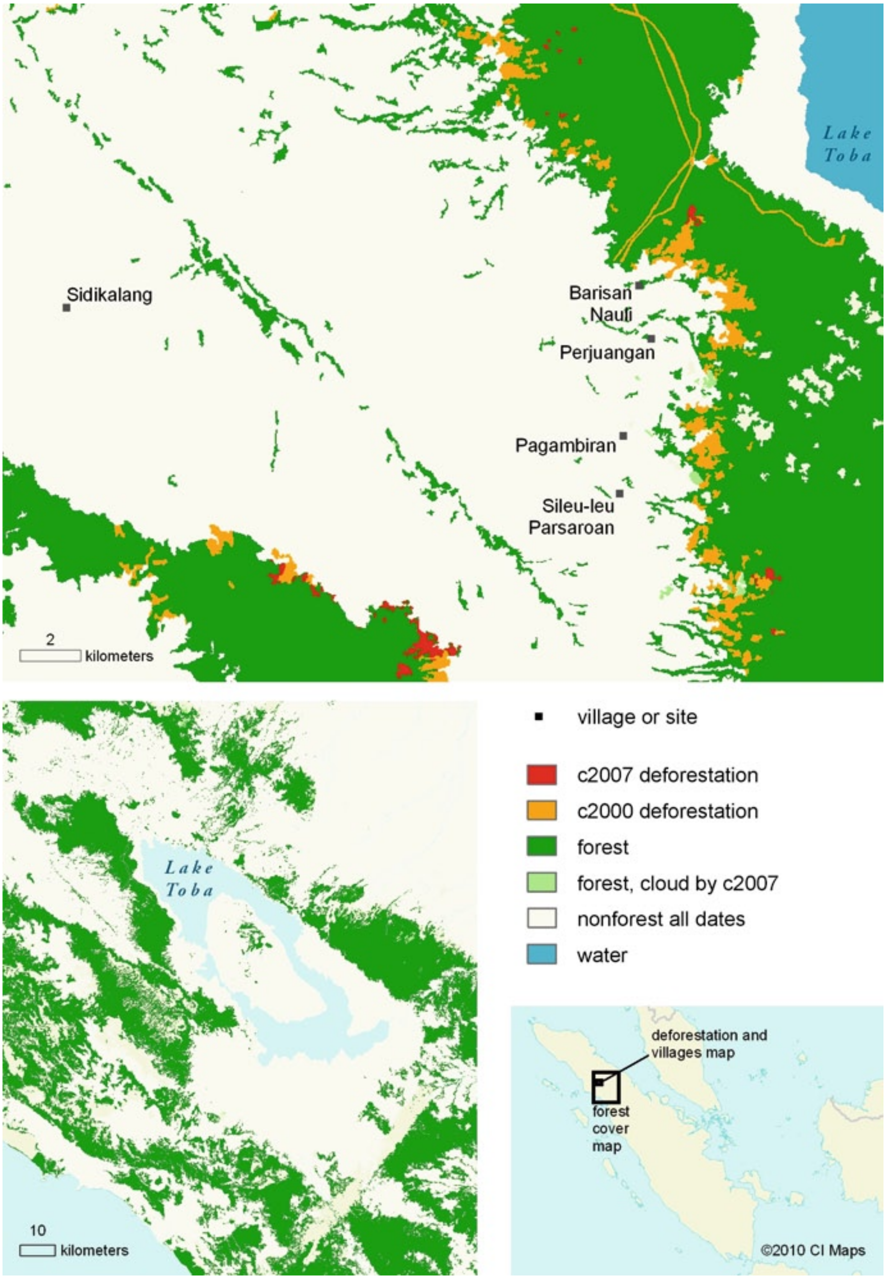

Fig. 2 Coffee communities on the boundary of a forest protecting the watershed of Lake Toba in North Sumatra, Indonesia (map by Kellee Koenig)

the more fertile forest soil, and to maintain and rehabilitate coffee farms when coffee productivity has decreased for lack of management and soil conservation. Finally, in contrast to neighboring Aceh where coffee is typically grown under the shade of planted legume trees, coffee in the Lake Toba area is mostly cultivated under full sun conditions, thereby foregoing the benefits of shade use for soil conservation and a longer productive life of the coffee bushes. Coffee is, however, locally grown under benzoin (*Styrax* spp.) and other productive trees elsewhere in North Sumatra (Garcia Fernandez 2004).

