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Are trees buffering ecosystems and livelihoods in agricultural landscapes of the Lower Mekong Basin?

Consequences for climate-change adaptation

Minh Ha Hoang, Meine van Noordwijk, Jefferson Fox, David Thomas, Fergus Sinclair, Delia Catacutan, Ingrid Öborn, Tony Simons

World Agroforestry Centre

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Abstract

People and ecosystems in the Lower Mekong Basin (LMB) are vulnerable owing to the interaction between unsustainable land-use practices and climate change. This review analyzes 1)) the impacts of continuing land-use and climate changes in the LMB region; and 2) the potential role of increased use of trees in agricultural landscapes to reduce the negative impact of land-use changes. The analysis was based on a review of peer-reviewed literature identified by a keyword search and related unpublished data of the World Agroforestry Centre Thailand. The study confirms that natural resources and ecosystem services—particularly water, soil and biodiversity—are degrading in the LMB. However, trees outside forests, including agroforests, can help buffer both ecosystems and local livelihoods in agricultural landscapes, thereby enhancing their resilience. Several remaining challenges are discussed according to their links to technical, policy and social capital-building issues. Combining local knowledge and scientific knowledge in selecting optimal combinations and spatial arrangements of suitable trees and agroforestry practices is necessary in order to maximize synergies and reduce trade-offs among different ecosystem services, between ecosystem benefits and economic benefits, and between climate-change adaptation and mitigation purposes. Policy recommendations centre on strategies for participatory approaches, on enhancing agroforestry advocacy and on co-interest incentive schemes at farm scale to help address sustainability of agricultural landscapes. Further research is recommended on suitable trees and agroforestry practices to address identified trans-boundary issues, using a holistic landscape approach with high levels of participation and a nested framework for ecosystem management and monitoring.

Keywords: agroforestry, climate change, multifunctionality, tree-based strategy, vulnerability, ‘climate-smart’ landscape, buffering, resilience, ecosystems

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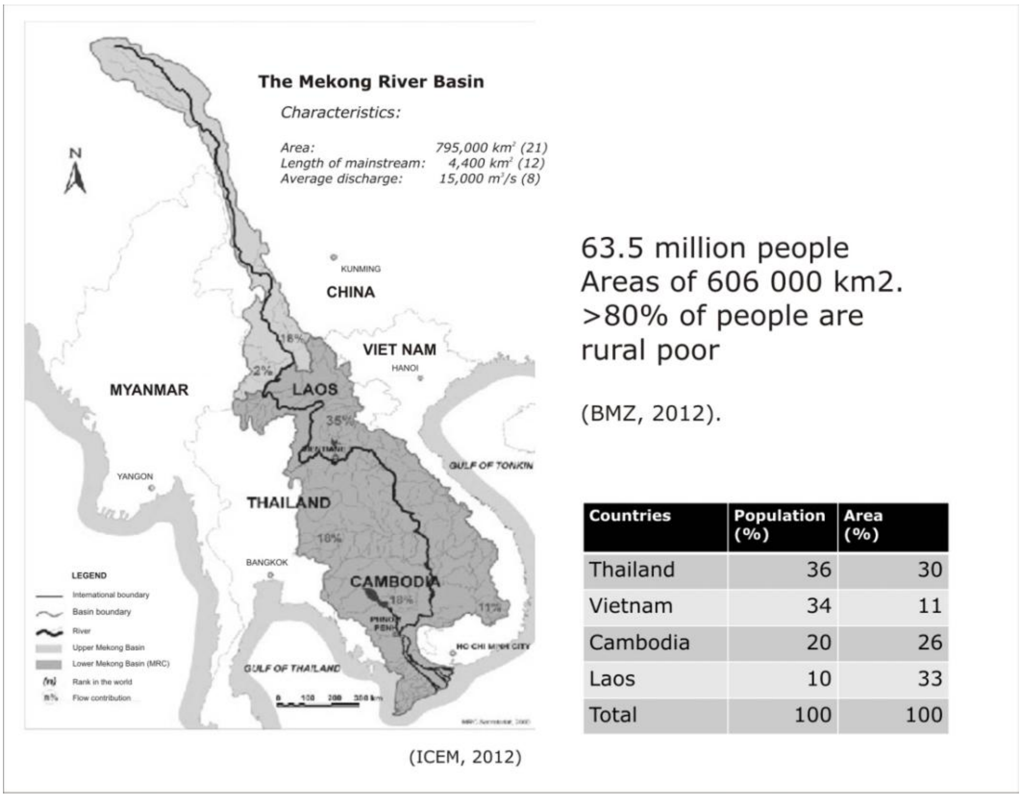
Content

1. Introduction

The Lower Mekong Basin (LMB) is a trans-boundary landscape of 606,000 km^2 located in the lower part of the Mekong River system. It is home to 63.5 million people in the four countries of Cambodia, Laos, Thailand, and Viet Nam, which are all members of the Mekong River Commission (MRC) (BMZ 2012). Over 80% of the population in LMB is classified as "rural poor" with livelihoods directly dependent on the availability of rain, reservoir and/or river water for food production (MRC 2003).



Countries	Population (%)	Area (%)
Thailand	36	30
Vietnam	34	11
Cambodia	20	26
Laos	10	33
Total	100	100

The region generates around half of the world's rice exports and provides food for over 300 million people (BMZ 2012), nearly five times its own population. Yet, the region is still rich in biological and cultural diversity, although this is under threat. The productivity and diversity of the region is threatened by increased population, deforestation and intensification of commercial agriculture driven by regional and global markets, as well as rapid expansion of urban and peri-urban areas (Fox and Vogler 2005; Grumbine and Xu 2011). The population is projected to rise to more than 82 million and the proportion of urban dwellers from about 20% today to 40% by 2030, with economic growth at around 4.5% per year (Mainuddin and Kirby 2009). Changes in climate, including temperature and precipitation patterns, which affect sea levels and river flows, can add substantial stresses to infrastructure and especially to the food, water, energy, and ecosystems that people depend upon (NIC 2010). Despite the natural resource base of the LMB being under threat, recent debates among Mekong countries have focused on the commercial exploitation of the region's natural resources rather than the need to sustain ecosystem functions.

While engineering options such as dam construction have been widely pursued in LMB, green options, such as promoting conservation farming, including how to manage trees outside forests and agroforestry (combining trees and shrubs with crops and/or livestock) for enhancing ecosystem buffering, are just emerging. For a long time, trees outside forests—including scattered trees, farm forests, woodlots and agroforestry (AF)—have been known for their benefits in preventing soil loss through erosion, enhancing nutrient and water recycling (and thereafter enhancing crop yields), in sequestering carbon, and improving access to feed, food and fuel for smallholders in the tropics (Matocha et al 2012; Pramova et al 2012; Grandstaff et al 1986). Agro-biodiverse, intermediate-intensity agroforestry options at farm and landscape scales are likely to increase farmers' capacity to deal with economic and climatic shocks as well as natural (and human-induced) disasters (Nguyen et al 2013; Hoang et al 2013). Such practices, however, remain blind spots for much research and development because they are misunderstood as being of only "traditional" value rather than as dynamic responses to contemporary pressures that build on local knowledge and practice. Today, with the landscape approach being taken seriously in international climate debates, the role of complex land uses and forest mosaics in maintaining and building both the multifunctionality of landscapes and the diversity of livelihoods has also received renewed recognition.

