Expansion of Rubber Mono-cropping and its Implications for the Resilience of Ecosystems in the Face of Climate Change in Montane Mainland Southeast Asia

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Abstract

Farmers in montane mainland Southeast Asia (MMSEA) have long practiced shifting cultivation with plots of land cultivated temporarily and then allowed to revert to secondary forest for a fallow period. In recent years, shifting cultivation has given way to more intensified forms of mono-cropped agriculture, including cultivated crops, orchards and, of increasing importance, rubber tree plantations. Today, more than one million hectares have been converted to rubber plantations. By 2050, the area under rubber trees in MMSEA is predicted to increase fourfold (Fox *et al*. 2012). This massive conversion of primary or secondary forests to rubber mono-cropping could threaten the resilience of both ecosystems and livelihoods. Despite environmental concerns and market fluctuations, both local farmers and outside entrepreneurs are likely to continue expanding rubber plantations because of their high economic returns. We argue that more diversified agroforestry systems that provide an optimal balance between economic returns and environmental sustainability are needed to improve the long-term outlook for the region in the face of climate change.

Key words: carbon, rubber, Southeast Asia, water

1. Introduction: Massive Land Use Conversion in Montane Mainland Southeast Asia

With "montane" defined as land above 300 meters elevation, montane mainland Southeast Asia (MMSEA) covers about one-half of the combined land area of Cambodia, Laos, Myanmar, Thailand, Vietnam and China's Yunnan Province (Fig. 1). The region is home to great biological and cultural diversity that is threatened by deforestation, commercial agriculture driven by regional and global markets, and the rapid expansion of urban and periurban landscapes (Fox & Vogler, 2005). The region's high seasonal, interannual, and multi-decadal climate variability and the resulting long history of catastrophic floods and droughts, with their impacts on regional socioeconomic wellbeing and political stability (Buckley *et al.*, 2010), are also of major consequence. These factors create a unique setting in which present-day human-environment interactions in MMSEA offer a preview of future challenges throughout the developing world.

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 for a fallow period. The staple crop is typically upland rice, but cultivated plots may include a range of secondary food and cash crops such as maize, cassava, banana, sugarcane, ginger and cardamom (Mertz *et al*., 2009). Fruit trees or other useful tree species may be planted on fallow plots leading to complex agroforestry systems, or they may be left entirely regrow naturally. These practices produce a unique landscape mosaic combining small agricultural plots with secondary forests. Studies conducted in the region 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; Fox *et al*., 2012).

Over the past half century, the five countries of MMSEA have witnessed a major shift from predominantly subsistence agrarian economies to industrialized

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societies. These changes have been accompanied by growing urban populations and establishment of a number of regional megacities. Simultaneously, the agricultural frontier has advanced as demand for land and resources from the growing population, both within the sub-region and from outside, has increased (Fox & Vogler, 2005).

A central dynamic of this change has been the rapid growth of boom crops (Hall *et al*., 2011). Among the many types of commercial products promoted and grown are numerous tree-based products such as rubber, coffee and cashews, and fast-growing tree species for pulp and paper. Between 2000 and 2010 the amount of the landscape occupied by tree crops grew at an annual rate of 4.32% per year (Li & Fox, 2011).

In recent years, entrepreneurs from China, Vietnam, Malaysia and Thailand have invested heavily in the expansion of rubber plantations to new areas of Laos, Cambodia and Myanmar, as well as portions of their own countries (Fox & Castella, 2013). One impetus for the expansion of rubber in the highlands has been the widespread shift from rubber to oil-palm production in more humid areas where rubber was grown before. By 2012, rubber plantations covered more than one million hectares of non-traditional rubber-growing areas of China, Laos, Thailand, Vietnam, Cambodia and Myanmar (Li & 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).

