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Rubber Plantations Expand in Mountainous Southeast Asia: What Are the Consequences for the Environment?

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SUMMARY For centuries, farmers in the mountainous region of mainland Southeast Asia have practiced shifting cultivation, with plots of land cultivated temporarily and then allowed to revert to secondary forest for a fallow period. Today, more than one million hectares have been converted to rubber plantation. By 2050, the area under rubber trees in the montane regions of Cambodia, Laos, Myanmar, Thailand, Vietnam, and China's Yunnan Province is predicted to increase fourfold. Preliminary research suggests this massive land-use change could lead to drier conditions at the local level plus surface erosion, loss of soil quality, sedimentation and disruption of streams, and risk of landslides. And it appears that when primary or secondary forests are converted to rubber, carbon emissions are likely to increase. Despite environmental concerns, both local farmers and outside entrepreneurs are likely to continue expanding rubber plantations because of high economic returns. Production systems that provide the best balance between economic return and environmental sustainability are needed to improve the long-term outlook for the region.

The mountainous region of mainland Southeast Asia harbors a wealth of natural resources, including globally important forests, multiple plant and animal species, and the headwaters of major rivers. Defined as land above 300 meters elevation, the region covers about one-half of the combined land area of Cambodia, Laos, Myanmar, Thailand, Vietnam, and China's Yunnan Province (Figure 1). Today, land use in the region is changing rapidly and on a wide scale, creating concerns about possible negative impacts on the local, and even the global, environment.

For centuries, farmers in this region have practiced diverse systems of shifting cultivation, in which plots of land are cultivated temporarily and then allowed to revert to secondary forest during a fallow period. The staple crop is upland rice, but cultivated plots may include a range of secondary food and cash crops such as maize, cassava, banana, sugarcane, ginger, cardamom, or opium poppies (Mertz et al. 2009). Fruit trees or other useful tree species may be planted on fallow plots, or the fallows may be left entirely to natural regrowth. These practices produce a unique landscape mosaic combining small agricultural plots with secondary forests. Although studies in the region have been limited, researchers largely agree that these traditional land-use systems are environmentally sustainable, protecting the region's rich biodiversity and soil and water resources (Ziegler et al. 2011).

Neither local farmers nor outside entrepreneurs are likely to return to less profitable forms of agriculture

Over the past decades, traditional forms of land use in many of these areas have evolved into more intensive agricultural systems. Plots tend to remain under cultivation longer, with less time allowed for the regrowth of secondary forests. In many instances, shifting cultivation has been replaced by permanent cropping, and in particular by rubber plantations.

One factor driving the transition toward more intensive agriculture has been population growth, including substantial migration from the lowlands. Another factor has been the expansion of road networks and markets, making it easier for farmers to purchase agricultural inputs and to sell their crops.

Government-sponsored crop-substitution programs have also driven a shift toward rubber. Several countries, including the United States and China, have made substantial investments in programs designed to eliminate the cultivation of opium poppies in the region. The ability to store and transport rubber easily as well as the overall return on investment make rubber far superior to any other cash crop as a replacement for opium.

National governments have accelerated land-use changes by introducing explicit policies to replace traditional shifting-cultivation systems with other forms of land use, including the permanent cultivation of annual crops, rubber and other tree-crop plantations, and greenhouse-based horticulture. Policies have included the outright banning of shifting cultivation, the creation of forest-protection areas that exclude population groups that have lived in the forests for hundreds of years, and the movement of people into more crowded settlements along the main roads and in the lowlands.

Attracted by the opportunity to convert traditional farming areas into high-value commercial operations, outside entrepreneurs, corporations, and governments have sought to gain control of land in the region through schemes ranging from joint ventures with local farmers to outright dispossession. Some farmers have enhanced their income by switching to the intensive production of cash crops. Others have been forced into contracts with unfavorable terms or have lost their land entirely.

While more intense agricultural production may pose a threat to fragile local environments, it is not possible to turn back the clock. Rubber plantations, in particular, have proven highly profitable. Given financial realities, neither local farmers nor outside entrepreneurs are likely to return to less profitable forms of agriculture, even if the earlier forms are potentially more environmentally friendly.

