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Swidden, rubber and carbon: Can REDD+ work for people and the environment in Montane Mainland Southeast Asia?

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ABSTRACT

Swidden (also called shifting cultivation) has long been the dominant farming system in Montane Mainland Southeast Asia (MMSEA). Today the ecological bounty of this region is threatened by the expansion of settled agriculture, including the proliferation of rubber plantations. In the current conception of REDD+, landscapes involving swidden qualify almost automatically for replacement by other land-use systems because swiddens are perceived to be degraded and inefficient with regard to carbon sequestration. However, swiddening in some cases may be carbon-neutral or even carbon positive, compared with some other types of land-use systems. In this paper we describe how agricultural policies and institutions have affected land use in the region over the last several decades and the impact these policies have had on the livelihoods of swiddeners and other smallholders. We also explore whether incentivizing transitions away from swiddening to the cultivation of rubber will directly or reliably produce carbon gains. We argue that because government policies affect how land is used, they also influence carbon emissions, farmer livelihoods, environmental services, and a host of other variables. A deeper and more systematic analysis of the multiple consequences of these policies is consequently necessary for the design of successful REDD+ policies in MMSEA, and other areas of the developing world. REDD+ policies should be structured not so much to 'hold the forest boundary' but to influence the types of land-use changes that are occurring so that they support both sustainable livelihoods and environmental services, including (but not limited to) carbon.

1. Introduction

Efforts for Reducing Emissions from Deforestation and Forest Degradation (REDD+) are expected to include payments to forest-rich developing nations by industrialized nations for achieving long-term reductions in carbon emissions by reducing the extent of deforestation and forest degradation, thereby protecting and enhancing carbon stocks (UNFCCC, 2009). The REDD+ framework could also produce co-benefits including the maintenance of ecosystem services (e.g., preservation of species diversity) as well as the conservation of indigenous livelihoods and cultures (Gibbs et al., 2007; van Noordwijk et al., 2009; Mertz, 2009; Ziegler et al., 2011). The Conference of Parties (COP) held in Cancun in 2010 showed an increased interest in the role of agriculture in REDD+ debates, and in opening up the range of potential REDD+ beneficiaries from forest sector and forest-dependent populations (as initially designed during COP13 of the UNFCCC in Bali 2007) to include a larger range of stakeholders at the interface between forest, plantations, and agriculture (Campbell, 2009; Negra and Wollenberg, 2011). COP18, held in Doha in 2012, marked a further step in the enlargement of the scope of REDD+ with attention shifted toward landscape-based approaches. Under the banner of "Living Landscapes", a reference to the interconnections between forests and agriculture and their impacts on people and society, Forest Day 6 – organized as a COP18 side event – explored the role of forested landscapes as a provider of ecosystem services to support human societies. This recent evolution in the REDD+ political debates provides an avenue for inclusion of agroforestry systems (i.e. complex landscape mosaics combining agriculture, managed forests and plantations), ranging from swidden agriculture systems to rural forests and smallholder plantations, into

Abbreviations: AGC, above-ground carbon; BGC, below-ground carbon; MMSEA, Montane Mainland Southeast Asia; REDD+, United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries; SOC, soil organic carbon.

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REDD+ schemes. The swidden landscapes of Montane Mainland Southeast Asia (MMSEA) form an arena where REDD+ debates are likely to have strong impact.

MMSEA, defined as land above 300 m elevation, covers about half the land area of Cambodia, Laos, Myanmar, Thailand, Vietnam, and China's Yunnan Province, and harbors an immense wealth of natural resources, including globally important stocks of forests and biological diversity, a rich heritage of indigenous cultures, and the headwaters of major river systems. For centuries swiddening (also called shifting cultivation or slash and burn agriculture) has been practiced in MMSEA by indigenous farmers who managed land in ways that integrated production from both cultivated fields and diverse secondary forests (Watters, 1960; Conklin, 1961; Spencer, 1966; Fujisaka et al., 1996). The latter often included everything from grass and bushes, to young open-canopy tree associations, to mature closed-canopy tree communities (Cairns, 2007). These diverse human-managed agricultural systems produced a unique landscape mosaic that combined both agriculture and forestry (Ramakrishnan et al., 2006; Ramakrishnan, 2007). Indeed swiddening is not simply agriculture or forestry, but a comprehensive landscape management system that operates on a timescale that cannot be captured by a snapshot of an individual forest plot or field (Fox et al., 2009).

Many of the most dramatic changes in the global landscape during the twentieth century had their origins in agricultural policies involving swiddening. For example, national policies in MMSEA have included the outright banning of swiddening, declaring an area a forest reserve and excluding people, and resettling people into the lowlands. Governments have often encouraged human settlements at such high population densities that the fallow periods necessary for forest regeneration cannot be maintained, making sustainable swidden impossible (Padoch and Pinedo-Vasquez, 2010; Fox et al., 2009). These policies also promoted and subsidized other forms of agriculture such as extensive, long-term cultivation of annual crops, tree crops cultivated in monoculture plantations (particularly rubber), and greenhouse-based horticulture (Rasul and Thapa, 2003; Padoch et al., 2007; Schmidt-Vogt et al., 2009; Ziegler et al., 2009a). While some farmers in the region have realized opportunities to convert their land to commercial crops, others have been forced or coerced to convert. There are many examples where entrepreneurs, corporations and even governments seek to gain control of swidden land through industrial agriculture schemes. The motivations of these schemes vary from outright dispossession of swiddeners to supposed "joint ventures" where corporate agricultural companies take control of villagers' customary lands for lengthy periods of time (Ngidang, 1997, 2002; Majid-Cooke, 2003, 2006).