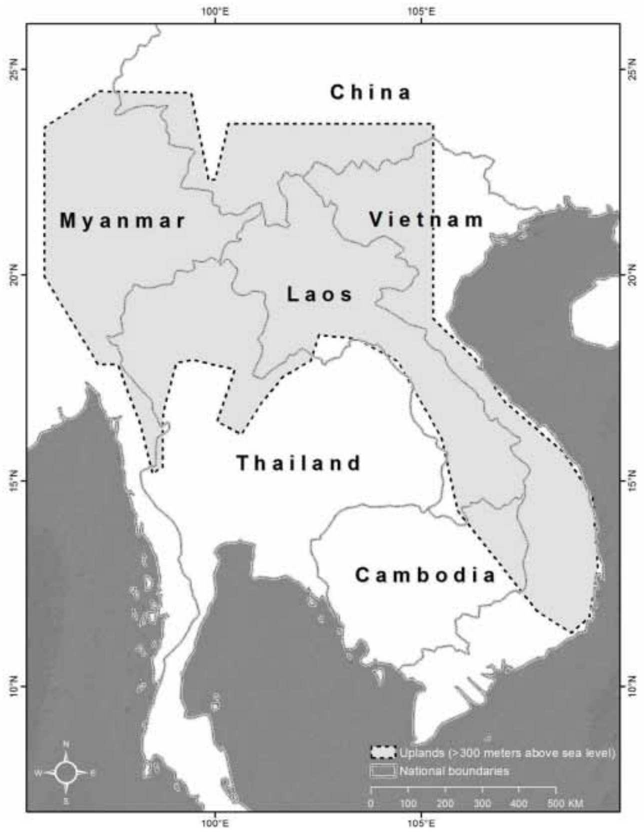

Fig. 1 Montane mainland Southeast Asia.

In addition to boom crops, heightened concern for environmental conservation has led state actors to zone large amounts of land as off-limits to agriculture and, increasingly, to try to enforce that zoning. In 1990, there were 115,759 km^2 of protected areas in these five countries (IUCN & UNEP-WCMC, 2014). By 2010 this area had more than doubled to 252,698 km^2. In the lower Mekong countries of Thailand, Laos, Cambodia and Vietnam this figure represents 22% of the landscape, the largest proportion of national land area demarcated for conservation zones of any region of the world (PADP, 2003). Despite this protection, forest cover in MMSEA fell from 50.7% to 45.7% between 1990 and 2010, as a result of losses in Cambodia, Laos and Myanmar (Meyfroidt & Lambin, 2009). In Thailand, the agricultural frontier has closed and forests are beginning to regrow on former cropland while in Vietnam large government-supported afforestation and reforestation programs are resulting in forest expansion, but poor forest quality is still an issue (Hoang *et al*., 2011).

One factor driving the transition toward more intensive agriculture has been the expansion of road networks and markets, making it easier for farmers to purchase agricultural inputs and sell their crops. Finally, crop-substitution programs, designed to eliminate the cultivation of opium poppies, have motivated a shift toward rubber and other cash crops. National governments in the region have accelerated this trend by formulating 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 (Ziegler *et al*., 2009). Policies have included the outright banning of shifting cultivation, declaring areas to be forest reserves and excluding the people who had lived there for centuries, moving them into more crowded settlements 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 intensive cash crop production. Others have been forced into contracts with unfavorable terms or have lost their land entirely (Fox *et al*., 2009).

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 (Jumpasut, 2014). Given financial realities, neither local farmers nor outside entrepreneurs are likely to return to subsistence forms of agriculture. As a response to the changing situation, the Chinese have gone as far as to redefine rubber plantations as forests, thereby increasing the area they have declared under forest cover. But are rubber plantations really as beneficial to the environment as natural forests? Are they more or less beneficial than the traditional systems of shifting cultivation that they are replacing? Given the current pace of expansion, it is particularly critical to answer these questions and determine the environmental implications of this large-scale change in land use in the face of a changing climate. The sequential drought and flood events in mainland Southeast Asia in 2010 and 2011 exemplify the potential vulnerability of current land-use systems to extreme climate events.

2. Climate-driven Vulnerability

The monsoon regime dominates the atmospheric circulation in mainland Southeast Asia, resulting in highly seasonal precipitation, with 80%-90% of total precipitation falling during the six-month summer monsoon season (approximately May-October). The time of onset, duration, intensity and frequency of breaks in the summer monsoon circulation and precipitation can vary significantly, resulting in a relatively high frequency of extreme precipitation years, both low and high (Lim *et al.*, 2012). Drought due to deficient monsoon rainfall can produce widespread crop failure and famine. Excessive rainfall often produces flooding in densely populated low-lying cities, such as Chiang Mai and Bangkok, which experienced large floods in 2005 and 2011, respectively (Wood & Ziegler, 2008; Ziegler *et al*., 2012). Over the past millennium, numerous multi-year "megadroughts" are known to have occurred in the region with devastating consequences, ranging from political upheavals, *e.g*., during the 1756-1768 drought, to massive death tolls (*e.g*., during the drought of 1876-1878 (Cook *et al*., 2010). Extreme monsoon rainfall variability, including lengthy droughts, during the 14th and 15th centuries, is thought to have contributed to the fall of the Khmer Empire based at Angkor (Buckley *et al.*, 2010).

Variations in monsoon timing and intensity are known to be associated with Pacific- and Indian Ocean-based coupled ocean-atmosphere oscillations, *viz*. the El Niño-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD), respectively (Ummenhofer *et al*., 2011). Many of the historical megadroughts affecting the region, for example, were associated with severe El Niño events (Davis, 2001; Cook *et al.*, 2010). Indian Ocean sea surface temperature (SST) changes produce regional drought (or heavy rains) during the positive (or negative) phase of IOD (Saji *et al.*, 1999; Ashok *et al.*, 2001). In the future, global climate change is expected to have significant effects on the Asian monsoon circulation with consequences for the mean and variability of the regional climate in mainland Southeast Asia.