As a response to the changing situation, the Chinese government has gone so far as to redefine rubber plantations as forests, thereby increasing the declared areas under forest cover. But are rubber plantations really as beneficial to the environment as natural forests? And are they more or less beneficial

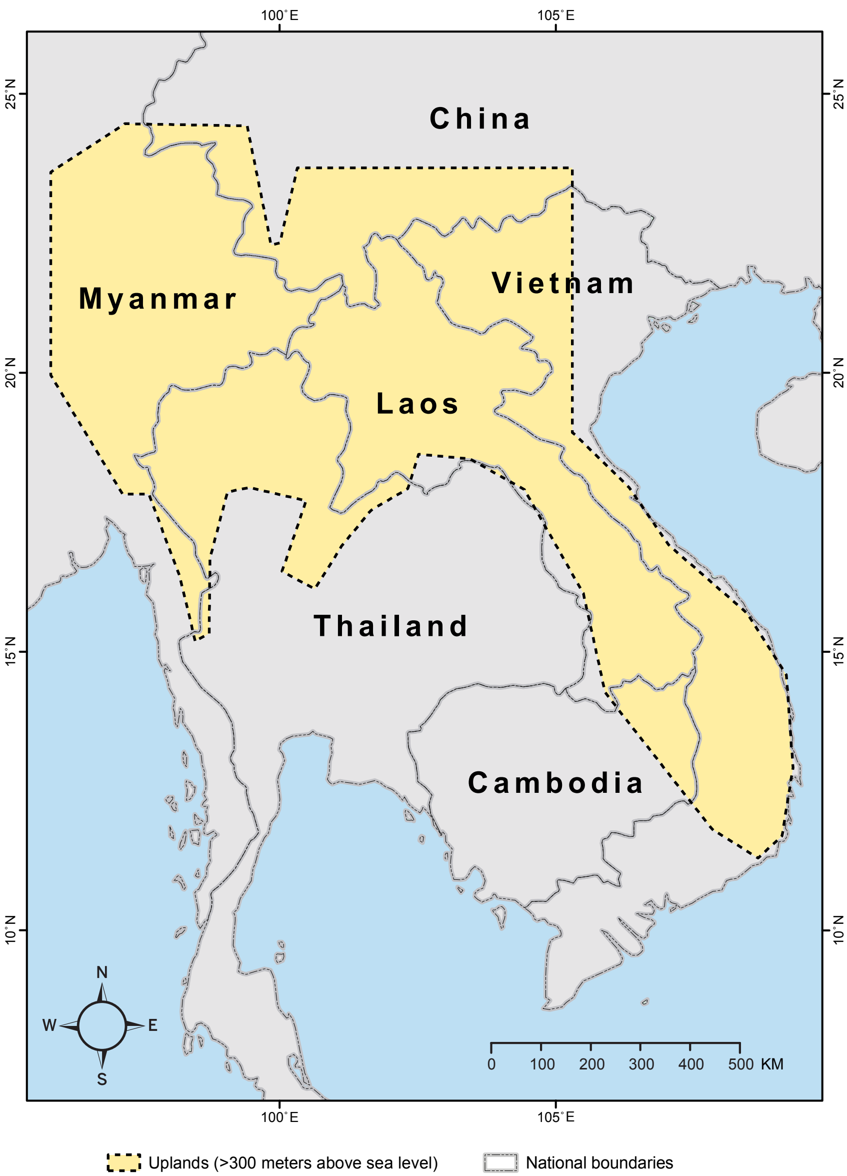

Figure 1.
Defined as land above 300 meters elevation, the mountainous region of mainland Southeast Asia covers about one-half the combined land area of Cambodia, Laos, Myanmar, Thailand, Vietnam, and China's Yunnan Province.

Source: Miguel Castrence, East-West Center Spatial Information Laboratory.

than the traditional systems of shifting cultivation that they are replacing? Given the current pace of expansion, it is particularly critical to determine the environmental implications of this large-scale change in land use.

Expansion of Rubber Plantations

Worldwide consumption of natural rubber (*Hevea brasiliensis*) has been increasing steadily for many decades. Although rubber is a native of the Amazon basin, 97 percent of the world's natural rubber supply today comes from Southeast Asia (Li and Fox 2012).

Historically, rubber trees were cropped in the equatorial zone between latitudes of 10°N and 10°S in areas with 12 months of rainfall. In mainland Southeast Asia, these climates are found in parts of southern Thailand, southeastern Vietnam, southern Myanmar, and peninsular Malaysia. In the 1950s, however, the Chinese government began conducting research on growing rubber in nontraditional environments with cooler temperatures and a distinct dry season (Fox and Castella 2013). State rubber plantations were established in Hainan and Yunnan Provinces in areas as far north as 22°N. China's success in growing rubber in these environments has greatly expanded the habitat in which rubber is planted today. Across Southeast Asia, hybrids are now grown at elevations of 300 meters and above and in areas with two- to three-month dry seasons.