Because agricultural policies affect how land is used, they not only affect carbon emissions, but farmer livelihoods, environmental services, and a host of other variables. Thus, a deeper and more systematic analysis of the multiple consequences of these policies is necessary for the design of successful REDD+ policies. Again, for many years governments in MMSEA have systematically attempted to eradicate swidden agriculture through multiple policies leading to increasing uniform landscapes and disconnection of agriculture and forestry (Castella et al., 2013). Recently, REDD+ debates have pointed to the potential benefits of complex landscape mosaics in managing trade-offs between ecosystem services (e.g. carbon sequestration, biodiversity) and smallholders' livelihoods (Mertz, 2009; van Noordwijk et al., 2009). While REDD+ research initially focused on deforestation, i.e. land use transition from forest to non-forest, attempts to deal with the degradation aspect of REDD have brought to the fore a number of new technical and institutional questions (Mertz et al., 2012). Most governments in MMSEA area are still struggling with the REDD+ readiness phase (i.e. forest governance reforms). On-the-ground projects still largely involve feasibility assessments, with only a few actually piloting REDD+ payments to communities (see www.forestcarbonasia.org or www.forestsclimatechange.org), mainly in forest conservation areas. Therefore, little experience has accumulated about how to accurately measure and monitor carbon emissions from mosaic landscapes undergoing forest degradation.

Studies on the impacts of forest degradation on biodiversity have shown mixed results (Gardner et al., 2012; Phelps et al., 2012). Little empirical evidence on the influence of REDD+ on local livelihoods and tenure security exists, partly due to the lack of actual payment schemes (Mertz et al., 2012). Across the region, replacement of various types of swidden agriculture with oil palm, rubber or other agroforestry systems are underway—and they need to be at the heart of REDD+ carbon sequestration debates. A recent case study in Laos exemplifies the current drama related to REDD, rubber, and swidden. In July 2009, the Lao-Thai Hua Rubber Company submitted a proposal to register some of its rubber plantations as an afforestation/reforestation project under the Clean Development Mechanism (LHTRC, 2007). This proposal triggered a lively debate among various stakeholders (public, private, NGOs, and development projects) whether rubber companies, often singled out as responsible for massive deforestation, could also benefit from Clean Development or REDD+ mechanisms for their perceived role in increasing carbon sequestration. In this example, the rubber company provided a preliminary analysis concluding that replacing traditional swiddens by rubber-based agro-forestry would provide a positive carbon outcome.

Ziegler et al. (2012), however, found great uncertainty in the net ecosystem carbon changes that can be expected from many transitions from swiddening to landcovers that are perceived to store more carbon. The inclusion of forest degradation in REDD+ therefore calls for a range of new research efforts to address issues related to mitigation of carbon emissions in a context of land-use change within swidden systems (i.e., shortening of the fallow and/or lengthening of cropping periods) and conversion from swidden to plantation tree crops. The call is urgent, as swidden agriculture is rapidly disappearing in MMSEA as farmers are pushed by national policies and drawn by market forces toward high-value commercial crops, especially rubber. Oil palm is an analogy in insular and peninsular Southeast Asia.

In this paper, we first summarize the growing demand for rubber in MMSEA. We then examine the history of land-use policies in southern China and Laos to show that while policies in both countries are leading to an increasingly homogenous landscape dominated by rubber, the impact of those policies on the livelihoods of smallholders and their food security diverge immensely. By extension we argue that REDD+ policies seeking only to increase tree cover can have a range of impacts on smallholder livelihoods that vary from beneficial to destructive. We then examine the differences in carbon storage in swidden fallows and rubber plantations to determine to what extent REDD+ policies incentivizing transitions from swidden to rubber will produce carbon gains. Finally, we question whether it is possible to design REDD+ policies that are likely to contribute to the reduction of terrestrial emissions and also enhance development and food security objectives in MMSEA.

2. Rubber (*Hevea brasiliensis*) expansion in MMSEA

Worldwide consumption of natural rubber has increased at an average rate of 5.8 percent per year since 1900 (Rubber Board, 2005). Synthetic rubber accounts for approximately 57% of the total, but natural rubber is cheaper and of superior quality for high-stress purposes. Jet and truck tires, for example, are almost entirely natural rubber. In the decade between 2008 and 2018, Prachaya (2009) forecasts that total rubber consumption will increase from 22.1 to 23.2 million tons while the relative share of natural rubber will increase from 43% to 48%. Consumption of natural rubber is anticipated to increase from 9.6 million tons in 2008 to 13.8 million tons by 2018—a growth of 3.7% per year (Prachaya, 2009).

The vast majority of the world's rubber supply comes from Southeast Asia with Thailand accounting for 31%; Indonesia 30%; and Malaysia 9%. A native of the Amazon basin, rubber trees have historically been cropped in the equatorial zone between 10°N and 10°S in areas with twelve months of rainfall. In mainland Southeast Asia these climates are found in portions of southern Thailand, southeastern Vietnam, and southern Myanmar. In an attempt to free itself from the world market and to promote economic development, China began investing heavily in the 1950s in research on growing rubber in non-traditional environments having cooler temperatures and a distinct dry season. State rubber plantations were established in Hainan and Yunnan provinces in areas that lie as far north as 22° latitude. China's success in growing rubber in these environments has greatly expanded the habitat in which rubber is planted today. Hybrids are now grown at elevations exceeding 1000 m (Qiu 2009) and in areas with lengthy (2–3 month) distinct dry seasons across most of MMSEA.

