Segregate or Integrate for Multifunctionality and Sustained Change Through Rubber-Based Agroforestry in Indonesia and China

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Abstract Rubber (*Hevea brasiliensis* L.) production systems have conserved forest biodiversity in some parts of Asia and are a threat elsewhere. A holistic view on these two sides of the coin is needed. The roles planted trees and agroforestry play in the transformation of lives and landscapes depend on the stage of "forest transition" and the spatial configuration, segregation or integration, of the landscape. "Forest transitions" need to be understood at the level of the actual *pattern* of change, (one level up) at the level of *drivers* of change, and (one level down) at the level of *consequences* for ecosystem goods and services. To close the loop on a *feedback* mechanism, forest transitions also need to be understood at the level of mechanisms that link desirable or undesirable consequences of changes in tree cover to the drivers, providing positive or negative feedback. "Forest ecosystem services" can be partially fulfilled by agroforests as a form of domesticated forest. We revisit the theoretical framing of agroforests as part of forest transition and discuss a case study of the rise and decline of complex rubber agroforests in lowland

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Sumatra (Indonesia) and the recent expansion of monoculture rubber in China replacing agroforestry systems. Both cases indicate a complex of driving and conditioning factors but also a current lack of incentives to reverse the trend toward landscape segregation. Complex agroforests represent an intermediate stage of intensification, between natural forest and home garden, and may occupy an intermediate stage in the way landscapes develop under the influence of land users and other stakeholders. Although complex agroforests represent considerable value (biodiversity and carbon stocks) of relevance to external stakeholders, incentive systems for the land users need to match these values; otherwise, these systems will disappear when more intensified and simplified tree crop systems take over. Current analysis of the choices in land sparing versus land sharing, and segregation versus integration, emphasizes the convex or concave nature of the bifunctional trade-off curves.

Keywords Biodiversity • Swidden • Sustainagility • Trade-offs • Tree regeneration

Introduction

Multifunctionality Through Integration or Segregation

The title of this book suggests that agroforestry may be the future of land use in at least some parts of the world. In other parts of the world, it is or is on its way to be part of the history of land use. The rise, decline, and continued dynamics of any land use respond to drivers, consequences, and feedback mechanisms. In the context of the debate on sustainability of meeting the ever-increasing demand for food, feed, and fiber production (Tilman et al. 2002) and the similarly increasing scarcity and expressed value of environmental integrity (Kumar 2010), the potential role of complex agroforests and other land use of "intermediate intensity" has caught the attention of researchers (Vandermeer et al. 1998; Swift et al. 2004; Schroth et al. 2004; Michon et al. 2007; Scherr and McNeely 2007; Steffan-Dewenter et al. 2007). Such agroforests may serve as an integrated, multifunctional, or "*land sharing*" solution (Jackson et al. 2010; Tomich et al. 2001) and form an alternative or complement to the segregated "*land sparing*" approach of agricultural intensification and simplification based on substituting ecological functions by technical means and external inputs (Sanchez 1994; Green et al. 2005). In its crudest and simplest form, the hypothesis suggests that intensification will increase supply and decrease farm-gate prices, leading to recovery or avoided clearance of forest and abandonment of marginal land; investment in agricultural intensification might thus, if the hypothesis were true, directly lead to biodiversity conservation and qualify for REDD+funding (under emerging schemes to Reduce Emissions from Deforestation and Degradation, Minang et al. 2012). Evidence supporting the hypothesis is mostly indirect (Angelsen and Kaimowitz 2001; Rudel et al. 2009) and contradictory effects at intermediate scale – profitable forms of intensification attracting migrants to forest margins – exist, but intensification may still be a *necessary though not sufficient* condition for biodiversity, watershed, and carbon stock conservation (van Noordwijk et al. 1995a; Tomich et al. 2001), depending on the direct negative consequences of intensification.

A rapidly increasing literature quantifies the trade-offs between productivity and ecosystem services at various scales (Polasky et al. 2005; Woltmann et al. 2007; Nelson et al. 2009; Perfecto et al. 2009; Fischer et al. 2010; Phalan et al. 2011). Beyond the efficiency and persistence scales of such studies, however, the "sustainagility" aspects of maintaining the options and resource base for continued change (Verchot et al. 2007; Jackson et al. 2010) also need attention. As output per ha will have to keep increasing to match growing demand, however, an input-based operational definition of land-use intensity is needed before dynamic hypotheses on the relationship of intensification with output per ha and other functions can be quantitatively tested (van Noordwijk and Budidarsono 2008). Van Noordwijk et al.[11, 12] analyzed whether a "segregate" or an "integrate" choice would achieve more of a fixed production goal plus a maximized biodiversity goal on a limited area of land. The equations suggest a simple quantitative criterion: if the trade-off curve between productivity and biodiversity is concave, spatial segregation of functions and specialization is the better choice; if the trade-off function is convex, integrated solutions to multifunctionality targets are attractive, at least from a planners' perspective. In this chapter, we will revisit this theoretical framing in the light of the "land pressure" that exists as human needs for both goods and services keep growing and discuss two case studies from Asia, both involving rubber (*Hevea brasiliensis* L.) but in different types of agroforestry systems, one complex and one simple, with different consequences on surrounding biodiversity.

Simple or Complex Agroforestry Systems: Innovation and Multifunctionality

Joshi et al. (2003, 2005) and Pretty et al. (2006) explicitly discussed the type of progress in productivity that is possible in resource-conserving agriculture. Simple systems are in general easier to improve than complex ones and tend to have higher growth rates, making them more interesting for investors (McNerney et al. 2011). Simple systems, however, tend in general to become more complex over time and may get bogged down by complexity, in the same way as tree growth slows down with increased maintenance costs of existing biomass. In research on technological progress, empirical scaling laws suggest that per doubling of cumulative production costs per unit production decrease typically around 20% (for coal plants 12%, ethanol production 20%, photovoltaic cells 23%, and transistors 43% as analyzed by McNerney et al. 2011). From a producer's perspective, the negative exponential decline in costs reflects a decreasing rate of success in innovations, unless market demand keeps growing exponentially at rates faster than the cost decline. Most agricultural or forest products no longer match this type of efficiency gain, and their production cannot keep up with increases in industrial wage rates.