In order to help identify strategies for sustainable land use in the rapid changing context of the LMB region, this paper reviews 1) the complex impacts of on-going land use and climate changes in the LMB region; and 2) the potential role of trees outside forests in helping reduce the negative impacts of the changes. On the basis of our review, possibilities and challenges in promoting trees outside forest, including agroforestry practices and systems, are discussed. We see reduced vulnerability as dependent on the maintenance of ecosystem services and the use of appropriate policy instruments at multiple scales (van Noordwijk et al 2011a; Scherr at al 2012, Harvey at al 2013). Existing peer-reviewed literature was searched using a set of keywords related to our research assumptions (Section 2 below).

2. Theory and methods

In this review paper, we began with the assumption that buffering is a key part of ecosystem services provided by natural capital but that it interacts with (and is partially substitutable by) buffering provided by social capital. Lack or loss of either type of buffering implies vulnerability. We hypothesized that the trends in the LMB are a decreasing supply of buffering while demand is increasing, with uncertainty related to climate, global markets, etc. We then analyzed current trends, impacts and potential roles of trees outside forests in enhancing buffering by reviewing existing peer-viewed literature searched on a set of relevant keywords, along with review of relevant unpublished data on land use and livelihood transitions of the Mae Chaem catchment in Northern Thailand. On the basis of these reviews, we revisited the hypothesis and its policy implications.

We adopted an interdisciplinary framework that views the LMB as a dynamic socio-ecological system (Folke 2006). Systems linking people and nature, known as social-ecological systems, are increasingly understood as complex adaptive systems (Levin et al 2013). Governance of trans-boundary issues becomes increasingly important as we move from individual livelihoods through to larger landscape units. Vulnerability of lives and landscapes within the LMB were analyzed using an Earth system approach (Steffen et al 2004). This focuses on connections amongst climate-system components—including regional atmospheric circulation, land cover and hydrology—with national and local socio-economic systems. We assumed that changes in climate variability and land use interact strongly with the evolution of socioeconomic systems and infrastructure in the region and can either exacerbate environmental problems or, if anticipated and prepared for, create opportunities to establish more sustainable socio-ecological management (Cruz et al 2007; ADB 2009; NIC 2010).

In the context of this paper, “resilience” and “vulnerability” are opposing, multidimensional concepts that refer to the ability of people and landscapes to cope with variability (both natural and as a result of human disturbance) and adapt to change, including change in variability. Lives and landscapes become vulnerable when they are pushed beyond comfort zones, for example, through collapse of key buffer and filter functions that shield and sustain them. The concepts of “buffers” and “filters”, as used here, are related. Buffers reduce variability, while filters (selectively) reduce transmission. Technical definitions of “buffer” are indeed based on variance reduction. For example, stream flow is buffered, although still variable: if it would be the same amount every day buffering would be 100%. The concept of buffering applies to anything that varies in situations where variation matters: prices, rainfall, temperature, politics, human health in the face of diseases, crop health in the face of pests, soil water content, etc. Buffering cannot, however, shift mean values over a longer time period. In the context of landscape analysis, buffers and filters are most commonly related to water flows and erosion/sedimentation processes. Strips of land along river banks, or in other strategic positions in a landscape, which have a filter function can be called “filters” themselves. The term “buffer” is often used as a shortened term for “buffer zone”, an area in-between intensive agriculture and areas for conservation of natural habitat and associated biodiversity. The buffer zone is intended to buffer human influence on wildlife and wildlife influence on humans (van Noordwijk et al 2011a).

In the context of ecosystems, the buffering capacity of ecosystem state variable X with respect to Y is defined as the ratio of variance in X to the variance in forcing function Y (Jorgensen 1997; van Noordwijk et al 2011a). Forcing functions are defined as external variables that potentially influence ecosystem behaviour, whether natural or anthropogenic

(Rutger at al. 2001). Buffering capacity varies with the forcing functions considered, but the most salient ones are those that, after accounting for all available buffering effects, have the strongest impact on system behaviour. “Robustness” refers to a system’s ability to continue to function when intrinsic and extrinsic disturbances occur. “Resilience” can go beyond robustness and include the ability to reorganize after being challenged (Levin 1998; Levin and Lubchenko 2008; Folke et al 2010). Buffering of human lives and livelihoods from climatic variability is an important ecosystem service, but it depends on the resilience of the components that provide the buffering. A livelihood is resilient if it can maintain its key functions (e.g. physical security, food, safe water, income, etc.) and absorb the impact of disturbances without undergoing major decline in production and well-being (Speranza 2013).

3. Results and discussion

3.1. Land-use change as a driver of vulnerability

During the last decade, the agricultural frontier in LMB has advanced into areas of remaining forest as demand for land and resources has increased both from growing populations within the region and to meet demands from outside (Fox and Vogler 2005). The commercialization of agriculture and its promotion by LMB governments is driving land-use change towards more cash crops such as rubber, coffee, cashews, and fast-growing wood species for pulp and paper, as well as toward higher cropping intensities (Rowcroft 2008; Hall et al 2011).

Between 2000 and 2010, the area of land occupied by tree crops grew at an annual rate of 4.3% (Li and Fox 2011). In upper watershed areas of the LMB, changes in land-use patterns during recent decades have been closely associated with transitions from traditional forest–fallow shifting cultivation of upland rice, which incorporated a diverse array of minor subsistence crops, into fixed-field intensive production of upland rice and cash crops. How this transition progressed during 1989–2008 in a major upper tributary catchment of the Ping River Basin in northern Thailand can be seen in the following diagram constructed from data in neighbouring Mae Chaem (Figure 1). Although timing and types of commercial crops vary by location, basically similar types of processes have been occurring in mountain zones of the LMB.