Investors from China, Vietnam, Malaysia, and Thailand are investing heavily in rubber plantations in non-traditional rubber growing areas of Laos, Cambodia, and Myanmar, as well as portions of their own countries—e.g., northwest Vietnam and northeast Thailand. In Laos more than 140,000 ha of rubber have been planted in the last decade; and the plantation area may reach 300,000 ha during the next decade (Douangsavanh, 2009). In Cambodia, the Ministry of Agriculture plans to expand the area under rubber cultivation from 100,000 ha to as much as 800,000 ha by 2015. In Myanmar, rubber is expanding into border areas in Kachin and Shan States. In Thailand, rubber has expanded to include over 64,000 ha in the north and 348,000 ha in the northeast. The rubber growing area in Vietnam increased from 395,000 ha in 1999 to 550,000 ha in 2007, with 4,500 ha planted in the northwest region. The government has a target of 700,000 ha of rubber by 2020. Collectively more than 1,000,000 ha of rubber have been planted in the last several decades in non-traditional rubber growing areas of China, Laos, Thailand, Vietnam, Cambodia, and Myanmar (Li and Fox, 2011). By 2050, the area of land dedicated to rubber (and/or other monoculture plantation crops) in these areas could quadruple, largely by replacing lands now occupied by evergreen broadleaf trees and swidden-related secondary vegetation (Fox et al., 2012).

3. Rubber policies, land use, and livelihoods in MMSEA

Over the last half-century, government policies and institutions have affected land-use practices across the borders linking China, Thailand, Laos, Vietnam, Cambodia, and Myanmar. Political and economic reforms have facilitated labor mobility and a shift in agricultural practices away from swiddening toward a diverse array of cash crops, rubber being one of the foremost (Ziegler et al., 2009a). The impact of rubber on smallholders, however, varies immensely. In the largest rubber producing countries, the smallholder sector dominates production: 93% of rubber in Malaysia; 90% in Thailand; 89% in India; and 85% in Indonesia (Rubber Board, 2005). Rubber presents an interesting opportunity for smallholders as it can be intercropped both during the years before tapping as well as placed within the context of a longer-term agroforestry systems (Michon et al., 2007). Viswanathan and Shivakoti (2008) suggest that rubber cultivation, when integrated into existing farming systems, can result in significant increases in household income and greater resilience in the face of volatile markets. While the intensity of production of rubber grown in a diversified agroforestry system is lower than that of monoculture rubber (and may even vary inversely with market prices), rubber grown in an agroforestry system provides smallholders with independence from external economic and political influences. This independence has been a key to their historical success.

Fox and Castella (2013) examined the different types of rubber farming that are developing in the region and explored the impact these systems are having on local livelihoods in China, Laos, Thailand, Cambodia and Myanmar. Here, we look closely at the situations in China (Xishuangbanna Prefecture, Yunnan Province) and Laos. The China insights draw from results of a project on which author Fox was the principal investigator (Xu et al., 2005; Sturgeon and Menzies, 2006; Ziegler et al., 2009a; Sturgeon, 2010a,b). The insights for the Laos situation are drawn from research by both authors Castella and Fox (Hett et al., 2012; Castella et al., 2013; Phanvilay, 2010). These projects employed a mix of quantitative and qualitative methods, including various participant observation and survey methodologies. They also collected a wide range of documentation (both published and grey literature) related to development initiatives in the region. Individual and group interviews were conducted with government officials at scales ranging from village to national. Interviews were also conducted with private individuals including villagers, business people, and others operating at community, provincial, national and regional scales.

3.1. China

In China, the government implemented the Household Responsibility System between 1978 and 1983, dismantling the farming communes and turning farmers into entrepreneurs by giving them long-term lease rights to agricultural land. Yunnan government officials implemented a policy called *liangshanyidi* (freehold and contracted forestlands and swidden fields) that had the objective of stabilizing forest lands and swidden fields through land titling and demarcation. This reform shifted forest management from the state to individuals for forest regeneration by leasing or contracting forest lands to individuals (Xu et al., 2006). China considers rubber plantations as forests and consequently includes them in the forest land data they provide to FAO Forest Resource Assessment database (http://www.fao.org/forestry/fra/en/).

The government also undertook a major state campaign to encourage upland farmers to plant rubber at elevations below 700 m in fields used for swiddening, and later subsidized a state anti-poverty campaign encouraging farmers to plant rubber on sloping lands. In 2002, the "Grain for Green" campaign was introduced to promote the development of China's western provinces and protect the environment; this program provided farmers with grain for eight years if they planted forest cover on degraded slopes. In Xishuangbanna Prefecture, authorities began counting rubber trees as forest cover about the same time a rapid rise in rubber prices occurred. Eager for wealth, households began planting rubber in their traditional woodlots, in village forests, and on the remaining and steeper slopes. Below 700 m, and even higher, rubber became ubiquitous.