In agriculture, long-term trends toward declining farm-gate prices for primary products imply that labor efficiency has to keep increasing. Recent increases in food prices show that the pattern is not a monotone decrease, however. In ecology, the relationship between complexity and dynamic properties (“stability”) has been studied for more than four decades (May 2001) and has led to a redefinition and cross scale refinement of both complexity and “dynamic stability” concepts. It may not be particularly productive to ask whether “complex agroforests” are superior or inferior to simple tree crop production systems unless we can be sure of the evaluation perspective, but we can try to understand the conditions under which they emerge in the landscape and the drivers of their subsequent decline. For resources with a dominantly local use pattern, the farm-gate value per unit product decreases with its frequency of occurrence, and this implies that a diverse portfolio is more valued than a specialized one, supporting the emergence of fine-grained landscape mosaics. For products with a national or global market where demand is not easily satisfied in local production, farm-gate value per unit product increases with frequency of occurrence if there are “economies of scale” linked to transport, processing, know-how, and social linkages along the value chain. A shift from local to national and global markets thus induces loss of globally relevant diversity and coarsening of landscape mosaics.

Forest Transition and the Rise and Decline of Agroforests

While at continental scale Asia has turned the corner on “forest transition” (Rudel et al. 2005) and has reported an increase in forest area during the last decade (FAO 2010), the net increase does not imply that gross deforestation and forest conversion have been brought under control (Meyfroidt and Lambin 2011). Countries with increasing forest areas have increased their external footprint (net balance of imported and exported agricultural plus forestry products converted to area using national statistics on productivity) by an average of 50% of the reported domestic forest increase[3] (Meyfroidt and Lambin 2009; Meyfroidt et al. 2010; Minang et al. 2010). Planted tree cover replacing natural forest can occur in a gradual process of agroforest development (early stages of “forest domestication” *sensu* Michon et al. 2007), by direct replacement of natural forest, by plantation forestry or tree crop development, and/or after a phase interlinkage) and interrupted by of “degraded land” with low tree cover (Fig. 1a). The various components of the “tree cover transition” may not spatially move at the same rate, as a recent study in peri-urban trends in Tanzania showed (Ahrends et al. 2010), and the zone with “intermediate, low tree cover” stages can expand and contract as a consequence. Tree planting is, however, more likely at some distance from the forest edge (Santos-Martin et al. 2011), as (illegal) extraction is more profitable than growing trees and tending them.

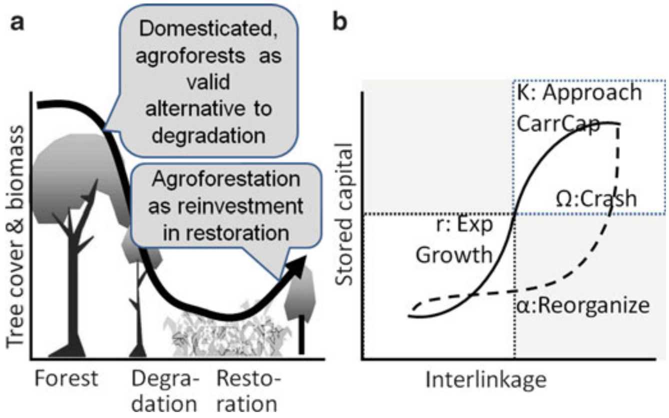

Fig. 1 (**a**) Tree cover transitions as temporal and spatial model with two primary roles for agroforestry (Van Noordwijk et al. 1995a); (**b**) Eight-shaped dynamics of stored capital and interlinkage of systems in their r, K, and Ω/α phases of growth, saturation, and crash/reorganization

Nonlinear System Dynamics and Punctuated Change

Changes in land use may follow a gradual incremental pattern, increasing or decreasing tree cover, or have an episodic, punctuated, transformational character (Fig. 1b). The eight-shaped looping of stored capital and component linkage as proposed by the Resilience Alliance (Folke et al. 2004; Chapin et al. 2009) suggests that there are three major stages: an exponential growth phase from a low and slow start (r-phase), a gradual and asymptotic approach to the "carrying capacity" for current technology and environment (K-phase), and a crash/reorganization (Ω/α-phase) stage that resets the clock. The postulated increase in interlinkage can be understood to operate across ecological, social, economic, and policy aspects. It is based on fine-tuning of relations around a new production system and increasing resource use efficiency with a diminishing-returns-type approach to the carrying capacity of the environment for the type of resource use.

Such eight-shaped looping may occur in systems at different scales. Relevant to our current discussion are three of such scales:

A. The (agro)forest patch and its processes of maturation and rejuvenation
B. The adoption of a certain land-use system in a landscape or regional economy
C. Societies in their development from frontier patterns of resource extraction to fully interlinked systems where social and environmental links are appreciated and reflected in functioning institutions

While we will focus on level B, the biodiversity aspects of A and policy implications of C reflect two other nonlinear systems of interaction.

At level A, a forest patch cycles through r-phases (pioneers, exponential growth) and K-phase (gradual approach toward carrying capacity and strong interlinkage) and interrupted by crash and reorganization Ω/α phases, while the forest as a whole may be in a steady state. Rubber's natural habitat is the species-rich Amazonian rainforests, mostly along rivers in forests that are frequently disturbed where *H. brasiliensis* is a pioneer species surviving into mature secondary forest stage. In parts of Asia, rubber after introduction naturalized into similar habitat and came to be cultivated as part of a diverse forest system (Gouyon et al. 1993; Salafsky 1994; Dove 2000). Patch-level, internal rejuvenation is also possible in rubber agroforests (Wibawa et al. 2005), replacing the field-level rotational cycle, with associated benefits for maintenance of tree diversity at plot scale as well as continued income and avoiding dependence on financial investment in a replanting cycle.

At level B, the adoption of new land-use systems normally has a slow start where local evidence that it works and is attractive needs to be built up before widespread use follows. Expressed against time, adoption curves are often S shaped, but in Fig. 1b, the "stored capital" or area allocated to a certain land use is plotted against the degree of linkage. The "linkage" dimension reflects the need for any land use, and thus also agroforestry, to match:

(a) Knowledge and technology to deal with the biophysical constraints of the production environment
(b) The surrounding ecology (including pest/disease, pollinator, dispersal relations, as well as lateral flows of soil, water, wind, or fire)
(c) The economic land/labor relationship and demands for domestic consumption and/or external markets
(d) Social systems that relate to land/labor relations, access to resources, and management of conflicts and jealousy
(e) Governance systems that control resource access and permit for market access, taxes, and subsidies
(f) Infrastructure that influences accessibility of markets and processing facilities

All of these can be involved in the positive feedback loops that start a period of exponential growth. Ecological (b) and socioeconomic factors (c, d, and e) can also involve in the negative feedback processes that lead to the gradual approach of a saturation level. It is unlikely that all these six types of relations (with human, natural, financial, social, political, and physical capitals) develop in one go. Any of the six categories can be a primary constraint to the use of trees in productive agroforestry systems (Roshetko et al. 2008; van Noordwijk et al. 2008a). In some cases, the land-use system "collapses" ecologically as pest and diseases catch up or due to market oversupply, but a more gradual replacement by better alternatives is also possible; there may be issues of definition and terminology whether the "something better" is a new variant of the same or a new land-use system.