From the constellation of factors contributing to deforestation, it was clear that the problem could not be addressed through incentives targeting individual farmers, such as conventional certification, but had to involve entire communities which controlled the access to the forestland. The principal aim was to stop deforestation and the degradation of standing forest with their implications for C storage and biodiversity, rather than reforesting already converted forest land which was considered unrealistic under the given socio-political conditions. The project therefore offered the communities an agreement whereby it would provide technical assistance with coffee agroforestry practices and quality improvement and would help them access specialty markets for their coffee. The project would also work with the government to include the communities in a Community Forestry Management scheme as established by Indonesian law that would legalize the coffee harvesting though not the sale of the land. In return, the communities would permanently demarcate and monitor a jointly agreed *de facto* forest boundary. In a subsequent step, the project would help the communities to access markets for the C sequestered in agroforestry plantings on the former forest land, following the example of the Mexican case study presented above.

The community of Perjuangan was the first to accept the offer. Starting in 2006, the project provided farmers with training in coffee agroforestry practices and integrated pest management through a combination of field schools and demonstration plots in the communities, which included a strong focus on the advantages and practicalities of shade coffee. The field schools also provided training in organic compost making, coffee pruning and management, diversification with avocado (*Persea americana* Mill.), sugar palm (*Arenga pinnata* (Wurmb) Merr.) and timber trees (*Toona sureni* (Blume) Merr., *T. sinensis* (A. Juss.) Roem.), post harvest management, marketing, and community-managed nurseries. The *de facto* forest boundary of Perjuangan was agreed upon and demarcated with cement blocks and a tree row in the presence of government officials in early 2009. In collaboration with the local Watershed Management Board, the project facilitated the submission of an application for the inclusion of 10,000 ha of former forest land into the Community Forestry Management scheme to the Minister of Forestry and the Head of Dairi District in October 2009. In late 2010, these community conservation agreements were supported by approximately 475 households in Pagambiran, 340 households in Sileu-leu Parsaoran, around 370 households in Perjuangan, and 24 members of the local farmer group in Barisan Nauli, which has a population of approximately 2000. In 2010, the 280 farmers of Sileu-leu Parsaoran managed to arrange their first sale of coffee to a major exporter, demonstrating their increased capacity to produce a quality product, and connect that product with the international market.

The expected declaration of the converted forest land as “community forest” will allow the communities not only to legally harvest their coffee, but also to directly benefit from C revenues that would be generated through agroforestry plantings and forest conservation on this land. However, to enable the C revenues to flow, there are still legal barriers since the legal framework of C trading in Indonesia does not yet permit smallholder participation in the global voluntary C markets, though promising advances in the respective policy discussions have been made, for example through the publication of the draft “National Strategy for the Reduction of Emissions from Deforestation and Forest Degradation (Nastra REDD plus)” in 2010.

Case Study 3 – Tapajós-Arapiuns Extractive Reserve, Brazilian Amazon

In this section we discuss the contribution of agroforestry and a specific Brazilian market for reforestation credits to increasing the ecological and economic viability, thereby helping to conserve its forest C stocks and biodiversity. The study area is the Tapajós-Arapiuns Extractive Reserve in western Pará State, Brazilian Amazon. Similar to the previous case study, C trading is not (yet) a component of the project which uses another environmental service market to create incentives and rewards for practices that, while mainly targeting sustainable timber and non-timber supplies, also conserve landscape C stocks and biodiversity.

Protected areas, including sustainable use reserves and indigenous lands, are widely recognized for their contribution to reducing deforestation and forest degradation in the Amazon (Nepstad et al. 2006). They play a key role in the conservation of the biodiversity and C stocks of this largest of tropical forests. Extractive reserves as a specific form of inhabited protected areas were created as a response to the conflicts between traditional rubber tappers and expanding cattle ranches in the western Brazilian Amazon during the 1980s (Cardoso 2002). The first extractive reserve was created in 1990 and today there are more than 11 million ha of extractive reserves and more than ten million ha of (closely related) sustainable development reserves in the Brazilian Amazon (ISA 2007), forming large-scale corridors with other forms of protected areas and indigenous lands (Fig. 3). Ruiz-Perez et al. (2005) demonstrated the effectiveness of the Alto Juruá Extractive Reserve in the western Amazonian state of Acre in reducing deforestation rates compared to surrounding areas.