Today farmers in Xishunagbanna who planted rubber in the 1980s and 1990s have seen a dramatic rise in household incomes. They have become successful entrepreneurs able to build houses, buy cars, and send their children to school, including university (Sturgeon, 2010b). Sturgeon argues some ethnic-minority rubber farmers in Xishuangbanna have achieved a standard of living today that has more in common with middle-class urban residents than with most fellow farmers (Sturgeon, 2010b). The rubber success story in China is considered by other countries in the region as an example of a win-win strategy, for which forest cover increases, poverty in remote rural areas is alleviated, and national income is generated via export. Although other countries desire to emulate this success through the introduction of rubber as a cash crop, most have not initiated policies that will secure access to land (long-term lease rights in the case of China) or provide the necessary extension services and subsidies, such Grain for Green program in China.

3.2. Laos

Government officials in Laos have relied on external inputs of knowledge and investments from state and private entrepreneurs from neighboring countries, particularly China, Vietnam and Thailand, to develop its rubber industry. Arguing poverty and lack of knowledge, the Lao government has bet on investments from neighboring countries to trigger a huge increase in rubber planting, especially in northern and southern provinces. A large range of institutional arrangements for managing the land, labor, and capital necessary for rubber production has emerged in recent years. These arrangements include smallholders, contract farming, and concessions with a number of variations in each type according to who provides the main factors of production (i.e., land, labor, capital, market outlet and technical knowledge). How contracts and concessions are negotiated between farmers, companies, and government agencies greatly influences rubber institutions at the village level. Investors prefer the concession arrangement as a way to protect their investments; smallholders are concerned that these arrangements limit their access to knowledge, land, and profits.

Senior government officials negotiate large tracts of state land with private companies placing the land under the direct management of the company with limited interactions with local populations. Labor is frequently of foreign origin (Chinese or Vietnamese), limiting the transfer of technology to local farmers. Companies are sometimes allocated rights to prospect and negotiate with villagers for land deemed physically appropriate and accessible, but whose availability is uncertain and subject to local approval. The resulting model of rubber development is a joint venture between foreign investors and farmers in a contract farming arrangement. Inputs and profits are supposed to be shared as determined by negotiations among investors, district authorities, and village representatives.

Two main kinds of contracts can be identified: (i) the 2+3' model, for which farmers provide land and labor, and the company provides capital (in the form of seedlings, fertilizer and other equipment), technology, and access to markets; and (ii) the '1+4' model, for which farmers provide land and the company hires labor (perhaps the contracted farmer), capital, technology, and market access. Approximately 7 years after planning when the trees become productive, benefits are shared according to conditions agreed upon in the initial contract—usually 70% of the benefits go to the farmers and 30% to the company under '2+3'; and 30% to the farmers and 70% to the company under '1+4', but, sometimes benefits are split equally. Eager to support the emergence of a smallholder-based rubber industry, the government has actively promoted the '2+3' model. In contrast, investors eager to secure their investment and profits have pushed for the '1+4' model. If farmers become too indebted waiting for their trees to become productive (7 years), investors can acquire the farmers' land tenure rights and convert them into concession-type tenure.

Farmers have more control in places where they have (1) knowledge of how to grow rubber trees (e.g., many villagers located close to the borders with China and Thailand have worked on rubber farms in these countries), (2) capital (e.g., better-off farmers with good relations with district authorities), and (3) agency (e.g., belong to farmers' groups). In such instances, they can negotiate advantageous arrangements that limit the role of investors as credit providers, or even resist companies' offers if they have already secured market access on their own (e.g., villagers in Sangthong district as documented by Castella et al., 2008). Thus, smallholder rubber arrangements can emerge even in places where rubber companies are actively promoting other institutional arrangements.

Contracts between foreign investors and farmers are often vaguely written or non-existent, and pose a major concern for farmers because it is unclear who will benefit from the profits of rubber planting. The notion of a contract and its sanctity are not well understood by either investors or farmers in Laos. For example, some contracts are not legally binding due to lack of jurisdiction. In development projects involving land concessions, several undesirable aspects have emerged: for example, uncompensated loss of assets (both private villager and state/public assets); uncompensated loss of resource entitlements by villagers (e.g. non-timber forest products) and of public goods (e.g. watershed protection services) by the state; and configurations of resource use that secure resource control but decrease net benefits and fail to capitalize effectively on the overall comparative advantages of the country (Douangsavanh et al., 2008; Baird, 2010). Other issues contract farmers face include inadequate village consultation, varying degrees of coercion, inconsistent understanding and interpretation among contracting and governing parties, low levels of technology transfer from investors to villagers, and disputes over land and wages (Shi, 2008).

3.3. Summary

While we have less data for Cambodia and Myanmar, the situation in those countries appears to be worse. In both countries farmers have been forcibly relocated for rubber plantations, employed by armed groups to establish tracts of rubber, and coerced into planting rubber themselves due to land-use restrictions (see Undercurrents, 2009; Fox et al., 2008). In Thailand, the situation for smallholders is much better. The Thai Office of Rubber Replanting Aid Fund (ORRAF), a government supported institutions, assists smallholders by providing free or subsidized inputs, extension information, low-cost credit, and supports community organizations and the formation of rubber cooperatives. ORRAF also supports smallholder activities such as fish ponds, livestock, crops, and handicrafts in order to aid farmers to maintain their livelihoods between the time they plant rubber and begin to tap.