At level C, the expansion of human use of natural habitat and emergence of associated governance, resource access, and tenure systems reflect the values of wider society. The objectives of a pioneer-to-mature society may emerge in a sequence such as:

(a) Resource extraction to support national income (and political elites) with limited local connectivity

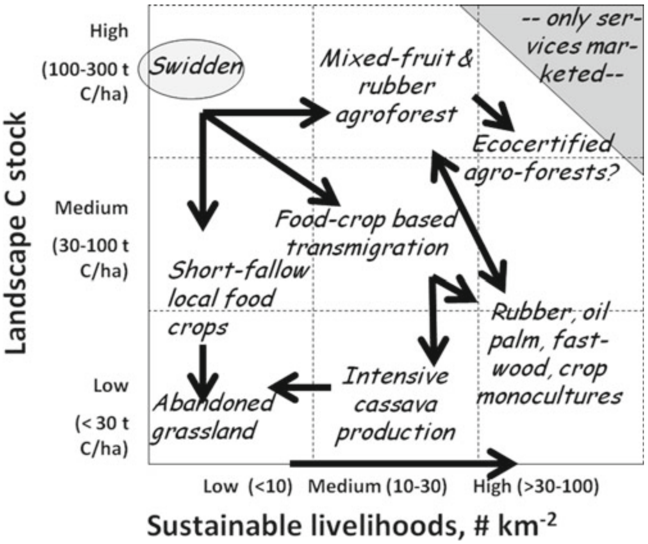

Fig. 2 Historical patterns of land-use change in lowland humid tropics of SE Asia with market-oriented agroforests leading the change away from subsistence local food production (Source: van Noordwijk et al. 2009)

(b) Economic growth or the initiation/expansion of value chains that benefit the wider economy (creating employment and capturable value downstream)
(c) Social welfare in the political center of power which may include concerns over flooding of cities by rural poor
(d) Social welfare in the political periphery of marginally productive landscape
(e) Environmental integrity and its impacts on water flows, biodiversity, and/or greenhouse gas emissions

The environmental policy category is the most recent concern, and its role relative to the social and economic ones is still contested. The balance between these objectives tends to change with time, with considerable change during the lifetime of trees. Punctuated change (Ω/α) may occur through "revolutions" or "reformation" episodes in autocratic systems or in a more regulated election cycle in democratic arrangements.

At the interface of issue scales A, B, and C, agroforests are currently understood to be an intermediate stage in intensification in a spatial as well as temporal sense. They occur somewhere along the home garden – natural forest spatial gradient around villages, depending on topography and the settlement pattern. Two extremes, found in different parts of Asia, are a) settlement and landscape access via valleys and b) settlement and transport via ridges. When landscape patterns are subject to intensification (Fig. 2), changes in landscape components are interlinked (Fig. 3). Agroforests may represent a transient temporal stage in landscape intensification, with the opportunity (or threat) of replacement by more specialized monocultural

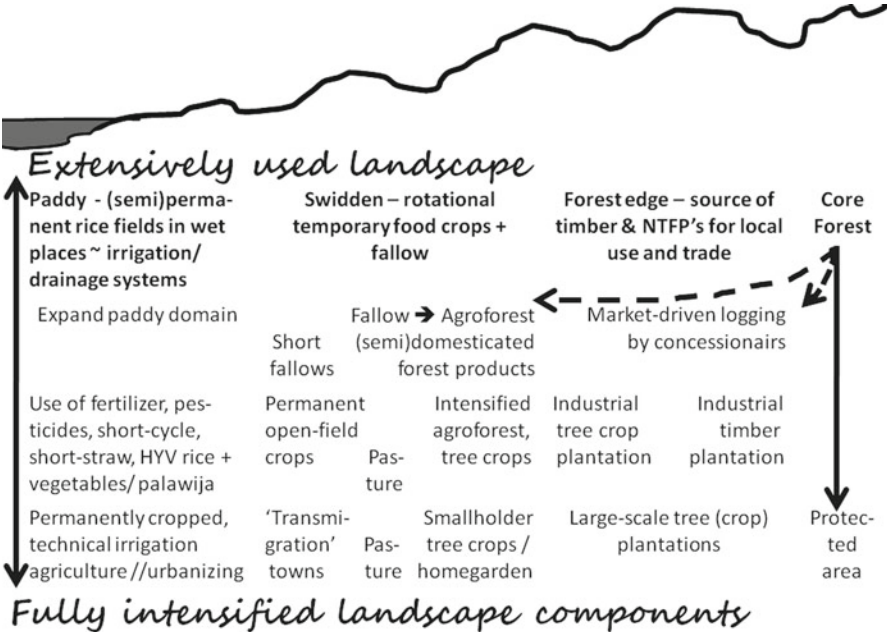

Fig. 3 Schematic transect of a landscape toposequence in (sub)humid Asia in four stages of intensification and the "intermediate" position of agroforests in spatial as well as temporal sense

tree crop systems in response to economic opportunity, unless innovations toward higher labor efficiency remain feasible and are utilized. Data on typical labor use per ha of different land-use systems, together with dependency ratio (fraction of nonworking members of the human population) and fraction of agricultural work of the labor force, can be used to calculate an equilibrium human population density for the main land uses (Murdiyarso et al. 2002). Strong correlations between landscape topography, human population density, and dominant land use (Hadi and Van Noordwijk 2005) suggest that agricultural intensification should be understood alongside demographic transitions and a switch to urban or service sector employment.