Expectations are that climate warming will cause intensification of the monsoon, resulting in greater interannual and multi-decadal variability in the form of more frequent and more severe droughts and floods (Overpeck & Cole, 2007). Ashfaq *et al*. (2009), using regional downscaling of CMIP3 global model simulations, projected a reduction in monsoon precipitation in South Asia, resulting from a delayed onset and more frequent monsoon breaks associated with weakened local Hadley circulation. Upward trends in temperature and the frequency of high temperature extremes have been detected in the region; significant rain days have decreased in number and the proportion of annual rainfall derived from extreme events has increased (Manton *et al*., 2001). Observations indicate a shift toward a drier climate in the region that began in the mid-1970s (Cook *et al*., 2010), along with a weakening of the relationship between ENSO and the Asian monsoon. These findings may be linked to a higher frequency of positive IOD events in recent decades (Ummenhofer *et al*., 2011). Due to the anticipated climate changes in mainland Southeast Asia, the dry season is expected to lengthen and intensify. In contrast, the rainy season is expected to shorten and intensify, with dramatic increases in rainfall occurring in the wettest months. Thus, both seasonal water shortages and floods may be exacerbated (Mainuddin & Kirby, 2009).

The role that forests and other plant communities may play in mitigating climate change has put a premium on efforts to measure the carbon content of plants in forests and in various agricultural systems (Gibbs *et al.*, 2007; Ziegler *et al*., 2012). Particular concern is focused on areas where land-use systems are changing, resulting in carbon gains or losses. The limited available data suggest a substantial overlap between below-ground carbon stored under traditional systems of shifting cultivation and under rubber plantations (Ziegler *et al.*, 2012; Yuen *et al*., 2013; Fox *et al*., 2013). 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. Maintenance or expansion of protected forests could certainly increase carbon sequestration. Yet it is difficult to set land aside when populations in the region are growing and both local farmers and outside entrepreneurs are beginning to profit from a booming rubber industry.

3. Trans-boundary Environmental Issues

Forest conversion and agricultural intensification not only contribute to carbon emissions and high costs associated with more irrigation and fertilizers, but generate other major issues that threaten the resilience of ecosystems and livelihoods at the landscape scale and that agroforestry can mitigate. These issues are explored in the four subsections that follow.

3.1 Accelerated drought and flooding in downstream areas because of water and land-use change upstream

Both an increase in intensive rain-fed annual crops and areas of commercial tree crops will require more off-season water for cultivation. A projected drier climate with increased rainfall variability makes the water supply less predictable. Increased buffering of water storage is thus needed. The buffering capacity of landscapes, however, has been declining because of reductions in rainfall recharge resulting from changes from land-cover types of high infiltrability (*e.g*., undisturbed forests) to those that generate substantial surface runoff, including intensely cultivated hillslopes, where accelerated erosion occurs (Ziegler *et al*., 2004, 2007, 2009). Technical approaches to increasing water storage through construction of dams and reservoirs provide water for hydropower generation and downstream irrigation, but may result in a reduced capacity to absorb unexpected rainfall towards the end of the rainy season, as seen in the 2011 Bangkok floods (Ziegler *et al*., 2012). Reservoirs in northern Thailand often have no storage capacity left as their operational rules prescribe maximum water supply for the dry season. Their total economic costs have been huge (Cook *et al*., 2010). Reducing the risk of droughts during dry seasons and years, and floods during wet months requires technical *plus* natural buffering to secure downstream ecosystems and livelihoods.

3.2 Reduction of agro-biodiversity

The increasing prevalence of rubber monocultures on land that used to have agro-diverse land uses has reduced the biological buffering against pests, weeds and diseases and increased the risk that farmers are exposed to in the face of climate variability and market fluctuations (Aratrakorn *et al*., 2006). Agro-biodiverse, intermediate-intensity agroforestry options at farm and landscape scales could increase farmers' capacity to deal with economic and climatic shocks as well as natural (and human-induced) disasters (Qiu, 2009; Hoang *et al.*, 2011). Such practices, however, remain blind spots for much ongoing research and development because they are misunderstood as being of only 'traditional' value, rather than dynamic responses to contemporary pressures that build on local knowledge and practice.