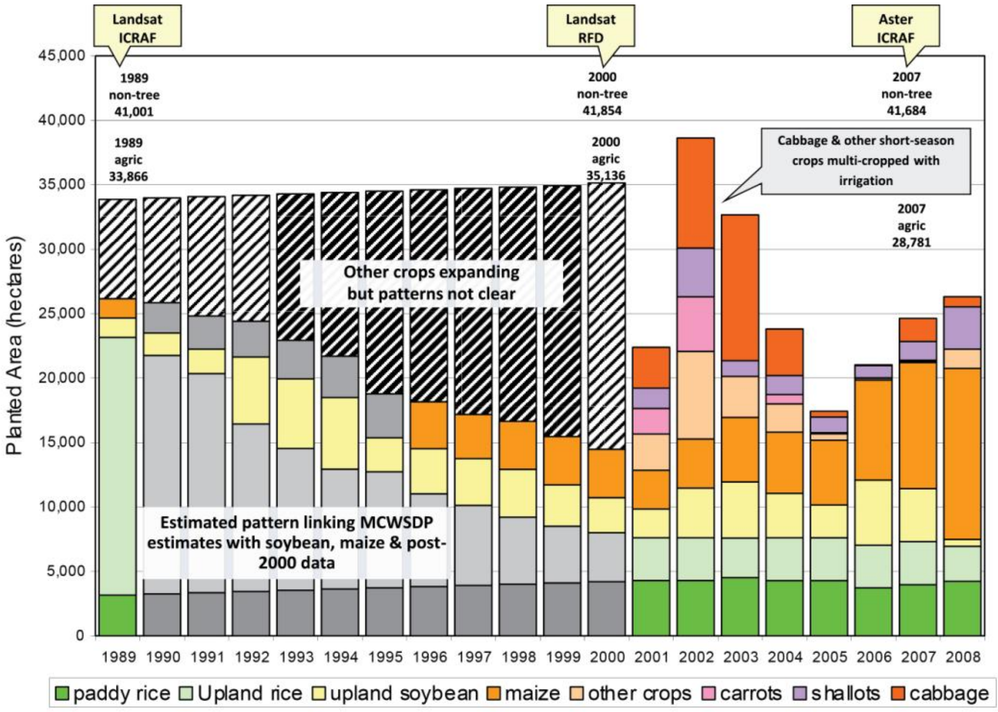


Figure 1. Mae Chaem crop and livelihoods' transitions, 1989–2007
Note: MCWSDP = Mae Chaem Watershed Development Project (source of data for 1989) [note: other crop data from local district agriculture office]; RFD = Royal Forest Department (conducted official interpretation of 2000 Landsat data); ICRAF = World Agroforestry Centre (conducted official interpretation of 1989 Landsat and 2007 Aster data)

In addition to the perceived impacts of commercial boom crops, increased 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 the LMB as a whole, almost a quarter of the land area (22%) is demarcated for conservation, which is the largest proportion of any region of the world (PADP 2003). Despite this, the forest transition is still proceeding rapidly (Meyfroidt and Lambin 2009). Forest cover in mainland Southeast Asia fell from 51 to 46% between 1990 and 2010 as a result of losses in Thailand, Cambodia, Laos and Myanmar. While overall population pressure has been a major determinant of past deforestation in Cambodia and Thailand, a strong correlation between poverty and environmental degradation (deforestation and soil degradation) was identified in Laos (Dasgupta et al 2005). This deforestation has been linked to related environmental problems such as floods, siltation, and damage to aquatic habitats.

The number of trees outside forest increased: In Thailand, the agricultural frontier has halted and forests are beginning to regrow on former cropland, while in Viet Nam large, government-supported afforestation and reforestation programs are resulting in forest expansion. In northeastern Thailand, various types of tree plantations are replacing upland crops that first followed deforestation. For more mountainous areas, Thomas and colleagues compiled a picture of forest-cover change during an 18-year period (1989–2007) in a major upper tributary catchment in northern Thailand by analyzing a time series of Landsat 5, 7 and Aster images of Mae Chaem (Figure 2). This analysis indicated maintenance of a similar percentage of forest cover (87%) during the entire period, but it was changing into a much more segregated pattern. Moreover, forest characteristics changed with state agency programs to stop forest–fallow shifting cultivation, thus forcing agriculture into intensive fixed-field cultivation dependent on purchased inputs. A somewhat similar pattern can also be found in Viet Nam, as despite reported increased forest cover in the country, low-quality forest and continued deforestation for resettlement and cash crops still occurs in the Central Highlands (Hoang et al 2011). These changes reflect tree-cover transitions observed elsewhere in Southeast Asia: forest decline followed by later expansion of tree cover on agricultural land.

According to Garrity (2012), tree cover on farms in Southeast Asia exceeds 30%. It is anticipated that this trend may continue in LMB in coming decades due to population increase, urbanization and economic growth (Mainuddin and Kirby 2009). A recent strategy for mountainous northern Laos proposes that agriculture–forest segregation should be buffered in such a way that a diversity of livelihoods' opportunities and economic development pathways can be maintained (Castella et al 2013).