In recent years, entrepreneurs from China, Vietnam, Malaysia, and Thailand have invested heavily in the expansion of rubber plantations in new areas of Laos, Cambodia, and Myanmar, as well as portions of their own countries. One impetus for the expansion of rubber into the highlands has been the widespread shift from rubber to the more profitable production of oil palm in the humid areas where rubber was grown before.

By 2012, rubber plantations covered more than one million hectares of nontraditional rubber-growing areas of China, Laos, Thailand, Vietnam, Cambodia, and Myanmar (Li and Fox 2012). By 2050, the area under rubber plantations is predicted to increase fourfold, largely replacing secondary forests and land currently under shifting cultivation (Fox et al. 2012). What are the implications for the environment?

Rubber and Water: A Case of Bad Timing

In the mountainous region of Southeast Asia, farmers sometimes observe that conditions become drier in areas where rubber has been introduced. A two-year study in China's Xishuangbanna Prefecture provided information on this issue by comparing root water uptake at different soil depths under secondary forest, grassland, a tea plantation, and a rubber plantation (Guardiola-Claramonte et al. 2008).

Rainfall in the area is monsoonal, occurring primarily between May and October. The study found that tea, grassland, and secondary forest are all "in sync" with this pattern—the plants accelerate growth and produce new vegetation in response to rainfall. By contrast, rubber trees shed their leaves over a short period during the dry season and initiate new growth in late March. In the Amazon basin where rubber originated, this timing works well because it is rainy all year round. In Southeast Asia, however, this growth spurt occurs two to four weeks before the arrival of the first monsoon rains—in the very hottest and driest time of year. The trees manage to produce new leaves and buds at this point in the calendar by depleting moisture from deep within the soil.

The introduction of rubber plantations can reduce the flow of streams and lead to drier conditions throughout a catchment area

Climate modeling suggests that the expansion of rubber plantations should not affect rainfall across the region as a whole (Sen et al. 2012). At the local level, however, the impact may be profound. At the beginning of the wet season, streamflows may be diminished or dry out entirely because of rubber's high water use at the very peak of the dry season. The study in Xishuangbanna confirmed local beliefs that the introduction of rubber plantations can reduce the flow of streams and lead to drier conditions throughout a catchment area (Guardiola-Claramonte et al. 2008).

Rubber and Soil: Problems with Management

Another study in Xishuangbanna Prefecture describes a typical transformation process in which secondary forests were removed to make way for rubber plantations (de Blécourt et al. 2013). In this instance, trees were cleared from sloping land and terraces were built by hand. In other areas, terraces are often created using bulldozers. Either approach entails the removal of topsoil and exposure of subsurface soils that absorb water poorly. Mechanical terracing also tends to reduce water absorption by compacting the soil. This can potentially lead to accelerated surface erosion, disruption of natural streamflows, elevated stream sediments, and greater risk of landslides (Ziegler et al. 2009). Risks increase if terraces are cleared of vegetation before the roots of young trees have grown sufficiently to hold the soil in place or the crowns have spread sufficiently to provide protection from rainfall.

In Xishuangbanna, terraces were intercropped with upland rice, maize, groundnuts, or beans during the first four years after planting when the rubber trees were small (de Blécourt et al. 2013). Chemical fertilizers were applied once or twice a year. After the rubber trees matured, the understory vegetation was removed, either manually or using herbicides.

What impact did this disturbance have on the soil? Measures of soil carbon, the principal component of soil organic matter, provide a good indication. A high content of organic matter improves the physical properties of soil, including water retention and structural stability. Soil organic matter also provides nutrients and trace elements that are important for plant growth.

At the study site, carbon in the soil decreased rapidly during the first five years after secondary forests were converted to rubber plantations. The decrease then slowed, and a steady state was reached at about 20 years after rubber trees were planted. At this point, carbon stocks in the top layer of the soil averaged 68 percent of the original level under secondary forest (de Blécourt et al. 2013).