The concept of extractive reserves was criticized early on based on the commonly held view that extractivism in species-rich tropical forest is rarely a way out of poverty (Homma 1993). However, the economic basis of “extractive reserves” is not always extractivism, but may be family agriculture and agroforestry complemented by fishing and some hunting. Such is the case in the Tapajós-Arapiuns Extractive Reserve, an area of 650,000 ha with approximately 20,000 inhabitants in about 70 communities located mostly on the banks of the Tapajós and Arapiuns

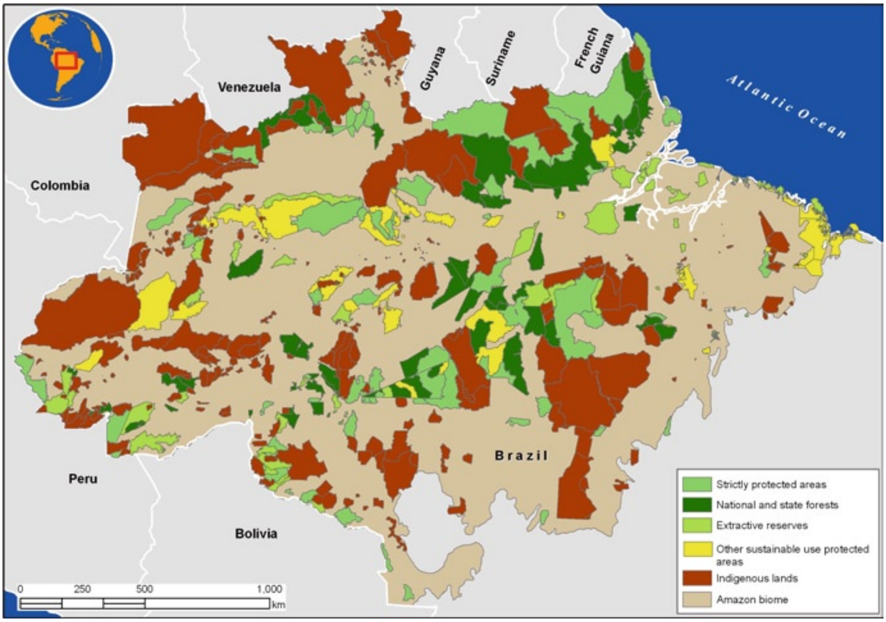

Fig. 3 Protected areas in the Brazilian Amazon. National forests, state forests and extractive reserves are different types of sustainable use protected areas (map by Luis Barbosa)

rivers in western Pará state (Fig. 4). The area was protected in 1998 after a history of conflict between communities and logging companies (Menton 2003).

The Tapajós valley has a strong agroforestry tradition, reaching back at least to the early twentieth century (Schroth et al. 2003). Farmers used to plant rubber seeds (*Hevea brasiliensis* H.B.K. M.-Arg.) in their slash-and-burn plots together with their staple cassava (*Manihot esculenta* Crantz) and some other food crops. After the second cassava harvest, the rubber saplings were tended for a few years until they could cope with the evolving fallow vegetation. The plot was then abandoned until the rubber trees had reached sufficient size for tapping at an age of 7–14 years (the earlier dates indicating that very small trees were tapped). At that time, paths connecting the rubber trees were cleared in these plantations turned secondary forests, and the trees were tapped about twice per week during the rainy season and allowed to rest during the dry season when the latex flow is reduced. Unlike in the very similar and better documented Indonesian rubber agroforests (Michon and de Foresta 1999), neither detailed biodiversity nor C studies have been carried out in the traditional rubber agroforests of the Tapajós. However, these agroforests can reach an age of more than 50 years, are structurally complex, and are responsible for the almost continuous tree cover of the banks of the Tapajós and Arapiuns rivers, merging further inland into secondary and old-growth forests (Fig. 4). They store significant amounts of C (a sample of eight rubber agroforests on the eastern river bank