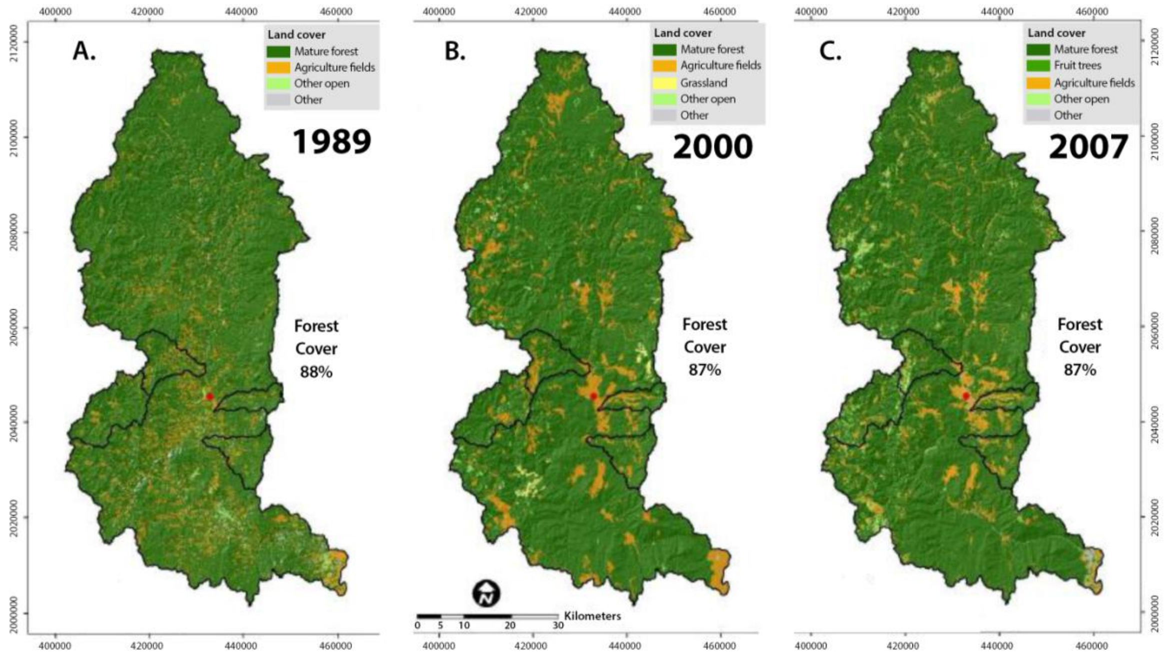


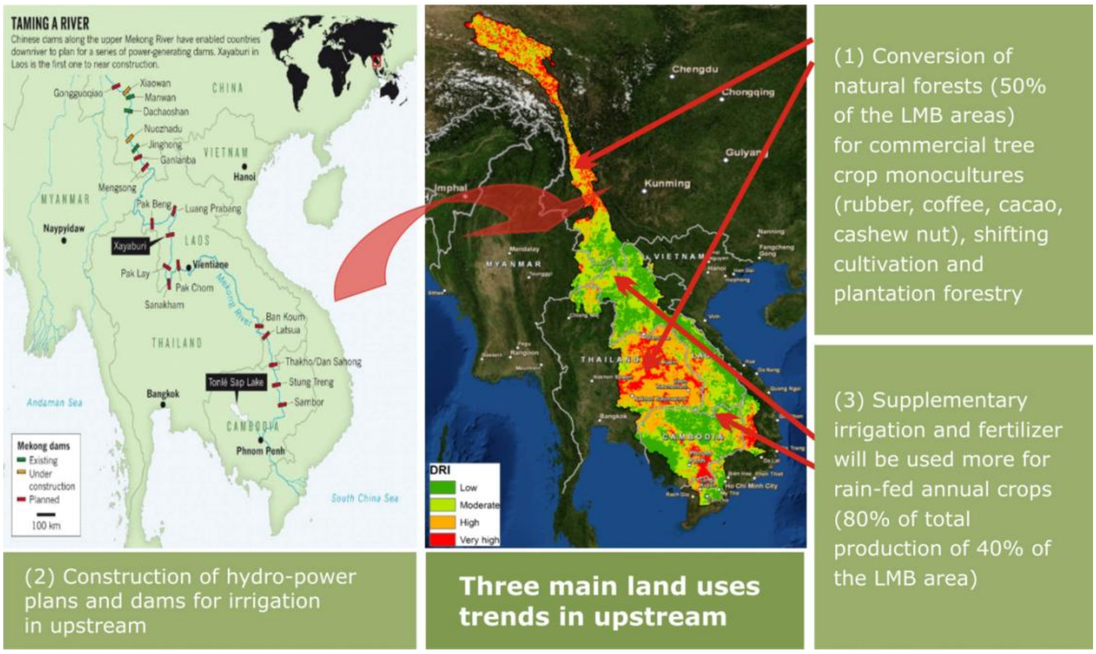
Figure 2. Overall land-cover change in Mae Chaem, 1989–2007

More intensification in agricultural land: Intensification of the 40% of the LMB area used for agriculture is the second important trend. Rain-fed rice accounts for about 80% of the total production of annual crops in the region but is being progressively intensified through use of supplementary irrigation and increasing fertilizer input (Mainuddin et al 2012). Crop and land-cover change shown in Mae Chaem is a clear example of this trend toward intensification even in mountainous upper tributary areas (Figures 1 and 2).

Modelling results suggest that current development of dams for irrigation and hydropower plants in upstream China and on Laotian tributaries will reduce flows downstream, particularly during the dry season, which will neither satisfy requirements for downstream irrigation nor prevent saltwater ingression in the delta (MRC 2004; Pech and Sunda 2008). The direct downstream costs of the dams through reducing fisheries, inundation of riverbank gardens and loss of nutrients for floodplain agriculture has been estimated at USD 500 million/year (Grumbine and Xu 2011). There is, however, another way to increase the productivity of rain-fed agriculture without high water consumption. According to

Mainuddin and Kirby (2009), Rain-fed crop productivity in the LMB can be increased by replacing crop varieties and improving management practices, including agroforestry.

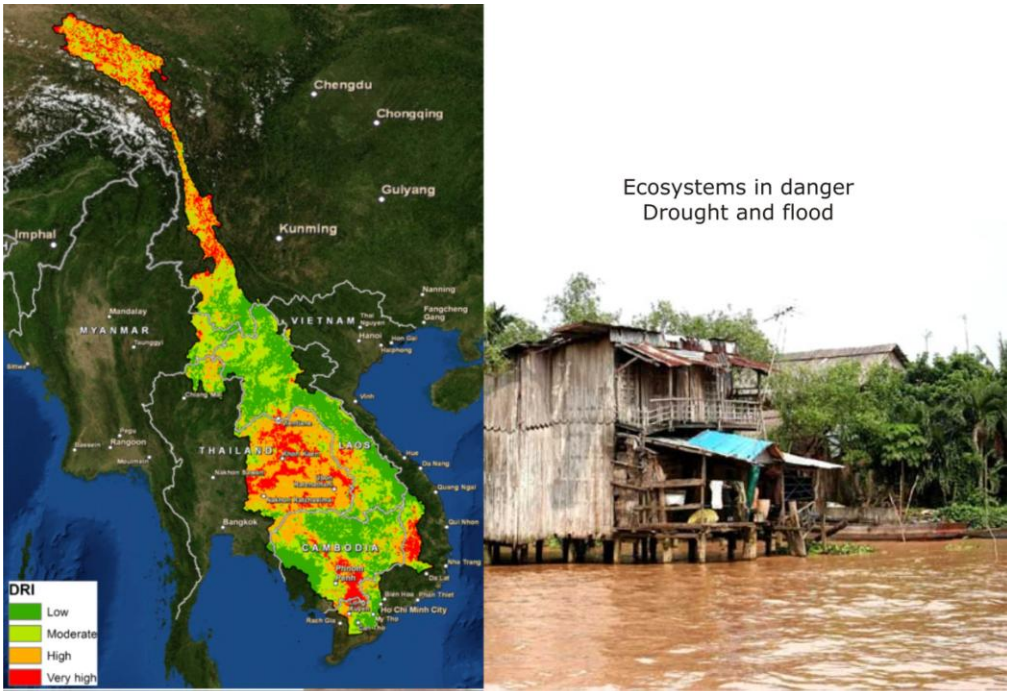
The challenges in promoting trees outside forest to enhance the buffering capacity of ecosystems and livelihoods in the LMB are discussed later in this paper.



3.2. Climate-driven vulnerability

The monsoon regime dominates atmospheric circulation in mainland Southeast Asia, including the LMB, resulting in highly seasonal precipitation, with 80–90% of total precipitation falling during the six-month summer monsoon (approximately May–October). The time of onset, duration, intensity and frequency of breaks in the summer monsoon's circulation and precipitation can vary significantly, resulting in a relatively high frequency of extreme precipitation years, both low and high. Drought owing to deficient monsoon rainfall can produce widespread crop failure and famine. Global climate change is expected to have significant effects on the Asian monsoon circulation with consequences for the mean and variability of regional climate in the region. Expectations are that climate warming will cause intensification of the monsoon, resulting in greater inter-annual and multi-decadal variability in the form of more frequent and more severe droughts and floods (Overpeck and Cole 2007). 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 that a shift toward a drier climate in the region began in the mid-1970s (Cook et al 2010), along with a weakening of the relationship between the El Niño–Southern Oscillation and the Asian monsoon (Ummenhofer et al 2011). In the LMB, the dry season is expected to lengthen and intensify, and the rainy season is expected to shorten and intensify, with dramatic increases in rainfall in the wettest months. Thus, both seasonal water shortages and floods may be exacerbated, as may saltwater intrusion into the Mekong Delta (Mainuddin and Kirby 2009). Furthermore, sea-level rises owing to climate change are projected to affect a minimum of 69% of the delta by 2030 and virtually all of it by 2070 during the flood season (Bindoff et al 2007).