Looking at the region as a whole, Bruun and colleagues (2009) observed that the establishment of rubber plantations tends to be harmful to soils not because of rubber trees per se, but rather because of destructive soil preparation and management. Mechanical terracing is associated with losses of soil organic carbon and severe deterioration of soil quality. Chemical fertilizers and pesticides may

One study estimated above-ground carbon in rubber plantations at less than one-half the level in neighboring forests

contaminate surface water and groundwater, presenting a health hazard to rural populations. In addition, the regular use of inorganic fertilizers, if not accompanied by organic soil amendments, can promote acidification and, eventually, a severe decline in soil quality. Although in principle mechanical terracing and intensive fertilization could be applied to many crops, in the mountainous region of mainland Southeast Asia, these practices are only observed on rubber plantations.

Rubber and Global Warming

Over the past century, the concentration of carbon in the earth's atmosphere, in the form of carbon dioxide (CO_2), has increased at an unprecedented rate. This increase in the concentration of atmospheric CO_2 is widely recognized as one of the primary causes of global warming. It is the subject of growing concern and international efforts to slow or reverse the trend.

Trees and other plants have a strong influence on levels of atmospheric CO_2 because about one-half of plant biomass consists of carbon. Plants take up CO_2 during photosynthesis, convert it into carbohydrate, and release oxygen into the atmosphere. Thus, plants act as carbon "reservoirs" or "sinks," sequestering and storing carbon.

When these plants die or are burnt, the carbon stored in them is released back into the atmosphere. As of 2004, the destruction and degradation of forests accounted for an estimated 17 percent of all human-induced carbon emissions (Figure 2) (IPCC 2007).

The role that forests and other plant communities play in reducing atmospheric CO_2 levels has put a premium on efforts to measure the carbon content of plants in forests and in various agricultural systems. Particular concern focuses on areas where land-use systems are changing, resulting in carbon gains or losses. And nowhere is this concern more acute than in the high-elevation areas of mainland Southeast Asia.

In Southeast Asia as a whole, measures of above-ground carbon in mature rubber plantations range widely—from 25 to 143 megagrams per hectare (Mg/ha) (Ziegler et al. 2012). One study in Xishuangbanna estimated above-ground carbon in rubber plantations at less than one-half the level estimated for neighboring forests (Li et al. 2008). Measures of above-ground carbon in rubber plantations overlap substantially, however, with values reported for shifting-cultivation systems, which range from 25 to 110 Mg/ha.

The limited available data also suggest a substantial overlap between below-ground carbon stored under traditional systems of shifting cultivation and under rubber plantations (Ziegler et al. 2012). This overlap in measures of above-ground and below-ground carbon suggests that a transition from traditional shifting cultivation to rubber plantations will probably not lead to substantial increases or decreases in levels of carbon sequestration.

Compared with either shifting cultivation or rubber plantations, the maintenance or expansion of protected forests could certainly increase the sequestration of carbon. Yet, it is difficult to set land aside for natural forests when populations in the region are growing and both local farmers and outside entrepreneurs are beginning to profit from a booming rubber industry.

At the same time, rubber is a tree crop, and environmental concerns are often voiced as a justification

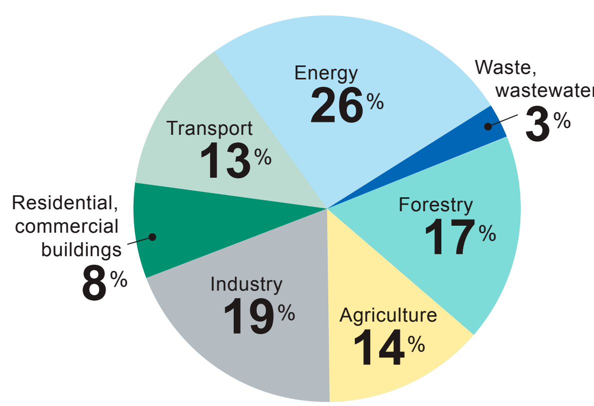

Figure 2.
Share of economic sectors in total carbon dioxide (CO_2) emissions from human sources in 2004. The destruction and degradation of forests contributed 17 percent.
Source: IPCC (2007).

for expanding rubber plantations. The studies reported here, however, suggest that a switch from traditional systems of shifting cultivation to rubber will not necessarily improve carbon sequestration.

Expansion of the area under natural forests is probably not a realistic option except under government protection

A United Nations Plan to Slow Climate Change

The United Nations Framework Convention on Climate Change includes a program to achieve long-term reductions in carbon emissions by Reducing Emissions from Deforestation and Forest Degradation (REDD+) in developing countries. Launched in 2008, REDD+ is a joint program of the Food and Agriculture Organization (FAO), the United Nations Development Program (UNDP), and the United Nations Environment Program (UNEP).