Questions for the Case Studies

In the rest of this chapter, we will contrast two case studies of dynamics in agroforestry landscapes: the current Ω/α phase of the rubber agroforest landscape of lowland Sumatra (case study in Bungo district, Jambi) following a century of r- and K-phase dynamics and the expansion of monocultural plantation/simple agroforest modes of rubber production in China and adjacent Laos. Our key questions on complex agroforest as "icon" for the way development+environment can be reconciled are:

1. How can the spatial and temporal patterns of change involving rise and/or fall of agroforests be understood at "driver" level from an actor perspective, including opportunities for increased labor efficiency and/or productivity growth, in its ecological, social, economic, and historical context?
2. What are consequences of these patterns for landscape multifunctionality? Are "intermediate intensity" agroforests inherently stable as a long-term contribution to landscape multifunctionality that includes effective biodiversity conservation?
3. What incentives would be needed to balance the productive and environmental aspects of such agroforests?
4. Are arguments for an "integrate" and "land sharing" approach to multifunctionality applicable and worthy of external support, or will a more segregated approach to environmental and productive functions be more efficient in the use of land?

After describing the two cases at driver (question 1) and consequences (question 2) level, we will briefly recapitulate segregate-or-integrate theory before discussing questions 3 and 4 for the rubber case.

The Sumatra Case Study

Pattern and Drivers of One Century of Rubber-Based Livelihoods in Bungo (Jambi, Indonesia)

Bungo district is located in the lowlands and foothills of the Bukit Barisan mountain range in central Sumatra and is administratively part of Jambi province. The government land-use designation of Bungo district consists of 10% protected natural forest in the foothills, 34% production forest (logged over), 50% agricultural lands, and 6% other land-use types (settlements, rivers, etc.).[5] The agricultural landscape includes (A) remnants of the traditional upland agriculture based on fallow rotations and upland rice as staple, (B) intensive rice paddy cultivation along rivers, (C) complex multistrata rubber agroforest on the peneplains, (D) home gardens, and (E) monocultural plantations of rubber and oil palm (*Elaeis guineensis* Jacq.). Land-use change and increases in human population density during the last century have been distinctly nonlinear (van Noordwijk 2005), with a first wave of migrants from elsewhere in Indonesia (mostly Java and northern Sumatra) arriving during 1905–1925 and a second wave starting around 1980.

The start of rubber agroforestry, a century ago, followed after Dutch conquest in 1906 which brought Jambi (and the neighboring sultanate of Damasraya that is now part of West Sumatra province) under the control of the colonial administration and opened up the area for plantation agriculture (Locher-Scholten 1994). Up to that time, swiddens for local food production had been combined with limited coffee and pepper production, traded via the Batang Hari River through Jambi town, located at the most seaward inhabitable place. Rapid adoption of the newly introduced *Hevea brasiliensis* from Brazil ("para rubber") by smallholders in the area, initially as part of the fallow in their swidden systems, transformed the landscape and beat attempts at establishing large-scale rubber plantations.[5] The area benefitted from the rubber boom of the 1920s, and farmers planted so many rubber trees that nonavailability of labor, not of land or trees, was the primary constraint to production. Rubber exports partly replaced rattan exports, and, after the rubber trees were established and intercropped, rice became scarcer, and the province became dependent on rice imports from elsewhere in Indonesia, which it could afford owing to the price of latex. Approximately 2 kg of rice was imported to the province per kg of dry rubber exported during the first two decades after rubber introduction, and this exchange left a financial surplus. In periods of high rubber prices, migrant labor from the Kerinci mountains and/or Java added to the labor force; when rubber prices declined (and Kerinci's coffee or cinnamon boomed) the labor force went elsewhere. Sustainagility required absence of social, cultural, or political restrictions to local migration. The ecophysiological flexibility of rubber, where the trees recover and gain in future productivity if not tapped, in contrast to other crops that need constant care to stay in productive condition, provided sustainagility to the farmer (Vincent et al. 2011a).

By the 1930s, Jambi became a "backwater," with most of the economy based on rubber. The Batang Hari River was the dominant mode of transport. A broad-sweep summary of the last century in Bungo (Table 1) suggests that shifts in national policy context had a profound impact on developments locally, as did the global ups and downs of natural rubber prices. Prices were high after World War I and became depressed in the late 1920s by oversupply and glut in demand but increased in World War II to the level that it sparked the development of a fossil-fuel-derived synthetic rubber as competitor. There have been price swings since that time related to global fossil-fuel prices through its relationship with global economic mood swings and through its effects on the processors' choice between natural and synthetic rubber.

Thus, the spatial and temporal patterns of the rise of rubber agroforests can be understood from the perspective of local actors, who replaced their upland rice for rubber but maintained the matrilineally inherited paddy rice (Otsuka et al. 2000) as basis of local food security, augmented with traded rice.

According to local custom, planting trees brought communal land under private control, and a small number of tappable rubber trees were enough to establish a claim (Suyanto and Otsuka 2001). The emphasis was thus on extensive rubber gardens, while the local rules in many villages established "fallow rotation reserves" (locally called *sesap-nenek* or "ancestors' bush") where tree planting was not allowed, so that after the rice was harvested, the land would return to the common pool (van Noordwijk et al. 2008b; Cramb et al. 2009). The private sector, mostly Chinese merchants from Jambi city, invested and supported rubber development by providing free seed, as the river ensured their captive market with all products passing through the town they controlled. This happened largely below the radar screen of the colonial administration, which supported a European plantation sector that largely failed to compete.

Table 1 Five broad categories of policy objectives reflected in key events affecting landscape "multifunctionality" in different periods of time in Bungo district (Jambi province, Sumatra, Indonesia)

	A	B	C	D	E
Historical period	Resource extraction	Economic growth	Center-based welfare	Decentralized welfare	Environmental integrity
1906 Jambi conquest by Dutch	Colonial power focused on generating economic surplus for home country		Elements of "ethical policy" slowly pay attention to education		
1910–1925 Initial rubber expansion		Export-oriented rubber industry transforms lives and landscapes		Rubber boom, area attracts migrants	All areas in reach of rivers get cleared for rubber
1925–1965 Political backwater		Out of the mainstream		Gradual decline	Riparian zones become "jungle rubber"
1970s National development: logging	Logging concessions	Trans-Sumatra Highway planned and implemented			Land use becomes oriented toward roads
1980s National development: transmigration	Logging concessions		Transmigration serves people from center		
1990s National development: oil palm	Logging industry transformed to pulp and paper industry for lower valued and smaller trees	Centrally controlled oil palm concessions and pulp/paper industry	1997 "Asian crisis" drives urban people back to rural livelihoods	National parks try integrated conservation and development (ICDP) with limited success	
2000s Local development: decentralization, environmentalism		Oil palm and pulp/paper industry protected		District government empowered, smallholder oil palm increases	Coal mining; all ex-logging concessions become fast-wood plantations