3.3 Erosion and depletion of the soil organic carbon sink

Conversion of natural forest to cultivated land generally leads to a reduction of soil organic carbon stocks because of reduced litter inputs, higher top soil temperatures that lead to higher decomposition rates, and soil disturbance that increases decomposition due to increased aeration and destruction of physiochemical protection mechanisms (Brunn *et al*., 2009). Intensification of rubber monocultures and rain-fed rice on steep slopes may cause accelerated erosion (Sidle *et al.*, 2006; Ziegler *et al*., 2009). When the soil surface layer is eroded, the *in situ* carbon and various nutrients are washed away and often exported from the hillslope and even outside the catchment (Brunn *et al*., 2009). Subsoils with lower soil organic carbon content and water-holding and infiltration capacity are then exposed, further increasing surface run-off. Groundwater dynamics are potentially affected by dry-season water use of rubber as a commercial tree crop (Guardioloa-Claramonte *et al*., 2008, 2010). This illustrates how land productivity may be reduced at a landscape scale by efforts to increase economic gains locally and hence why there is a need for cross-scale approaches to landscape management. Such approaches need to foster the development of social capital at the scales at which ecosystem services manifest if they are to be effectively managed.

3.4 Long-term impacts and complexity at the landscape scale

It usually takes time before unintended effects of human changes in agro-ecosystem functions can be seen. This is because interactions involve lag times before ecosystem resilience reaches a tipping point. For example, irrigation of a commercial agricultural landscape was seen to affect water quality and quantity adversely in the delta area of northwestern Mississippi after 20 years of monitoring (Coupe *et al*., 2012). Accelerated drought during the dry season due to mono-cropping of rubber in the Upper Mekong river basin was found after 15 years of systematic observation (Zhang *et al*., 2012). Furthermore, policies aimed at one sector in one part of MMSEA may cause unintended ecological consequences in other sectors and places (Coupe *et al*., 2012). The complexity of socio-ecological systems needs to be better captured as a basis for multi-stakeholder negotiations of development trajectories that work for all. This requires a long-term, integrated landscape approach to research, development and monitoring at multiple scales ranging from the local to the regional.

4. Conclusions and Recommendations

New, site-specific assessments are needed for a better understanding of the environmental implications of rapidly expanding rubber plantations in MMSEA. Assessments at multiple sites will improve understanding of land-use changes across this highly diverse region. Transition from some 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 dramatic. Specifically, it is doubtful whether a REDD+ scheme could be devised to support these sorts of transitions because the carbon volumes involved may be too limited to interest investors, and payments to farmers may be too small to motivate a switch from rubber. Given the economics at play, it seems inevitable that strong demand and high prices for natural rubber will continue to drive a transition from traditional farming systems in the highlands of mainland Southeast Asia to landscapes dominated by rubber plantations. In a more ideal world, farmers would transition to more diverse agroforestry systems combining both crop and tree production in ways that improve climate change mitigation through carbon sequestration and adaptation through resilience to unexpected climatic events or market fluctuations.

For example, 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. An enabling institutional environment is necessary for increasing the inclusion of rubber in mixed agroforestry systems. Policymakers responsible for managing the current rubber boom must recognize the competing views and diversity of actors in environmental decision making and actively seek to include local people in decision-making processes. Such a multi-stakeholder landscape approach has historically been lacking in the interactions between policymakers and farmers throughout much of montane mainland Southeast Asia.

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Prof. ZIEGLER’s research addresses the interactions among physical and ecological systems in Southeast Asia, with water resources serving as a common nexus. His work typically involves developing environmental monitoring programs that facilitate understanding catchment processes, as they vary both naturally and anthropogenically over different spatial and temporal scales. He seeks to work with others who have an interest in various aspects of water resource management, environmental health, natural hazards or hillslope/catchment hydrology. He is currently interested in exploring environmental impacts of land-cover change, the risks to rural populations in developing areas of ingesting contaminated drinking water, exposure to anthropogenic contaminants (heavy metals and pesticides) and exposure water-borne pathogens (*e.g*., parasites, bacteria). This type of research is a multi-disciplinary balancing act, grounded in science, but with an interest in incorporating elements of human geography.

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Sidney B. WESTLEY has worked as a writer, editor and publications director for more than 40 years, including 22 years in East Africa. Before joining the East-West Center in 1994, she worked for research organizations in the fields of forestry and agroforestry, immunology and molecular biology, animal science, development, and African history. At the East-West Center, she has worked on a variety of publication projects, including *The future of population in Asia* (with Robert D. Retherford) and *Asia's energy future: Regional dynamics and global implications* (with Kang Wu and Fereidun Fesharaki). From 1994 to 2004, she was the series editor and principal writer for the East-West Center’s quarterly publication, *Asia-Pacific Population & Policy,* and she is currently the series editor for the *National Transfer Accounts (NTA) Bulletin.* From 1996 to 2011, Ms. Westley coordinated an annual workshop on communicating with policymakers about population and health as part of the East-West Center's Summer Seminar on Population. She holds a B.A. in government from Smith College.

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