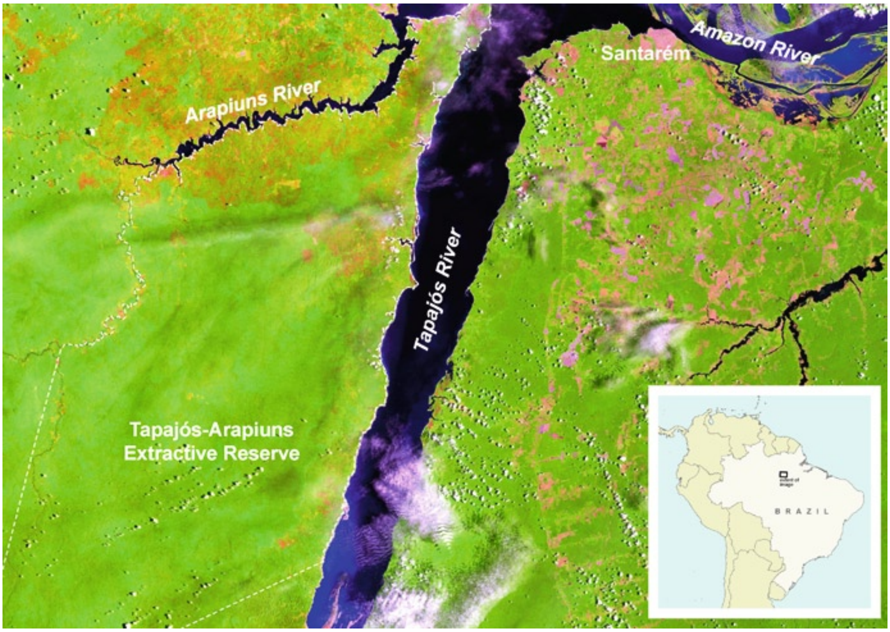

Fig. 4 Location of the Tapajós-Arapiuns Extractive Reserve on the left bank of the Tapajós River in western Pará state, Brazilian Amazon. On the satellite image, the more disturbed "agroforestry zones" along the river banks can be distinguished from the relatively intact interior of the reserve. The contrast to the unprotected area south of the city of Santarém is clearly visible (map by Kellee Koenig)

had estimated C stocks in the aboveground tree biomass of 143 (S.D.= 63) Mg ha^{-1}; G. Schroth, unpublished data) and provide wildlife populations of the adjacent forest with seasonal food resources such as rubber seeds and fruits from interspersed fruit trees (Schroth et al. 2003). However, their main potential from a landscape point of view in this "forest frontier situation" would be to offer a sustainable source of income to their owners, thereby increasing the economic viability and ecological integrity of the reserve as a whole. Unfortunately, in recent years low and fluctuating prices of rubber latex and sometimes even difficulties to sell latex in the region have meant that most rubber agroforests at the Tapajós are now abandoned and the cultivation of cassava in slash-and-burn systems for self-consumption and sale of roasted flour (*farinha*) on the market in Santarém has become the main activity and source of income of the reserve inhabitants. This strong reliance on slash-and-burn agriculture in a seasonally fire-prone region is considered undesirable by the reserve administration. With the growing human population, it risks driving an inland expansion of the agricultural frontier within the reserve, and to potentially increase deforestation, human-wildlife conflict, and hunting (Carvalho and Pezzuti 2010). Furthermore, community meetings revealed that cassava growing and roasting are considered much heavier and unhealthier work by the often elderly reserve inhabitants, compared to rubber tapping in the shade.

These traditional rubber agroforests are being planted from seeds, and although some trees in a plantation can be very productive, most trees are of low productivity (Schroth et al. 2004b). A government sponsored attempt in the late 1990s to provide the communities with grafted saplings has been unsuccessful owing to high mortality, apparently related to logistical problems in seedling distribution and insufficient technical assistance (species of several other tree crop species suffered a similar fate). However, even in the surroundings of Belterra and Aramanaí on the eastern river bank, where farmers had, until recently, ready access to grafting technology from commercial rubber plantations, grafted rubber plantings are the exception rather than the rule, suggesting that the use of seeds to establish rubber agroforests is a conscious strategy to reduce costs and risks, both ecological ones from fire and drought, and economic ones from unpredictable markets and government policies (Schroth et al. 2003). A technological package to improve the productivity of new and existing rubber agroforests without interfering with their "low input logic" has been developed (Schroth et al. 2004b) and presented to more than 20 communities in the extractive reserve in 2004. But despite considerable interest from the communities it had limited impact given that with the low rubber prices of the time, few new agroforests were established and most existing agroforests were not tapped. Recently, the market price of natural rubber has increased and, in addition, the federal government of Brazil has announced a subsidized price for Amazonian rubber (Brasil 2010) which could dramatically change this situation, but this subsidy has not yet become available to the communities in the reserve at the time of writing.