Source: Martini et al. (2010)[5]

The reliance on river transport in the formative years of the rubber industry in Jambi implied a path dependency of the current value chain: processing industry is geared toward handling low-quality “slab” rubber and pays low prices for all rubber assuming that it has low quality – which proves to be a self-fulfilling prophecy. In contrast, in West Kalimantan where road-based transport became important in early stages of rubber establishment, factories were set up for clean sheet rubber with an associated farm-gate-to-factory value chain. Changes toward price-to-quality relationship and reduced length of the farm-factory chain of intermediaries face a high resilience of status quo actors. Only in the past decade have efforts to create a more direct quality-price relationship started to change the value chain.[1]

The “jungle rubber” aspect (Gouyon et al. 1993; de Foresta et al. 2000; Michon 2005) of smallholder rubber became more apparent in the 1930–1960 period, when the area was a political backwater. Jambi was not a front-runner in the struggle for Indonesian independence and was administered as part of West Sumatra until that province fell out with national government in the late 1950s. In stark contrast to the rapid initial spread of rubber in farming communities that still were rather “remote,” subsequent rubber germplasm was hardly adopted – even though a three- to fourfold increase in dry rubber yield per tree was achievable through clonal selection (Joshi et al. 2003; Penot[6]). In the 1990s, farmers were aware of a “yellow” and “red” type of rubber, derived from material introduced by the agricultural extension service in the 1940s, but they were not actively pursuing such germplasm known to be more productive. The substantial risk of failure of newly planted rubber, mainly due to damage by wild pigs, was quoted as the main reason (Joshi et al. 2003). The transition to planting material that has any appreciable cost and is planted at final density with low tolerance of loss proved to be more difficult (Williams et al. 2001) than the initial adoption of an exotic alternative to local latex-producing trees. When the use of fire in land clearing became controversial in the 1990s (Stolle et al. 2003), techniques based on large-sized planting material became popular, with some effort to obtain seedlings from grafted rubber plantations but with unclear genetic status of the material planted (Vincent et al. 2011b; Wibawa et al. 2005). The use of fire in land clearing is considered essential by farmers who want to plant an upland rice crop in the first year with the rubber (Ketterings et al. 1999), partly because it mobilizes organic soil phosphorus pools (Ketterings et al. 2002); it may lead to high within-field erosion and sediment transport, without much loss beyond field borders (Rodenburg et al. 2003).

Nonlinear Changes in Context: Rise and Decline

The big changes of the past three decades can be traced back to key changes in national policies: the policies surrounding logging concessions, development of the Trans-Sumatra Highway, and its impacts on economic geography, especially where the road cut across different river systems rather than follow the course of the river. Demographic change came with transmigration projects starting in the 1970s.

The new economic activities and labor force, mostly from Java, largely bypassed the local rubber-based economy. However, Miyamoto (2006a, b, 2007) recorded an increase in land-use intensity and rate of forest clearing before the Trans-Sumatra Highway was operational, as local farmers may have anticipated the increased availability of labor that would make larger rubber areas profitable through share-tapping agreements.

There is not a single example in Jambi where the Indonesian selective logging system (Sist et al. 1998) aimed at allowing regrowth of the forest for a second round of logging after 30 years has worked. Throughout Jambi, the increased accessibility of the logged-over forest by the network of logging trails connecting to public roads, the presence of a labor force brought in for the logging operations, and the policy vacuum at the end of a logging concession gave the appearance of a "free-for-all" phase of illegal logging, land claims, and conversion (Colfer 2005). Oil palm concessions were planned and licensed by the provincial government for virtually all logged-over forests, often including large tracts of smallholder-managed (and "owned") rubber agroforest. The direct link between local government and Jakarta-based elites was severed in the 1997–1998 beginning of the "*Reformasi*" period, giving more authority to local elites and entrepreneurs.

In the 1990s, establishment of large-scale oil palm plantations was protected from competition from independent smallholders by restrictions on establishment of independent mills with excess processing capacity. While commercial logging activities sanctioned by government concessions stopped in 2000, loss of natural forest cover continued. Ekadinata and Vincent (2011) analyzed land-cover change between 1973 and 2005 in Bungo district, an area of 4,550 km^2. During that period, natural forest cover declined from more than 75–30%, while monoculture plantations of rubber and oil palm increased from 3 to over 40%; rubber agroforests decreased from 15 to 11%, but most of the rubber agroforests present in 1973 had been converted to monocultures in 2005, while new rubber agroforests emerged elsewhere in areas under natural forest in 1973. Rubber agroforest appears to be a predominantly transient type of land use with high likelihood of conversion. Difficult access to the remaining forested land added more pressure to rubber agroforest conversion into more intensive agricultural systems.

Consequences: Agroforests as Last Haven for Lowland Forest Biodiversity in Jambi

With the intended and ongoing conversion of all "production forest" in the province of Jambi to fast-wood plantation for the pulp and paper industry, rubber agroforests have become a last haven for lowland forest biodiversity in the landscape, as protected areas in Sumatra mostly cover the hills and mountains or coastal peat swamp (Laumonier et al. 2010). Bungo district includes a portion of the Kerinci Seblat National Park (the largest park in Sumatra) at higher elevation and in the past provided ecological connectivity to the Bukit Dua Belas National Park (east of Bungo).

Table 2 Floral diversity in rubber agroforest in tree, sapling, and seedling stages compared to secondary forest in Bungo district (Jambi, Indonesia; eight replicates in Rantau Pandan and eight in the Muara Kuamang/Kuamang Kuning area)

Stratum	Parameter	Secondary forest $n = 16$	Rubber agroforest (RAF) $n = 16$
Tree (dbh ≥10 cm)	Number of species	9.6	6.0*
	Number of individual tree	12.4	12.7 ns
	Density (N ha^{-1})	621.9	634.4 ns
	Shannon-Wiener index	4.5	2.6**
Sapling (dbh <10 cm, height >2 m)	Number of species	11.2	10.6 ns
	Number of individual tree	18.2	18.0 ns
	Density (N ha^{-1})	3650.0	3600 ns
	Shannon-Wiener index	4.3	4.2*
Seedling (height <2 m)	Number of species	15.4	15.7 ns
	Number of individual tree	45.6	60.9 ns
	Shannon-Wiener index	4.3	4.0**

Source: Tata et al. (2008b)

Note: asterisk denotes significant difference of RAF to forest at $p = 0.05$; ** at $p = 0.01$ based on *t*-test (for diversity index) and based on Dunnet test for other parameters; *dbh* diameter at breast height (1.3 m); circular plot of 200 m^2 (for trees), with 50-m^2 subplots for saplings, 25-m^2 subplots for seedlings

The rubber agroforests that originally developed along the rivers in the beginning of the twentieth century became an ecological corridor that connected to the lowland protected areas, especially when roads attracted the focus of development to other parts of the landscape. Current pressure on conversion, however, means that only a limited number of "stepping stones" are left rather than a continuous corridor. Riparian zone connectivity between protected areas in the region through rubber agroforests (RAF) has never been recognized in conservation planning and did not get active policy support.