Indeed, changes in climate and land use interact strongly with the evolution of socioeconomic systems and infrastructure in the region. Together, they seem to exacerbate environmental problems, which threaten the resilience of ecosystems and livelihoods at farm and landscape scales.



3.3. Complex trans-boundary issues and their consequences

More severe drought and flooding because of water abstraction and monoculture: More intensification of rain-fed annual crops and increased areas of commercial tree crops will both require more off-season water for cultivation. A projected drier climate with increased rainfall variability makes water supply less predictable. An increased buffering of water is thus needed, but the actual buffering capacity of landscapes is declining because of reduction of forest and riparian wetlands and increased erosion from monoculture cultivation of crops on sloping land (Bradshaw et al 2007; FAO 2008). Technical approaches for increasing buffering through construction of dams and reservoirs also use water for hydropower generation and downstream irrigation, frequently leaving little capacity to absorb unexpected rainfall towards the end of the rainy season, as was seen in the 2011 Bangkok floods: reservoirs in North Thailand had no storage capacity left because their operational rules prescribed maximum water supply for the dry season. Total economic costs were huge (Cook et al 2010). Pech and Sunada (2008) suggest that, in order to satisfy requirements for further irrigation expansion in the LMB and to prevent seawater intrusion into the Mekong Delta, flow needs to be generated during the critical dry months, either from points above Kratie or from Tonle Sap Great Lake. However, modelling results generated by the Mekong River Committee (2004) show that development of Chinese dams and six dams on Laotian tributaries will have the effect of reducing flows beyond even the standard deviation of wet and dry years (estimated to be around 23%) at Kratie. Data from 15 years (1994–2008) of paired catchment water observations in the upper part of the Mekong River Basin in Xishuangbanna, China, showed that soil-water storage during the rainy season was not sufficient to maintain the high evapotranspiration rates of rubber plantations, resulting in zero flow and water shortages during the dry season (Zheng et al 2012). Reducing drought risk during dry seasons and years, and floods during wet months, requires technical plus natural buffering to secure downstream ecosystems and livelihoods.

Reduction of biodiversity: The increasing prevalence of monocultural practices on land that used to have agrobiodiverse land uses reduces biological buffering of pests, weeds and diseases and increases risk to farmers in the face of climate variability and market fluctuations (Foley et al 2005; Tengo and Belfrage 2004). Furthermore, conservation of plant richness is important since plant diversity provides floral resources, alternative hosts that help support pollinators, natural enemies, soil quality and yield stability (Egan and Mortensen 2012). Moreover, it is one of three key sources for tree diversity in an agricultural landscape (Ordonez et al 2013).

***Erosion and depletion of soil organic carbon*: ** Intensification of crop monocultures and Rain-fed rice or maize on steep slopes can cause serious erosion. When the soil's surface layer is washed away the subsoil is exposed, which has lower soil organic carbon content and water-holding and infiltration capacity. This further increases surface run-off. Groundwater dynamics are also affected by dry-season water use, for example, by rubber plantations in the upper part of the Mekong River Basin (Zeng et al 2012).

Long-term impacts and complexity at landscape scale: It usually takes some 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 found to have adversely affected water quality and quantity in the delta of the northwestern Mississippi only after 20 years of monitoring (Coupe et al 2012). More severe dry season droughts due to expansion of rubber monocultures in the Upper Mekong Basin were only confirmed after 15 years of systematic observation (Zeng et al 2012). Moreover, policies aimed at one sector in one part of the LMB may cause unintended ecological consequence in other sectors and places (Coupe et al 2012).

Livelihoods' vulnerability: Commercialization of agriculture and more intensified cropping in LMB make local farmers more exposed to volatility of external markets. Smallholding farmers, with no savings or insurance, are particularly vulnerable when prices of agricultural products drop and/or prices of irrigation, fertilization and/or other inputs increase.

3.4. Buffering ecosystems and livelihoods with agroforestry: opportunities and challenges

Different tree-based land uses are more or less useful in providing multifunctionality in products and soil-related ecosystem services, depending on species, management, and location in a landscape (Table 1). In addition to the buffering effects listed, examples show that land-use practices also contribute to climate mitigation through increasing carbon storage in biomass and soil; by reducing pressure on natural forests if in buffer zones (example 2); by reducing soil carbon losses through erosion on sloping land and reducing the use of nitrogen fertilizer thanks to nitrogen-fixing species (example 3; Table 1). Examples of the benefits of tree-based land use appear to be captured mainly at field and farm levels, but as Willemen et al (2013) suggest, there has been "little assessment of tree-based ecosystem approach benefits relative to other land uses in the landscape, of interactions among land uses, or of patterns of tree-growing and impacts across the landscape".

Table 1. Examples of "win win" situations with trees and shrubs outside forests in different major agro-ecosystems of the Southeast Asian region

AF practices (example number)	Water, climate and biodiversity buffering	Economic buffering	Reference
Shade trees in perennial crops and high-value species in buffer zones in the highlands			
Shade trees as components of rubber, coffee and cocoa in Indonesia (example 1)	Improved water retention and filtration; improved resilience of crop to drought	Rubber, coffee and cocoa provide important income to smallholders and the country	Nyhus and Tilson 2004 Sunderlin and Resosudarmo 1996
Agroforestry in buffer zones in Southeast Asia (example 2)	Enhanced biodiversity	Provide higher productivity and income per unit of land	Nyhus and Tilson 2004, Sekhar 2007
Legume species and bamboo in crops on sloping land			
Legumes used as fallow and hedgerow species in upland rice fields in northern Viet Nam (example 3)	Reduce erosion and water run-off; improved water infiltration	Significantly increased upland rice yields after improved fallow using legumes	Hoang et al 2001 Hoang et al 2002
Bamboo in the northern central uplands of Viet Nam (example 4)	Provide micro-climate	Create alternative, off-farm, income-generating activities	Ly at al. 2012
Home and forest gardens in coastal areas			
Home and forest gardens in the central coastal zone of Viet Nam (example 5)	Enhance biodiversity	Food security when annual crops fail due to flooding and drought	Nguyen et al 2013 Hoang et al 2013
Fruit trees in perennial crops and woody trees in paddy fields in lowland areas			
Rubber agroforests in Indonesia; rubber intercropped with high-value fruit (durian and oil palm) in southern Thailand (example 6)	Adaptation to extreme weather events	Provide diversified products, adapt to market fluctuations	Van Noordwijk et al 2012 Simien and Penot 2011
Trees in paddy fields in central Laos and Northeast Thailand (example 7)	Improved soil fertility, micro-climates, providing shade	Increased firewood accessibility, livestock fodder, human food and medicines	Kosaka at al. 2006 Grandstaff et al 1986