As seen in these examples from China and Laos, national policies affect how the transition between traditional farming and commercial rubber production impacts the livelihoods of smallholders. As the Xishuangbanna example shows, swidden farmers can manage access to and use of their lands when given appropriate support (e.g., recognition of long-term use rights) and when provided with extension services and subsidies during the initial periods of rubber planting and production. It is clear that smallholder rubber production is a viable and effective proposition in moving households and communities out of poverty. On the other hand, externally imposed, large-scale policies (such as commercial estates being established in Laos) affect swidden farmers adversely. Even when laws and ordinances have been drafted that could assist smallholders to maintain control over their land and invest in commercial crops, lack of financial and human resources and competing policy and political agendas have prevented these measures from being implemented effectively. Consequently, villagers in many communities are selling their land, allowing migrants to move in. In other communities, farmers are struggling to maintain community lands and forests in the face of growing pressures from investors and government institutions to impose concession arrangements.

Fox and Castella (2013) suggest that in order to promote the establishment of a vibrant smallholder rubber sector the state must effectively implement national policies and institutional structures to support smallholder rubber cultivators. National legislation is needed that recognizes customary claims to swidden fallows and grants farmers and farming communities legal access to the land they have traditionally used through either secure tenure or long-term use rights. In addition to access rights, governments should develop agencies that provide integrated access to technology, capital, markets, labor, and knowledge (Ribot and Peluso, 2003). An example of this is the services provided by the Offices of Rubber Replanting Aid Fund (ORRAF) in Thailand (Douangsavanh et al., 2008). It could also be useful to establish a governing and coordinating body to work closely with all sectors related to the rubber industry. At the local level, smallholder farmer groups need to be organized and/or supported in order to strengthen rubber cultivation, tapping, processing and marketing. We argue by extension that similar institutional arrangements will be imperative for implementing REDD+ policies if we seek to support the sustainability and economic viability of smallholders' production.

4. Carbon sequestration and environmental services

Under most REDD+ scenarios, landscapes involving swiddening qualifies almost automatically for replacement by other land-use systems—including rubber—because swidden lands are perceived to be degraded and inefficient with regard to carbon sequestration (Bruun et al., 2009; Mertz, 2009). Swiddening, however, includes a wide range of land-use and management practices that affect carbon cycling differently. For example, pioneer swiddening involves cutting plots in primary forest, then cultivating for a few years before new plots are established elsewhere, allowing regeneration of mature secondary vegetation on former cultivated plots. In comparison, rotational swiddening involves moving from plot to plot within the same landscape after short (<5 years), intermediate (5–10 years), or long (10–25+ years) fallow periods.

Recent syntheses aimed at increasing understanding of plausible biomass or carbon stock changes expected with land-cover conversion provide insight on a few major end member land covers such as forest, tree plantations, crop-lands, and grasslands, but they lack attention to swidden and rubber per se (e.g., Guo and Gifford, 2002; Murty et al., 2002; Gibbs et al., 2007; Don et al., 2011; however see Bruun et al., 2009). Although rubber could be lumped into a general plantation category, lack of specific attention to this important contemporary land cover stems from the fact that only recently has it been planted in plantations at scales large enough to be of environmental concern in MMSEA (Qui, 2009; Ziegler et al., 2009a). Again, more than a million ha of land have been converted to rubber in MMSEA; and this area is expected to increase 4 fold over the next few decades (Fox et al., 2012). Many of the lands expected to give way to rubber are associated with swiddening (Fox et al., 2012).

Swidden systems are unique in that they form a dynamic land cover, for which biomass and carbon stocks change dramatically over time between the planting and mature fallow phases. While the burning phase results in the emission of CO_2, this loss may be offset to some degree by carbon sequestered during the fallow phase (Mertz, 2009; Geist and Lambin, 2002; FCPF, 2010). Depending on land-use history, length of fallow, and the degree of disturbance during the cultivation phase, successive fallow regrowth includes vegetation associations ranging from poor-quality grasslands to mature secondary forests that are high in biomass and species diversity (Lawrence, 2004, 2005; Cairns, 2007; Bruun et al., 2009; Messerli et al., 2009; Rerkasem et al., 2009). While swidden systems potentially vary greatly in their ability to sequester carbon, they are nevertheless often lumped into a single category representing a principal agent of forest degradation, deforestation and carbon emissions (Mertz, 2009; Geist and Lambin, 2002; FCPF, 2010).

Biome-averaged above- and below-ground carbon biomass estimates for tropical forests range from about 40–510 Mg C/ha (Ziegler et al., 2012; Yuen et al., submitted for publication), but values at individual sites may be much higher (e.g., Yamakura et al., 1986; Zheng et al., 2006). For example, in a rubber growing region of Xishuangbanna prefecture, Yunnan Province, China, Lu et al. (2010) estimated that the total above- and below-ground carbon stock in a tropical seasonal forest ranged from 272 to 377 Mg/ha, with almost a third being associated with the top one meter of soil. In comparison, above-ground carbon (AGC) stocks for rubber (15–61 Mg/ha) were only 21–50% of those (71–122 Mg/ha) estimated for forests in Xishuangbanna (Li et al., 2008). The great variation was related to the relatively high elevations (>800 m) at which rubber clones were being grown. Outside MMSEA, above-ground carbon stock estimates for mature rubber in Brazil, Ghana, Hainan, Indonesia, and Thailand range from 60 to 103 Mg/ha (van Noordwijk et al., 2000; Cheng et al., 2007; Wauters et al., 2008). The wide range of reported AGC stocks (25–143 Mg/ha) associated with mature rubber stands in Southeast Asia (Ziegler et al., 2012) demonstrate that this tree-based land cover in some environments could sequester substantially less carbon than various types of mature swidden fallows (Brown and Lugo, 1990; Jepson, 2006).