Initial transformation of forest to rubber agroforest resulted in a modest change in diversity and plant species composition, as active rejuvenation of forest species still took place (Lawrence 1996; Beukema and van Noordwijk 2004; Beukema et al. 2007; Tata et al. 2008b). The loss of forest cover significantly decreased species richness of vegetation in the (reproductive) tree stage. The structure of the seedling and sapling strata in forest and rubber agroforest, however, was not significantly different (Table 2). Selective culling of trees that stand in the way of rubber and have less value explains this pattern (Tata et al.[9]). The higher the intensity of RAF's management, the lower the species richness (Rasnovi[8]).

Rasnovi[8] reported 405 tree species of sapling stage encountered both in forest and RAF, while 241 species were found in forest only and 284 in RAF only, virtually all belonging to the native flora and indicative of the challenge of exhaustive enumeration of the forest diversity. About 71% of the saplings encountered in RAF belong to long-range zoochorous species, whereas in forest 64% of saplings have this dispersal mode. Autochory, that is, large seeds with limited dispersal range, accounted for 14.9 and 4.6% of species in forest and RAF, respectively (Tata et al.[9]).

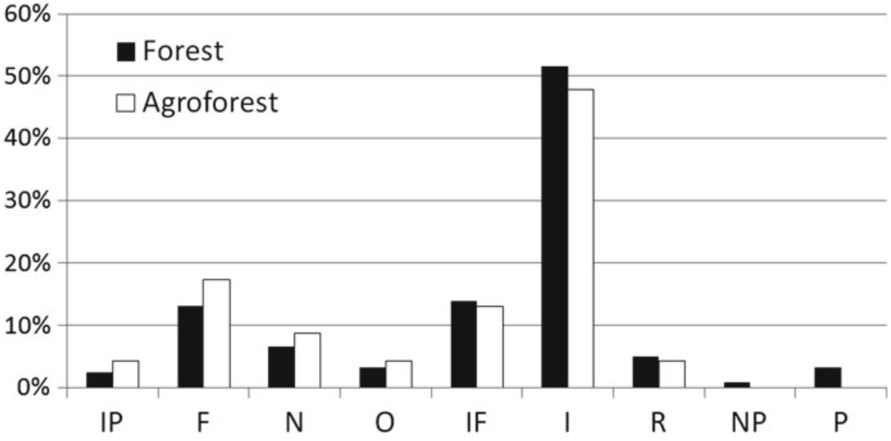

Fig. 4 Composition of bird guild types in rubber agroforest and forest in North Sumatra: *IP* insectivore-piscivore, *F* frugivores, *N* nectivore, *O* omnivore, *IF* insectivore-frugivore, *I* insectivore, *R* raptor, *NP* nocturnal predator, *P* piscivore (Source: Ayat et al. 2011[2])

Thus, RAF plays a role as refuge area of forest tree species for which the dominant mode of seed dispersal through birds and small mammals remains functional, but less so for the ecological group of trees with large seeds that tend to occur in later successional stages (Wunderle 1997); large seeds are ecologically functional in densely foliated forest patches where they allow saplings to reach a size that allows rapid response to gap (Chablis) formation. Among the trees that are allowed to reach reproductive stage in RAF, species with edible parts from a human perspective are positively selected, as are trees with use value as vegetable, spice, or medicinal use (Tata et al. 2008a); 64% of trees encountered in RAF had edible parts, compared to 29% of species encountered in the natural forest (Tata et al.[9]).

Diversity of the vegetation has a positive relationship with animal diversity, in particular birds and bats, which play important roles as dispersal agents, pollinators, and biological control agents. A recent study in North Sumatra showed that 14 out of 17 bird guilds found in forest comparator plots were also found in RAF.[2] The two commonest guild types of birds in both forest and RAF were insectivores and frugivores (fruit eating); frugivore birds were more frequent in RAF than in forest (Fig. 4), owing to a higher relative abundance of fruit trees in RAF.

Consequences: Local Appreciation of (Agro) Forest Diversity in Jambi

The main difference between forests and rubber agroforests, besides land-cover properties, is the tenurial system (de Foresta et al. 2000; Michon 2005). At the community level, forest is usually owned and managed communally, while rubber in the

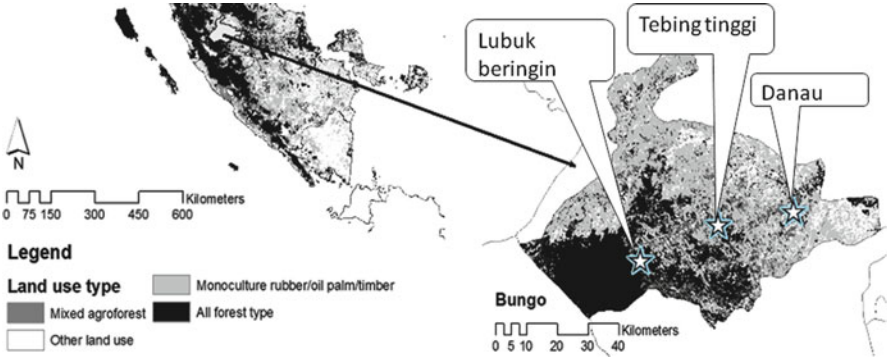

Fig. 5 Location of the three focal villages of the Landscape Mosaics Project in Bungo district

rubber agroforests is considered to be private property. At the government level, forests are under control of forest authorities, and only rubber agroforests that are located in agricultural zones are considered private property. Part of the current rubber agroforests are classified as production or watershed protection forest on the government maps, creating (potential) conflicts – but also opening space for negotiations such as the "village forest" in watershed protection forest that is managed as rubber agroforest with mutual consent (Akiefnawati et al. 2010). Within the local rules, rubber trees in rubber agroforests are privately owned, but products from other trees, such as durian (*Durio zibethinus* L.) or petai (*Parkia speciosa* Hassk.) and medicinal plants, can be collected by any villager. Decisions to intensify rubber agroforests thus reduce access to such forest resources in the landscape and involve a private gain but loss to the commons.