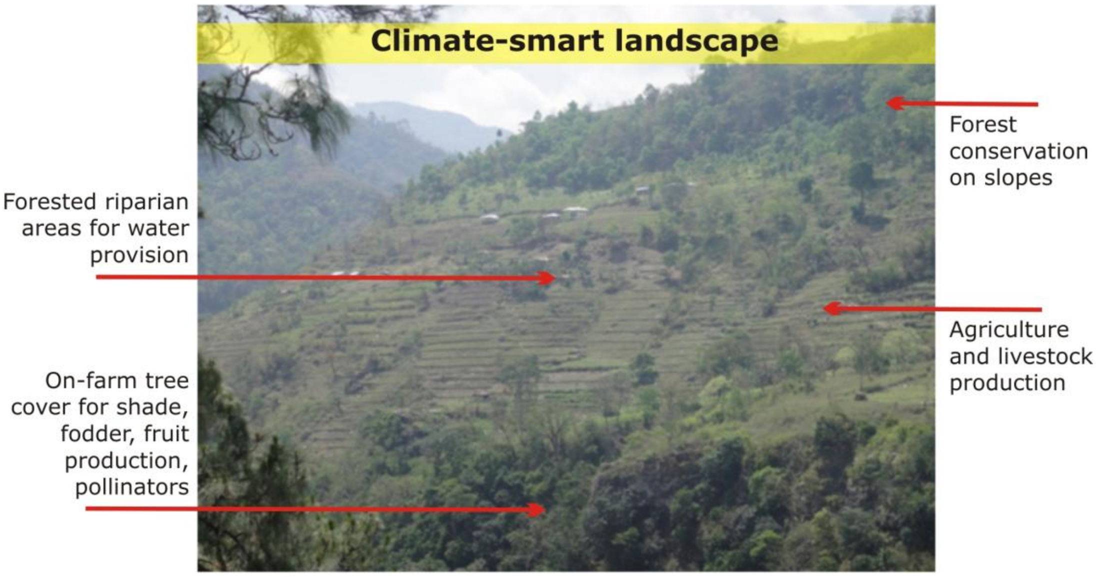
Despite the multiple values, the complexity of designing and managing AF practices and lower outputs from AF components often makes AF less attractive compared to intensified monocultures. Furthermore, concerns exist about losing crop land to trees, which makes mainstream agricultural policymakers reluctant to encourage incorporation of more trees into agricultural landscapes. This perceived trade-off between market-oriented agriculture and economic and ecological resilience today typically leads to changes in land use away from subsistence and local food production. Sustainable intensification of agriculture is an emerging and evolving concept (Godfray et al 2010) that may possibly marry development and implementation of multifunctional and biodiverse agro-ecosystems, including woody perennial crops and trees, with more highly productive and entrepreneurial farm management (Bommarco et al 2012). As a result, total production would not need to decline despite allocation of some land use for trees. Furthermore, landscape planning and monitoring can help map and assess ecological and economic interactions between trees and crops over time and space, and thus stimulate adoption of AF (Example 5, Table 1). Several challenges and research questions raised below may help further sharpen the research and development agenda for AF in the LMB.

Converting mono-cropping of commercial tree crops (rubber, cache nut, coffee) to multi-strata or parkland agroforestry by inclusion of suitable species in current plantation

3.4.1. Technical challenges

Suitability of trees and agroforestry practices for helping buffer ecosystems and livelihoods is related to the multifunctionality they can provide. Farmers' preferences, tree and site matching, seed dispersal, tree domestication and delivery via nurseries all play important roles in determining tree diversity (Ordonez 2013). Farmers are often well aware of functionality and manage different species for different purposes, related to how trees affect crops, ecosystem processes and more importantly how trees contribute to their livelihoods (Idol et al 2011), especially when crop failures are due to climate variability (Hoang at al 2013a). At field level, one key role of AF science is to accumulate local knowledge in a systematic way and use it in simulating potential environmental services and yield impacts of different techniques for managing trees and their interaction with crops. Tools to accomplish these tasks are particularly important for developing sustainable intensive agroforestry and agricultural practices. A good example of one such tool is the model named Water, Light and Nutrient Capture in Agroforestry Systems (WaNuLCAS, van Noordijk 2011b). At farm level, the potential economic impacts of AF practices is one of the most decisive factors affecting farmers' adoption, and farming system analysis is a good assessment tool.

Roles of trees as buffers and filters for water and soil flows, for biodiversity, and for economic returns over time and space need to be seriously considered in agricultural landscape planning and monitoring. This can start by identifying "hot spots" of change or vulnerability through the characterization and spatial mapping of land use and land-function changes. From that, priority areas for intervention and context-specific investment opportunities and options with trees and AF practices can be defined. A proper representation of land function in many cases can only be achieved at local scales of analysis (Verburg 2009). For this purpose, a package of methods and tools, which are integrated in a participatory modelling approach, is recommended at a watershed level. These tools include participatory mapping and role-playing games (Villamor at al. 2011); an agent-based model (Villamor 2012); development of meso-level, land-use-planning scenarios from multi-stakeholder discussions, governments' development plans, mitigation plans etc and projection of future land uses based on the scenarios using the Forest, Agroforest, Low-value Landscape or Wasteland (FALLOW) model (Lusiana et al 2011, 2012) for the entire landscape.



Harvey et al., 2013

Appropriate combinations and spatial arrangements of suitable trees and agroforestry practices is needed in order to maximize synergies and to reduce trade-off among different ecosystem services as well as between climate-change adaptation and mitigation (Harvey et al 2013). More research is needed on 1) the balance between how trees improve soil quality and infiltration and the same trees' consumption of water; and 2) trade-offs between carbon sequestration and water consumption/provision by the same tree. In order for forests and trees to contribute to conserving base flows, increased water infiltration in soils induced by trees must be greater than their water consumption (Viglizzo et al 2012). Furthermore, carbon accumulation based on increasing net primary production rates may simultaneously cut catchment water yields and, hence, water provision. Such potential trade-offs show the importance of considering soil properties and management when assessing benefits of different tree-based land uses (Pramova 2012) at nested scales.