For swidden systems, unless the fallow remains in a degraded, arrested grassland state, the biomass of advanced fallows should resemble that of secondary forests (Sabhasri, 1978; Schmidt-Vogt, 2001). A great range in biomass and species diversity should however be expected depending on disturbance history, as well as, contemporary forest use and fallow management (Lawrence et al., 2005; Nikolic et al., 2008). Biomass accumulation rate may also decline with each cycle of swiddening (Lawrence et al., 2010). For example, forest regeneration on former swidden fields in Thailand that were repeatedly cultivated (with opium) for long periods prior to fallowing, recovered more slowly than those generating on former rice fields that were cultivated less intensively (Fukushima et al., 2008). Total biomass after 20–29 years for all former upland rice and opium sites in Thailand was 12–52% (31–126 Mg/ha) of that in forests never cultivated (242 Mg/ha). For 30–49 year fallows, total biomass increased to 161–228 Mg/ha (Fukushima et al., 2008). Assuming carbon comprises 50% of the biomass (Gibbs et al., 2007), these values equate to AGC stocks of 15–63 Mg/ha and 80–114 Mg/ha for 20–29 and 30–49 year recovery periods. Similarly, biomass data from a site in northwestern Vietnam (Tran et al., 2010) suggest that AGC in secondary forests would be about 60 and 96 Mg/ha after 30 and 60 years. Elsewhere, Jepson (2006), working on swidden fallows in Sarawak, reported carbon stocks of 2–5, 17–29, 19–35 Mg/ha for two, four, and ten-year fallows. These values are in agreement with summarized carbon accumulation rates for fallows 0–20 years of age (2–3.5 Mg C/ha/year; Lugo and Brown, 1992).

Of importance to our comparison between rubber and swidden carbon sequestration, long-fallow swiddening AGC values in Southeast Asia (25–110 Mg/ha) have substantial overlap with the 13–143 Mg/ha range associated with rubber (Ziegler et al., 2012). Although caution is needed in directly comparing between different sites, the overlap in carbon biomass estimates prevents one from concluding unequivocally that rubber plantations sequester more above-ground carbon than swidden fallows—at least until the time when the sites are again cleared, and potentially, burned. This assertion still generally holds even if we consider the carbon extracted during tapping, which is on the order of 24 Mg/ha over a 30-year period (Cheng et al., 2007).

Stocks of below-ground carbon (BGC) on most tropical land covers are largely uncertain (Yuen et al., submitted for publication). For forests, a value of 20% of the AGC is often used as a conversion factor (Gibbs et al., 2007). Studies in Xishuangbanna, Thailand, and Malaysia suggest that BGC ranges from 10 to 33% of the AGC values (Yamakura et al., 1986; Zheng et al., 2006; Kenzo et al., 2009). For a post-fire secondary forest site in Sarawak, the maximum rooting depth was 2.3 m, with most trees roots extending down only one meter. Thus, if the Sarawak study is representative of secondary forests in general, it is plausible that mature swidden fallows elsewhere might also have shallow root systems with BGC values that are ≤20% AGC. As with swidden fallows, too few data exist to derive definitive BGC estimates in rubber plantations in the region (Yuen et al., submitted for publication). Data from Hainan (PRC), Thailand, and Cambodia suggest BGC for rubber ranges from 7 to 29 Mg/ha, with root:shoot ratios ranging from 0.1 to 0.3 (Cheng et al., 2007; Gnanavelrajah et al., 2008; Mizoue et al., 2009; Yuen et al., submitted for publication). As with AGC, the few BGC data that do exist for rubber and swidden once again do not allow us to unequivocally state that either land cover sequesters more carbon than the other in this component.

Soil organic carbon (SOC) also comprises an ambiguous percentage of the total carbon associated rubber and swidden landscapes. This uncertainty is important because the SOC fraction could be large, depending on the soil depth. In Indonesia the soil carbon stock was about 90 Mg/ha in permanent rubber agroforests and 50 Mg/ha in more intensively managed rotational rubber plantations (Palm et al., 2005; Bruun et al., 2009). Bruun et al. (2009) concluded that stocks of SOC in rubber plantations were 0–30% lower than those in traditional swidden systems. They also pointed out that the soil quality in some farmer-managed, unfertilized rubber gardens with relatively low intensity of tapping was similar to secondary forests associated with swiddening. However, negative soil impacts were greater in situations of intensified rubber cultivation where topsoil removal and compaction substantially altered physical properties.

A recent syntheses of SOC changes involving forest conversion, which does not include either rubber or swidden categories specifically, provides insights that are useful through analogy (Don et al., 2011): (a) transitions from forest to croplands and grasslands reduce carbon socks by 25–30 and 12%, respectively; (b) secondary forests contain 9% less carbon than primary forests; (c) afforestation of cropland increases SOC 29%; and (d) fallowing and conversion of cropland to grasslands increases SOC by 32% and 26%, respectively. In another review, Guo and Gifford (2002) determined transitions from forest to plantations decreased SOC on average by 13%. Through analogy, we would expect that both swidden agriculture and rubber cultivation to have time-averaged SOC stocks that are not greatly different, and in the neighborhood of 9–13% lower than forest.