Parallel to these efforts to revitalize rubber agroforestry, a new agroforestry practice was introduced in cooperation with the reserve administration over the past few years. In Brazil, the federal "forest supply" (*fomento florestal*) law of 1996 requires that companies that use wood from unsustainable sources (such as forest conversion) replant a proportional number of trees, with the long-term objective of creating a closed cycle of wood use and planting, thereby reducing the pressure on natural forests. In subsequent directives, a ratio of eight trees per cubic meter of wood has been established. In 2003, the environmental authorities decided to implement this legislation systematically in the Amazon and needed suppliers of reforestation credits that could be purchased by those wood consumers that had no own land or technical capacity to conduct reforestation operations to offset their consumption. The idea thus arose to technically and legally enable community organizations in the Tapajós-Arapiuns Extractive Reserve to reforest with native trees areas of reserve land that had been deforested through slash-and-burn agriculture or earlier logging and sell reforestation credits (not trees) to wood consuming companies in the region. This seemed to be a "win-win" approach that would allow the communities over the short term to earn additional income from credit sales and on the longer term to redirect their activities from slash-and-burn agriculture to the commercialization of non-timber and timber products from individually owned and registered single or mixed species plantations of commercial tree species. The environmental authorities, on the other hand, would increase their supply of credits that they could leverage to compel wood consuming companies to comply with the legislation while at the same time addressing the problem of insufficient land use options in the reserve.

The *fomento florestal* law did not explicitly mention the possibility of communities reforesting federal land (such as extractive reserves), but a request for clarification from the project to the Directorate of Forests in Brasília obtained a positive response, as long as the reforestation activity was not in conflict with the management plan of the reserve. Following an onerous administrative process that took well over a year and involved government agencies at the region, state, and federal levels, a previously existing association of five communities, which had been chosen for this project for its dynamic leadership, critical mass of members interested in reforestation, and existence of a (dysfunctional) community nursery, received the official authorization to administer reforestation projects in the reserve under this law. This was to our knowledge the first time that such an authorization was obtained by a community based organization in an extractive reserve in Brazil. While this administrative process was ongoing, inhabitants of the five communities as well as some neighboring communities produced timber tree seedlings in the community nursery and planted them in their slash-and-burn plots, as they previously used to do with rubber seeds and seedlings. In 2006 and 2007, the community association completed three credit sales totaling about R$ 25,000 (~USD 15,000) the returns of which were distributed to the participants, used to produce more seedlings in the community nurseries (which mostly employed women from the communities) and to cover the costs of administration and technical assistance. These sales increased substantially the demand for the new agroforestry practice among the participating and other communities in the reserve. In 2008, the project won support from the World Bank through its annual Development Marketplace competition which allowed the project to be scaled up to presently over 350 families from 46 communities, including some in very remote parts of the reserve that had rarely been reached by earlier projects. Although by choice of the communities all plantings were individually owned, the seedlings were produced in community nurseries and so community organization and technical support to communal work absorbed a large share of the project's resources. At the time of writing, the main challenge of the project was that in the course of the decentralization of the Brazilian forest administration, the responsibility for the implementation of the *fomento florestal* law had been shifted from the federal to state agencies, temporarily interrupting the community organizations' access to the reforestation credit market. This problem was being addressed through discussions with government agencies at different levels. While the outcome of these discussions is difficult to predict, it should be noted that the credit sales, while an important encouragement to the communities, are only part of the benefits they receive, the more important long-term ones being the creation of a basis for a reserve economy founded, once again, on tree products.

This project, like those described in the previous case studies, has the dual objectives of conserving the forest resources of the extractive reserve with its C stocks and biodiversity, and to improve the livelihoods of its inhabitants in a sustainable way. Although among its objectives are forest conservation, the partial substitution of slash-and-burn agriculture with tree based land uses and reforestation, the focus of the project is not on the (international) trading of C credits, but rather on an emerging domestic market for reforestation credits that is little known even in

Brazil. While the *fomento florestal* law and its directives established rigorous accreditation criteria and procedures for those who wish to offer reforestation credits, resulting in a complex administrative process that could not be managed by communities without competent external support, the process is still easier and faster than that involved in the development of most C trading projects. Given the potential size of the market (eight trees per cubic meter of unsustainably extracted wood, a broad category covering all wood derived from forest conversion and logging or fuelwood harvesting without sustainable management plan), the mainstreaming of the approach in Brazilian reserve management and forestry policy and practice would result in a significant boost to agroforestry and community forestry as components in the management of sustainable use reserves, thereby protecting their C and biodiversity resources and the livelihoods of their inhabitants. Moreover, due to the lower opportunity costs of land in reserve compared to non-reserve areas, reforestation credits are among the very few products for which sustainably managed reserves have a comparative advantage on the market.