Under REDD+, which is still largely at the planning stage, industrialized nations will pay developing nations to maintain or expand natural forests and some other types of tree cover. At the local level, farmers who protect or expand tree cover could receive regular payments that would help offset their income loss from discontinuing other types of agricultural production.

What level of payment would be required to motivate farmers, governments, or outside entrepreneurs to keep land under natural forests rather than planting rubber? An economic analysis of rubber production in two provinces of northeastern Thailand estimated that farm households could realize a net annual income from rubber ranging from US$1,821 to US$2,336 per hectare (Sawetwong and Dayananda 2008).

Payment for Environmental Services (PES) programs, which have been initiated in several countries, provide an important model for how REDD+ payments might be distributed to local farmers who convert or maintain land under natural forest. A review of PES programs in seven countries of Asia, Africa, and Latin America found that payments to rural households ranged from US$42 to US$515 a year (Mahanty, Suich, and Tacconi 2013).

This is clearly not enough to motivate farmers to protect or expand forests rather than planting rubber. Implementing such a program would also pose major challenges, both in terms of transparency and logistics. Indeed, in the mountainous region of mainland Southeast Asia, expansion of the area under natural forests is probably not a realistic option except in areas protected by national governments, such as national parks and watershed forests.

Conclusions and Recommendations

New, site-specific assessments are needed to better understand the environmental implications of rapidly expanding rubber plantations in the mountainous region of mainland Southeast Asia. Assessments at multiple sites across varied agricultural systems will improve understanding of land-use changes across this highly diverse region.

Transitions from short-fallow systems of shifting cultivation to rubber plantations could improve carbon sequestration, but the gains may be difficult to measure and, in any case, are not likely to be substantial. Farmers could also be encouraged to lengthen the fallow period of existing shifting-cultivation systems or to transition to other agroforestry systems, combining both crop and tree production in ways that improve carbon sequestration.

At present, too little is known about differences in carbon cycling among various agricultural systems—including rubber—to conclude unequivocally which types of land use sequester and store the most carbon. One key question, which cannot be answered at present, is what plantation owners will do after 25 to 30 years when their rubber trees are no longer productive.

There are other issues of concern. Rubber trees in the region are mainly drawn from a small pool of parent stock, which means that their genetic diversity is low. Studies have indicated that Asian rubber plantations are potentially vulnerable to South American leaf blight caused by the fungus *Microcyclus ulei* (Mann 2009). In an age of increasing connectivity, the fungus may well eventually find its way to Asia, producing an outbreak that could devastate local livelihoods and environments.

A second issue relates to price fluctuations. Although global demand for rubber is unlikely to diminish, short-term price fluctuations can pose a serious risk to producers who have become overly dependent on one crop.

Given the difficulty of predicting the impact of land-use transitions on carbon stocks, it is very difficult—perhaps impossible—to suggest land-use policies that will ensure a win-win situation for both farmers and the environment. Specifically, it is doubtful whether a REDD+ program could be devised that would effectively motivate farmers to maintain or increase natural forests. The carbon volumes involved may be too limited to interest investors, and payments to farmers would likely be too small to motivate a switch from rubber.

It is difficult to suggest land-use policies that will ensure a win-win situation for both farmers and the environment

Recognizing the economic and political realities as well as the limited information on environmental impacts, a few ideas can be suggested. In some parts of mountainous Southeast Asia, there are unprotected forests that could be managed under a REDD+ approach that focuses on maintaining and improving carbon sequestration. Another option would be to include rubber in mixed agroforestry systems. A study in Xishuangbanna found that tea-rubber intercropping systems sequestered atmospheric CO_2 and increased soil organic carbon better than rubber planted alone (Zhang et al. 2007). Leguminous cover crops planted between rubber trees can also substantially increase carbon accumulation in addition to improving soil quality and fertility (Ziegler et al. 2012).

Given the broad heterogeneity of land-use systems in the region, additional field studies are needed to develop recommendations adapted to local contexts. Another priority is the development of new analytical techniques to map existing land-use systems, measure soil quality and water availability at representative sites, and assess the impact of rubber plantations and other land-use alternatives on above- and below-ground stocks of carbon.

Government agencies responsible for regulating the current rubber boom need to recognize the competing views and diversity of actors in environmental decision making and make sure that local people are included in decision-making processes. The long-term protection of this large and biologically rich part of the world can only be assured through cooperation among investors, policymakers, and the local population groups who have lived in the region for centuries.

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