In general, the greatest losses of SOC should occur shortly after the initial forest conversion and then approach equilibrium—this is likely true for swidden fields and rubber plantations alike (Murty et al., 2002; Bruun et al., 2009). Immediate, long-lasting reductions in SOC should also result from soil excavations, for example terracing, to allow planting of rubber on steep slopes (Bruun et al., 2009). Unless cultivated swidden sites are severely degraded, fallowing should increase SOC on the order of 25% (assuming succession leads to grasslands or secondary forests). As newly planted rubber stands mature, SOC should also increase (from an initial value that resembles a cropland), although this increase may be less than that of fallowing because management of the rubber understory, including the removal of vegetation and fine/woody organic debris, likely limits carbon accumulation. In support, the modeling analysis of Gnanavelrajah et al. (2008) indicted the carbon accumulation rate for rubber was one of the lowest among 11 agriculture land-uses considered in Thailand.

With respect to recovery of soil carbon stocks after an initial transition, significant changes may not be recognizable over the course of one rotation of swidden fallow or rubber. In addition to initial carbon content, many other factors affect SOC at any location: i.e., climate, soil type, microbial communities, nitrogen cycling processes, and management (Murty et al., 2002). Importantly, differences between rubber and swidden SOC stocks are impossible to distinguish with this type of meta-analysis approach. However, even site-specific data are problematic because the SOC values associated with any recent transition reflect, in part, the impact of former practices. Thus, as with AGC and BCG, differences in SOC between swidden and rubber lands are difficult to verify.

Given all the uncertainties regarding AGC, BGC, and SOC outlined above, we believe it is impossible to predict accurately the extent that REDD+ policies involving swidden-rubber transitions will ultimately increase carbon sequestration (cf. Ziegler et al., 2012; Yuen et al., submitted for publication). Nonetheless, emerging carbon finance schemes are being developed across the tropics to provide economic incentives for more rural communities to transition away from swidden agriculture to other land use types, including rubber (FCPF, 2010; UNREDD, 2010; UNREDD Indonesia, 2010). Our analysis suggests that unless end-member carbon stock values were used—e.g., those for short-fallow swidden on degraded lands versus rubber growing in optimal conditions—transitions from swidden to rubber could only be viewed generally as neutral or uncertain in terms of changes in carbon sequestration.

In fairness, conversion of some short-fallow systems with low carbon stocks to rubber may be carbon positive. In addition, the replacement of truly degraded lands may also prove carbon positive—but care must be taken to prevent conversion of grasslands that are not degraded. Dewi et al. (2009) concluded that oil palm in Indonesia should only be allowed to replace shrub and grasslands having AGC stocks < 40 Mg/ha. A similar minimal threshold may also exist for rubber; and it may well be determined by specific biophysical conditions under which rubber is grown—importantly elevation. We estimate this minimum carbon biomass threshold to be approximately 13–35 Mg/ha, which represents the low-end estimates for high-elevation rubber sites in Xishuangbanna (Li et al., 2008).

New site-specific carbon and other environmental assessments are needed to gain a more clear understanding of consequences of the demise of swiddening, the spread of rubber, and the role of REDD+ in MMSEA. Looking ahead, REDD+ implementation will require improved, cost-effective techniques for assessing plot and landscape-level carbon stocks. This is particularly important for below-ground carbon, as this pool may be the critical deciding factor in determining optimal land use in terms of carbon sequestration. Uncertainties at both the plot and landscape scale are especially significant because many country REDD+ proposals world-wide target swidden farmers for exactly these types of land use transitions (FCPF, 2010; UNREDD, 2010).

Carbon sequestration aside, there are other important environmental issues to consider. Maintaining land under swidden agriculture can deliver superior biodiversity benefits compared with monoculture rubber plantations and some other agroforestry systems (Lawrence, 2004; Rerkasem et al., 2009; Padoch and Pinedo-Vasquez, 2010; Ziegler et al., 2011). Capital intensive farming methods that replace swiddening have their own set of environmental problems: e.g., accelerated erosion and landsliding on permanently converted hillslopes, degradation of stream water quality by pesticides and fertilizers, and stream desiccation caused by increased extraction of stream and groundwater for irrigation (Ziegler et al., 2009b). Furthermore, there is still great uncertainty regarding the potentially high water use of landscapes converted to alien monoculture plantations, particularly rubber in MMSEA (Guardiola-Claramonte et al., 2008, 2010; Qui, 2009; Ziegler et al., 2009a). These potential negative environmental consequences must also be balanced in REDD+ dialogues (Padoch and Pinedo-Vasquez, 2010; Ziegler et al., 2011).

5. Conclusions and recommendations: landscapes, livelihoods, and carbon transitions in MMSEA

Transitions from short-fallow systems and degraded lands to rubber could bring about both carbon and economic gains, but the realization of both goals will be challenging. Abandonment of swiddening to allow forest regeneration would undoubtedly increase carbon sequestration, but would produce negative economic consequences, unless offset with REDD+ payments. Furthermore, REDD+ incentives could also be applied to lengthening the fallow-period of existing swidden systems (e.g., transition from short- to intermediate/long-fallow swiddening or to other agroforestry systems). While these transitions are plausible, we question whether economic benefits would actually reach smallholders because the carbon volumes involved may be too limited to interest carbon investors. In Laos for example, government authorities have relocated villagers far from remaining forests on the belief that farmers would benefit from improved access to electricity, water, market, health and education infrastructures (Castella et al., 2013). As a result, the high carbon forests are under state management (e.g. national parks, national forest protection and production areas) while villagers are left with the management of poor forests under high population pressure (Bourgoin et al., 2013). This example shows the risk that REDD+ payments would not benefit poor households in marginal upland landscapes but the state, with unknown benefit sharing mechanisms.