Conclusions

The case studies have shown a number of ways how agroforestry can contribute to linking C storage through forest conservation and reforestation, with their (assumed) benefits for biodiversity conservation, and livelihoods improvement. The sequestration of C in the tree biomass of diverse and structurally complex land use systems is only one such role, although the one that has received the most attention in the literature. It is most important in mosaic landscapes, where natural forests have been reduced to fragments, thereby increasing the relative contribution of farm land to landscape C stocks and biodiversity. The C and biodiversity rich shade-cacao systems (*cabruca*) that make up the majority of the "forest" cover in the extremely biodiversity rich landscape of southeastern Bahia, Brazil, and the shade coffee systems of the Sierra Madre de Chiapas, Mexico, are prime examples for traditional agroforestry practices that combine environmental and livelihood functions. In forest frontier situations, on the other hand, the highest priority in a strategy linking agricultural development with climate change mitigation and biodiversity conservation must be to minimize the need for forest conversion by enabling land users to obtain an adequate and sustainable income from their land, thereby supporting direct forest conservation policies, while the C storage and biodiversity in the farming system itself, although highly desirable, are of secondary importance.

The three case studies have shown that agroforestry can play a key role in stabilizing land use mosaics (as in the Sierra Madre de Chiapas) and forest frontiers (as in North Sumatra and the Amazon) by linking land use policies with incentives based on commodity markets and various types of environmental service markets. Case studies 1 and 3 emphasized inhabited, sustainable use protected areas as a key policy tool for stabilizing forest landscapes that has been widely used in Latin America and that provides a useful framework for such mixed incentives. While in case study 1, C sequestered in agroforestry systems was directly traded, case study 3 illustrated that other types of environmental service markets or rewards, including ones operating on the sub-national or local level, may also result in positive outcomes in terms of C and biodiversity conservation and additional income for land users. Case study 2 from Indonesia where land conflicts are commonplace showed that the regularization of land tenure and use rights of forest boundary communities was a key topic in the stabilization of the forest frontier. It is being addressed as part of a package that also involves the production of an agricultural commodity (Arabica coffee) in agroforestry systems for specialty markets and sets the stage for a subsequent inclusion of C trading after clarification of the legal framework.

While all three case studies describe work in progress, several key lessons emerge. The first lesson is that the combination of different incentives can result in better and more lasting outcomes in terms of land use change than single types of incentives, such as C trading or certification, provided that the institutions to coordinate such complex incentive mechanisms are in place. Different incentives for similar land use practices (such as C and biodiversity conservation) can add up and reinforce each other. Also, through the bundling of several types of incentives, different groups of land users within the same landscape, such as coffee and cattle producers or recent migrants and established farmers, can be targeted simultaneously. The bundling of incentives also reduces the risk of losing past achievements and the trust of communities if one incentive becomes temporarily unavailable or less attractive, e.g., through policy changes or price fluctuations in commodity or environmental service markets. And finally, one incentive, such as the regularization of the land tenure situation, may be a precondition for other incentives, such as the participation in premium commodity and environmental service markets. This lesson implies that the standard requirement of additionality in land based C projects (i.e. the requirement that the land use change that a project intends to bring about would not happen in the absence of the C payment) should be carefully balanced with the goal of project sustainability, which will usually be greater if the intended land use change does not depend on C payments alone.

The second major lesson is that when designing incentive programs for agroforestry practices, their impacts must be considered at the scale of the landscape and must include plot or farm level effects as well as interactions between land use and natural vegetation with its typically high C stocks and biodiversity. Especially, land use systems cannot be considered “biodiversity- (or carbon-) friendly” if their low yields and the low incomes they generate drive additional conversion of natural habitat. Where the conversion of natural habitat for agriculture is unavoidable (and permitted by law), the primary preoccupation must be that it results in efficiently used, sustainable, and productive land use systems so that the need for further conversion is minimized. Contributing to these objectives is agroforestry’s most important role in C and biodiversity conservation at the agriculture-forest frontier.

Finally, agricultural development policies and forest conservation policies should be better integrated to avoid contradictions and achieve locally, nationally, and globally desirable outcomes in terms of development and environmental conservation. The probability that this lesson will be learned and applied in current frontier development regions, such as Central Africa and the Amazon, increases with the development of markets for C sequestration and other environmental services and the growing emphasis on sustainable production practices in international agricultural commodity markets.

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