Identifying indicators of links among environmental services may help in assessing and promoting synergies. Soil carbon plays a vital role in regulating climate, water supplies and biodiversity, and thus in providing services that are essential to human well-being (UNEP 2012). A survey of soil carbon in Laos found that the largest stocks of soil organic carbon are under forests, followed by forest–fallow shifting cultivation, while the smallest are under continuous monocropping (Chaplot 2010). Systematic review and meta-analysis of effects of afforestation or planting trees in agricultural areas showed a change in infiltration capacity of approximately three-to-four times (Ilstedt et al 2009). Thus, further research is needed to clarify prospects of soil carbon as a combined indicator of environmental services at nested scales. Other challenges are the site-specific nature of agroforestry and the lack of uniform methods to estimate carbon sequestration, making it difficult to compare results and expand from site to landscape level. There is even less empirical data on the impact of adding trees on balances among water use, water run-off, evapotranspiration, and water infiltration capacity, with primary empirical studies being greatly outnumbered by narrative reviews and policy-related reports and discussions (Malmer et al 2010).

3.4.2. Policy challenges

Creation of policies aimed at redirecting development pathways by integrating natural resources integrity is recommended for promoting agroforestry research and development. For example, combining incentive systems—including payments for watershed functions and carbon provided by trees, as well as support for poverty reduction—together with income from tree products will theoretically be sufficient to cover opportunity costs of monocultural agriculture or forest conversion in the uplands of northern Viet Nam (Hoang at al 2013b). According to Namirembe et al (2013), co-investment in stewardship together with secure rights is a more widespread and versatile approach for a variety of environmental services. In terms of tools to help support policy decision-making, analysis of trade-offs can help assess relative responses of individual social and economic indicators on the one hand, together with estimates of ecosystem services on the other, per unit of land-use change (Viglizo et al 2012). Another potential policy approach is based on compensation mechanisms to more equitably distribute costs of watershed management. For example, opportunity costs linked to forest conservation upstream can be compensated by payments for environmental services (Wertz-Kanounnikoff et al 2011). A major challenge is how to overcome commodity issues for environmental services, related to elites and corruption, which lead to inequality among land users (Gómez-Baggethun at al 2011). Institutional failures that erode resilience are brought about by lack of rule enforcement and corruption (Bingeman et al 2004). Thus, policy reforms by government agencies must consider strategies for designing participatory approaches and co-interest incentive schemes at farm scale in order to help alleviate the sustainability issues of agricultural landscapes (Kumaraswamy 2012).

3.4.3. Social capital-building challenges

In addition to appropriate policies and sufficient funding, several more socioeconomic factors are needed to effectively promote agroforestry and trees outside forests. Among them, participation by communities in decision making through enhancing advocacy (Sneddon and Fox 2007), access to markets and credit, investment costs, institutional capacity, and land and tree tenure (Harvey et al 2013) are all known to affect adoption of AF practices. Combining monitoring systems at different levels (local, landscape, regional) will provide a rich set of information on feedbacks and dynamics in socio-ecological systems. Involving stakeholders, especially the beneficiaries of ecosystem services, in the monitoring process will enhance overall adaptive capacity, incentives to learn, and the delivery of early warnings related to environmental change. These factors, along with improved communication of Mekong-related information in all riparian languages are only some of the challenges urgently needing attention. The main challenge lies in creating enabling conditions and processes for innovation, flexibility, and iterative and incremental learning (Viglizo et al 2012).

4. Conclusions and recommendations

Vulnerability of ecosystems and people in the LMB is seen through four regional trans-boundary issues, including 1) more severe drought and flooding linked with water abstraction and land-use change; 2) reduced biodiversity; 3) increased erosion and depletion of soil organic carbon; and 4) greater long-term impacts and complexity at landscape scales. The close interaction among these four trans-boundary issues in time and space justify a recommendation for more holistic, nested, landscape and policy approaches to solving problems.

Trees outside forests are useful in providing ecological and economic buffering, depending on species, management, and location in a landscape. Sustainable intensification of agriculture, including highly productive woody perennial crops and trees together with entrepreneurial farm management, are needed to help to make AF practices attractive to farmers.

The lack of assessment of benefits from tree-based land use relative to other land uses in the landscape justifies our recommendation for further research. Assessments need to focus on both ecological and economic interactions between trees and other land uses over time and space, especially during the most harsh climate conditions, such as flooding and drought. Combining local knowledge and scientific knowledge (modelling, farming system analysis, landscape analysis, trade-off analysis) in selecting optimal combinations and spatial arrangements of suitable trees and agroforestry practices is necessary in order to maximize synergies and reduce trade-offs among different ecosystem services, between ecosystem benefits and economic benefits, and between climate-change adaptation and mitigation purposes. The prospect of soil carbon as a combined environmental service indicator at nested scales, and the lack of required empirical data, result in a clear need for further research.

Creation and modification of policies to redirect development pathways through integrating natural resources integrity is recommended for promoting agroforestry research and development. We recommend that policymakers pay particular attention to strategies for participatory approaches and co-interest incentive schemes at farm scale to alleviate the sustainability issues of agricultural landscapes.

Several socioeconomic factors are clearly required for effective promotion of trees outside forests and agroforestry. Recommendations include appropriate enhancements of agroforestry advocacy, access to markets and credit, public investments, institutional capacity, land and tree tenure, and nested levels of monitoring systems with high involvement of stakeholders, particularly beneficiaries of ecosystem services.

Comparative assessments of current and future socio-economic and environmental impacts of tree-based strategies, in contrast to “business as usual” strategies are recommended to provide a base for informing decisions and mediating trans-boundary negotiations. This strategy is in line with the green economy that is currently considered an important direction for development in global agriculture.

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20. Lessons from eastern Africa's unsustainable charcoal business.
21. Evolution of RELMA's approaches to land management: Lessons from two decades of research and development in eastern and southern Africa
22. Participatory watershed management: Lessons from RELMA's work with farmers in eastern Africa.
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24. Promoting rainwater harvesting in eastern and southern Africa.
25. The role of livestock in integrated land management.
26. Status of carbon sequestration projects in Africa: Potential benefits and challenges to scaling up.
27. Social and Environmental Trade-Offs in Tree Species Selection: A Methodology for Identifying Niche Incompatibilities in Agroforestry *[Appears as AHI Working Paper no. 9]*
28. Managing tradeoffs in agroforestry: From conflict to collaboration in natural resource management. *[Appears as AHI Working Paper no. 10]*

29. Essai d'analyse de la prise en compte des systemes agroforestiers pa les legislations forestieres au Sahel: Cas du Burkina Faso, du Mali, du Niger et du Senegal.
30. Etat de la recherche agroforestière au Rwanda etude bibliographique, période 1987-2003