To determine how great the REDD+ incentives would need to be in order to solicit a positive response from farm households to allow their swiddens to regenerate to forest, it is necessary to consider the economic opportunity cost of the loss of the most lucrative agricultural activity, rubber. A recent economic analysis of rubber production in two provinces in Northeast Thailand (part of the non-traditional rubber growing area in MMSEA), determined the net benefit of rubber to farm households ranged from $1735 to $2226/ha/year (Sawetwong and Dayananda, 2008). Given that forests in MMSEA may sequester 20–200 Mg C/ha more carbon than rubber (this estimate includes AGC and BGC, but not SOC because soils are so variable—see discussion above), annual carbon payments would need to be on the order of $9.00 to $111/Mg C/ha to entice farmers to not convert their forested swidden fallows to rubber. The European Union set fines for noncompliance of carbon emissions standards at $60/Mg C excess CO_2 emitted (Hill, 2008), suggesting that a REDD+ policy might be able to pay farmers in less productive rubber growing areas (e.g., higher elevations, less rainfall) enough to cover their opportunity costs for participating in the program. Alternatively, the Cambodian government priced the carbon from its REDD projects at $3.00/Mg C (Khun, 2008). This value is clearly not enough to solicit farmer participation in REDD projects.

We therefore expect the growing demand and market for natural rubber to continue to drive a transition from traditional farming systems and their associated secondary vegetation in MMSEA to landscapes dominated by rubber plantations. The impact of rubber on smallholders can range from being a viable and effective means for moving households and communities out of poverty to a proposition that causes farmers to struggle to maintain their lands or even to lose them to commercial investors and government institutions seeking to impose concession arrangements. We expect carbon markets will have diverse and often unexpected impacts on environmental governance and decision making when parachuted into this complex resource management situation. In addition to the unexpected impacts REDD+ could have on livelihoods, too little is known about differences in carbon cycling among various types of swidden and replacement agriculture systems—including rubber—to know unequivocally which land-cover/land-use types provide the most viable basis for emissions mitigation.

Given the difficulty of predicting the impact of land-use/land-cover transitions on smallholder livelihoods, as well as on carbon stocks, it is highly risky—perhaps impossible—to suggest land-use policies that will ensure a win-win situation to rural farmers and the environment. Recognizing this risk, however, a few ideas can be suggested. In some parts of MMSEA, there are unprotected forests landscapes that can be managed under a REDD+ approach that focuses on protecting and improving carbon sequestration. The 69,000 ha Oddar Meanchey Community Forestry REDD project in northwest Cambodia is one such example (Poffenberger and Smith-Hanssen, 2009; Poffenberger, 2009). In other instances, swidden agriculture may still be the most rational land use for farmers from both economic and environmental perspectives; and therefore, should be encouraged in areas where it contributes to the preservation of ecosystem services and cultural identity (Fox et al., 2009; Padoch and Pinedo-Vasquez, 2010; Ziegler et al., 2011). Thus, REDD+ policies should not preclude maintaining or rehabilitating traditional swidden systems with fallow periods that are sufficiently long to allow regeneration of mature secondary forests (Ziegler et al., 2011). From a carbon perspective, intermediate/long-fallow swidden systems could conceivably represent optimal land-use options in some situations. In addition, lengthening the fallow periods in existing swidden systems or managing the tree and bush phases of fallows more effectively may result in maximum carbon benefits. As some transitions from swidden to alternative land uses may produce undesirable negative impacts on ecosystem services and local livelihoods, both carbon and non-carbon benefits, as well as economic considerations, must be taken into account in the development of REDD+ policies.

If we look further afield than MMSEA, we find the example of jungle rubber in Indonesia. Defined as a complex agroforest, this system historically enabled millions of Indonesians to secure their livelihood while preserving the ecological features of a forest (Tomich et al., 2001; van Noordwijk et al., 1995, 1997). Today income per capita from jungle rubber is declining due to increased population density and lower productivity in comparison with monocrop, clonal rubber or oil palm plantations (Feintrenie and Levang, 2009). Improved agroforestry solutions are needed to provide farmers with secure livelihoods without further endangering ecological and economic conditions. In addition to reducing carbon emissions, REDD+ policies should support the development of complex agroforestry systems that provide secure livelihoods, and protect biodiversity and other ecosystem services. Smallholders will require access to national agencies that provide technical support, extension, credit, transport and marketing of agroforestry products in order to both increase productivity of their land-use systems and reduce carbon emissions.

Finally, additional research is urgently needed to develop sound methodologies for assessing the impact of land-use transitions on carbon stocks as traditional swidden systems are replaced or transformed into other land-use practices—including forest management efforts supported through REDD+ projects. The design of successful REDD+ policies will require the active involvement of local people in planning, implementing, monitoring and evaluating development and conservation programs in swidden lands. To be actively engaged, smallholders need secure tenure for both agricultural and forest lands before they can participate in meaningful discussion with planners and government agencies concerning the future of their land (Robinson et al., 2011; Bourgoin et al., 2013). Positive market incentives and supportive government policies are better than standardized, top-down directives but opportunities and constraints for new land uses will be created by markets, national policies, and increasingly by global factors. Viable REDD+ mechanisms must therefore strike a balance between carbon objectives and associated co-benefits when dealing with apparently similar carbon-positive land-use transitions. If carbon markets are to help rather than hinder local development, they must recognize the competing views and diversity of actors in environmental decision making and actively seek to include local people in decision making processes. This is a view that has historically been missing in the interactions of policymakers and swidden farmers throughout much of MMSEA.

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