Some further insights into the role rubber agroforests play in provision of "forest services" were obtained as part of the Landscape Mosaics Project (Pfund et al. 2008, 2011). Three villages in Bungo district were selected based on an intensification gradient (Fig. 5): (1) Lubuk Beringin village (forest edge/low intensification), (2) Tebing Tinggi village (intermediate intensification), and (3) Danau village (most accessible, most intensified).

The perceived importance of the various forest (woody vegetation) types presents in a gradient of three villages, spanning the local forest margin to intensive use gradient (Fig. 6) across five countries (Laos, Indonesia, Madagascar, Tanzania, and Cameroon; Pfund et al. 2011). In the Jambi benchmark, the "forest margin" village Lubuk Beringin had three habitat types (Fig. 7), Tebing Tinggi had no natural forest left, and in Danau all secondary forest had been converted to agroforest. Some of the other sites included a "forest plantation" category not present in Bungo. The perceived importance to local livelihoods was quantified using a pebble-scoring technique, allocating 100 tokens across the functions (multidisciplinary landscape assessment method: Sheil and Liswanti 2006). The functions are here relabeled as three types of "goods" ("provisioning services": food, other items for local use, and marketable goods) and regulating and cultural services (Fig. 7).

Some of the other landscapes included an "other" category; the Bungo results did not. Figure 6 gives a breakdown of the "other goods" over four categories.

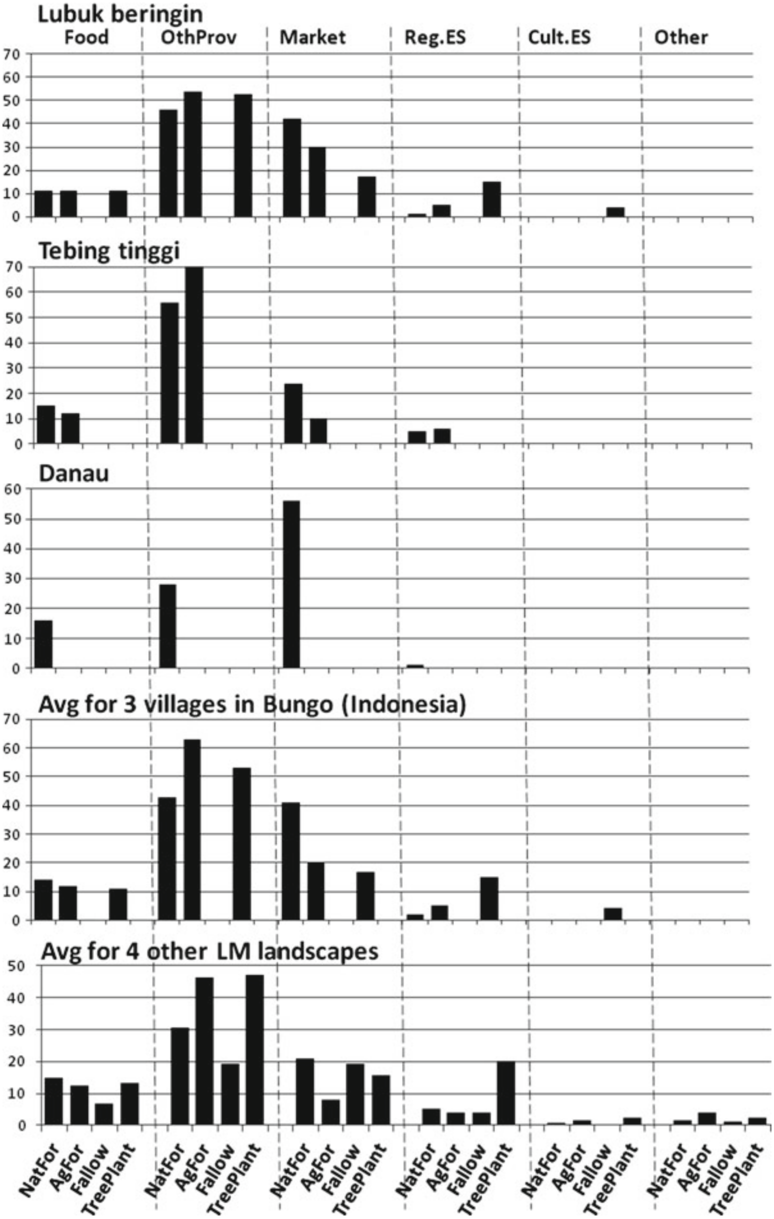

Fig. 6 The relative share of four habitat types, in as far as present in a landscape, in the total importance value (pebble-scoring result) assigned to four types of "nonfood goods" that can be obtained, mostly for home consumption and local use, in 3 focal villages of the Landscape Mosaics Project in the Bungo benchmark and as average for 12 other villages in 4 other countries (Laos, Madagascar, Tanzania, and Cameroon)

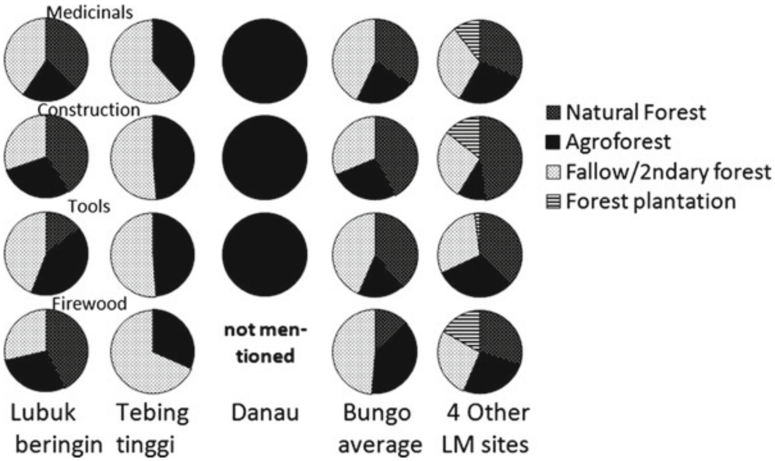

Fig. 7 Relative importance of food provisioning, other-good provisioning, marketable goods provisioning, and regulating and cultural services across up to four woody vegetation types ("natural" forest, agroforest, secondary forest, and forest plantation) in three focal villages of the Landscape Mosaics Project in Bungo, in Bungo as an average and across four other benchmarks (Laos, Madagascar, Tanzania, and Cameroon)