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31. Science and technological innovations for improving soil fertility and management in Africa: A report for NEPAD’s Science and Technology Forum.
32. Compensation and rewards for environmental services.
33. Latin American regional workshop report compensation.
34. Asia regional workshop on compensation ecosystem services.
35. Report of African regional workshop on compensation ecosystem services.
36. Exploring the inter-linkages among and between compensation and rewards for ecosystem services CRES and human well-being
37. Criteria and indicators for environmental service compensation and reward mechanisms: realistic, voluntary, conditional and pro-poor
38. The conditions for effective mechanisms of compensation and rewards for environmental services.
39. Organization and governance for fostering Pro-Poor Compensation for Environmental Services.
40. How important are different types of compensation and reward mechanisms shaping poverty and ecosystem services across Africa, Asia & Latin America over the Next two decades?
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44. Nina-Nina Adoung Nasional di So! Field test of rapid land tenure assessment (RATA) in the Batang Toru Watershed, North Sumatera.
45. Is Hutan Tanaman Rakyat a new paradigm in community based tree planting in Indonesia?
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54. Jatropha curcas biodiesel production in Kenya: Economics and potential value chain development for smallholder farmers
55. Livelihoods and Forest Resources in Aceh and Nias for a Sustainable Forest Resource Management and Economic Progress

56. Agroforestry on the interface of Orangutan Conservation and Sustainable Livelihoods in Batang Toru, North Sumatra.
57. Assessing Hydrological Situation of Kapuas Hulu Basin, Kapuas Hulu Regency, West Kalimantan.
58. Assessing the Hydrological Situation of Talau Watershed, Belu Regency, East Nusa Tenggara.
59. Kajian Kondisi Hidrologis DAS Talau, Kabupaten Belu, Nusa Tenggara Timur.
60. Kajian Kondisi Hidrologis DAS Kapuas Hulu, Kabupaten Kapuas Hulu, Kalimantan Barat.
61. Lessons learned from community capacity building activities to support agroforest as sustainable economic alternatives in Batang Toru orang utan habitat conservation program (Martini, Endri et al.)
62. Mainstreaming Climate Change in the Philippines.
63. A Conjoint Analysis of Farmer Preferences for Community Forestry Contracts in the Sumber Jaya Watershed, Indonesia.
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70. Le business plan d’une petite entreprise rurale de production et de commercialisation des plants des arbres locaux. Cas de quatre pépinières rurales au Cameroun.
71. Les unités de transformation des produits forestiers non ligneux alimentaires au Cameroun. Diagnostic technique et stratégie de développement Honoré Tabuna et Ingratia Kayitavu.
72. Les exportateurs camerounais de safou (Dacryodes edulis) sur le marché sous régional et international. Profil, fonctionnement et stratégies de développement.
73. Impact of the Southeast Asian Network for Agroforestry Education (SEANAFE) on agroforestry education capacity.
74. Setting landscape conservation targets and promoting them through compatible land use in the Philippines.
75. Review of methods for researching multistrata systems.
76. Study on economical viability of *Jatropha curcas* L. plantations in Northern Tanzania assessing farmers’ prospects via cost-benefit analysis
77. Cooperation in Agroforestry between Ministry of Forestry of Indonesia and International Center for Research in Agroforestry
78. "China's bioenergy future. an analysis through the Lens if Yunnan Province
79. Land tenure and agricultural productivity in Africa: A comparative analysis of the economics literature and recent policy strategies and reforms
80. Boundary organizations, objects and agents: linking knowledge with action in agroforestry watersheds
81. Reducing emissions from deforestation and forest degradation (REDD) in Indonesia: options and challenges for fair and efficient payment distribution mechanisms

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82. Mainstreaming climate change into agricultural education: challenges and perspectives

83. Challenging conventional mindsets and disconnects in conservation: the emerging role of eco-agriculture in Kenya's landscape mosaics
84. Lesson learned RATA garut dan bengkunat: suatu upaya membedah kebijakan pelepasan kawasan hutan dan redistribusi tanah bekas kawasan hutan
85. The emergence of forest land redistribution in Indonesia
86. Commercial opportunities for fruit in Malawi
87. Status of fruit production processing and marketing in Malawi
88. Fraud in tree science
89. Trees on farm: analysis of global extent and geographical patterns of agroforestry
90. The springs of Nyando: water, social organization and livelihoods in Western Kenya
91. Building capacity toward region-wide curriculum and teaching materials development in agroforestry education in Southeast Asia
92. Overview of biomass energy technology in rural Yunnan (Chinese – English abstract)
93. A pro-growth pathway for reducing net GHG emissions in China
94. Analysis of local livelihoods from past to present in the central Kalimantan Ex-Mega Rice Project area
95. Constraints and options to enhancing production of high quality feeds in dairy production in Kenya, Uganda and Rwanda

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96. Agroforestry education in the Philippines: status report from the Southeast Asian Network for Agroforestry Education (SEANAFE)
97. Economic viability of Jatropha curcas L. plantations in Northern Tanzania- assessing farmers' prospects via cost-benefit analysis.
98. Hot spot of emission and confusion: land tenure insecurity, contested policies and competing claims in the central Kalimantan Ex-Mega Rice Project area
99. Agroforestry competences and human resources needs in the Philippines
100. CES/COS/CIS paradigms for compensation and rewards to enhance environmental Services
101. Case study approach to region-wide curriculum and teaching materials development in agroforestry education in Southeast Asia
102. Stewardship agreement to reduce emissions from deforestation and degradation (REDD): Lubuk Beringin's Hutan Desa as the first village forest in Indonesia
103. Landscape dynamics over time and space from ecological perspective
104. Komoditisasi atau koinvestasi jasa lingkungan: skema imbal jasa lingkungan program peduli sungai di DAS Way Besai, Lampung, Indonesia
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106. Rapid Carbon Stock Appraisal (RACSA) in Kalahan, Nueva Vizcaya, Philippines
107. Tree domestication by ICRAF and partners in the Peruvian Amazon: lessons learned and future prospects in the domain of the Amazon Initiative eco-regional program
108. Memorias del Taller Nacional: "Iniciativas para Reducir la Deforestación en la region Andino - Amazónica", 09 de Abril del 2010. Proyecto REALU Peru
109. Percepciones sobre la Equidad y Eficiencia en la cadena de valor de REDD en Perú – Reporte de Talleres en Ucayali, San Martín y Loreto, 2009. Proyecto REALU-Perú.
110. Reducción de emisiones de todos los Usos del Suelo. Reporte del Proyecto REALU Perú Fase 1
111. Programa Alternativas a la Tumba-y-Quema (ASB) en el Perú. Informe Resumen y Síntesis de la Fase II. 2da. versión revisada
112. Estudio de las cadenas de abastecimiento de germoplasma forestal en la amazonía Boliviana

113. Biodiesel in the Amazon
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116. How can systems thinking, social capital and social network analysis help programs achieve impact at scale?
117. Energy policies, forests and local communities in the Ucayali Region, Peruvian Amazon
118. NTFPs as a Source of Livelihood Diversification for Local Communities in the Batang Toru Orangutan Conservation Program
119. Studi Biodiversitas: Apakah agroforestry mampu mengkonservasi keanekaragaman hayati di DAS Konto?
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125. A Comparative financial analysis of current land use systems and implications for the adoption of improved agroforestry in the East Usambaras, Tanzania
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