The results show that "goods" are substantially more appreciated than "services," with the given interview technique, in all five Landscape Mosaics sites (and in all 15 villages involved). Regulating services (mostly referring to water) got some mention; cultural services hardly received any. Within the "provisioning services," the role of food is relatively small (<20%), again with the Bungo (Indonesia) results aligned with the other four country studies; the "other goods" dominate (40–50%), and "marketable goods" (30–40%) are intermediate. The relative profiles of the various functions for each habitat type appear to vary more between the landscapes than they vary between habitats in a given place. For example, if firewood is important at all, any firewood is important irrespective of the nature of woody vegetation it comes from. Also, RAFs are at least as much appreciated as natural forests in a role as provider of nonmarketed nonfood products. The three test villages in Bungo differed in their landscape composition, human population density, as well as market orientation. In Danau, there was no natural forest or secondary forest left in the landscape at the time of the interview, so rubber agroforest had become the sole provider of "forest functions." Overall, however, this village is most focused on the marketable part of goods provisioning. Forest-based medicinal plants have been largely replaced by bought pharmaceuticals, leaving undomesticated fruits as a major reason that agroforests are appreciated locally (Lehébel-Péron et al. 2011; Therville et al. 2011).

Increasing market integration, assisted by a recent recovery of world market prices for rubber, has reduced the local relevance of diversity in semi-domesticated agroforest resources and has led to generally positive local perceptions of the opportunity for change toward monoculture intensified rubber and oil palm plantations

(Feintrenie et al. 2010; Feintrenie and Levang 2009, 2011). In some forest-edge villages, however, a positive reappreciation of the merits of rubber agroforests has taken place, and resistance to change into oil palm is expressed (Villamor and van Noordwijk 2011), partly in response to success in securing use rights in the "watershed protection forest" zone (Akiefnawati et al. 2010).

Case Study in Xishuangbanna, China

Pattern and Drivers of Half a Century of Rubber Plantation Economy

Rightly or wrongly, shifting cultivation is often held to be the principal driving force for deforestation in tropical Asia. Resource managers in these countries invariably see shifting cultivation as a single, simple system of farming in which the forest or scrub is slashed and burned to make swiddens. As argued by Rambo,[7] however, swidden agriculture is a composite farming system with high agro-biodiversity and livelihood flexibility, with a system built around patchy, phased removal of trees but not of the forest (Alcorn 1990). Swidden-fallow landscapes stay within the internationally accepted forest definition as long as the fallows reach a tree height of 5 m and a crown cover of 30% before opened for a next cycle, and thus shifting cultivation is not a driver of deforestation until a late stage in intensification and shortening of fallow periods.

Land use in the upper Mekong region has a direct ecological impact on lower Mekong locations. Economic development in the upper Mekong is not dependent on physical access via this river, and there is little direct reason to care about effects downstream, whether land use, climate change, or engineering projects are seen as the primary cause of change in river flow (Xu and Thomas 2010). Land-use change in the upper Mekong region has occurred where smallholder farmers switched from swidden agriculture to a plantation economy. While the number of hectares planted to these crops may still be relatively inconsequential, annual rates of change are significant. Recent research results suggest that most upland areas of Mekong will eventually see a major change in land use with the conversion from swidden agriculture to commercial tree crop plantation (Ziegler et al. 2009). As a result, biodiversity, as measured by the number of species found in the landscape (Xu et al. 2009), and carbon stocks both aboveground and belowground are declining, while watershed services deteriorate. In this context, the increase in rubber plantations received specific attention, as it alters the hydrologic system compared to native vegetation (Guardiola-Claramonte et al. 2010).

Bordering with Laos and Myanmar, Xishuangbanna prefecture is located in the upper Mekong, Yunnan province of southwest China. The prefecture covers only 0.2% of the land area of China, yet it contains 25% of all the plant species in the entire country (Cao and Zhang 1998); it also is a culturally diverse region. It is the home of many ethnic minority people including the valley-dwelling paddy-farming Dai people and upland shifting cultivators such as Hani (or Akha), Jinuo, Yao, Lahu, and Bulang. The Dai are Hinayana Buddhists but also worship nature in the form of "holy hills" and "temple yards." The Dai people have traditionally cultivated *Senna siamea* (Lam.) (Irwin & Barneby) (syn, *Cassia siamea* Lam.) for fuelwood for hundreds of years. Each Dai family would have a small plot of *S. siamea* near the village. They have also traditionally practiced homegarden agroforestry (Pei 1991). The Hani (called Akha in Thailand) are animists and place a strong emphasis on worshiping their ancestors, as exemplified in their strictly protected cemetery forests. They practice a composite swiddening system that includes jungle tea gardens in the forest, intensively terraced paddies, livestock grazing, and shifting cultivation in the uplands (Xu et al. 2009). Swiddens are called "taungya" by the Hani, which means "nonirrigated uplands" (compare Thai use of the term in Raintree and Warner 1986). Before 1949, Hani (or Akha), Lahu, and other upland ethnic groups paid taxes or tributes to the Prince in the Dai principality as well as exchanging forest products such as rattan, tea, and wildlife meat with lowland Dai people for betel nut (*Areca catechu* Linn.), metal, salt, etc. The lowland-upland networks also allowed lowland political centers to extend their governance over the uplands and helped upland communities to access markets and information. Customary rules maintained a ring of forest surrounding the hamlet as well as at the foothills of mountains, which served as an ecological and political buffer between the lowlands and uplands. Land property relations within and across ethnic groups were diverse, flexible and overlapping, and certainly fuzzy from the perspective of private, exclusive property (Sturgeon 2004). These socially constructed patterns of interdependence fostered a certain degree of autonomy and self-governance for indigenous people and allowed them to govern an ecologically diverse but integrated landscape for cultural and subsistence needs. The mosaic landscape is however considered by state and scientists as "unproductive"; the practices of shifting cultivation or rotational swidden-fallow agroforestry are considered "backward" land-use practices.

Between 1950 and 1985, forest cover in this region decreased dramatically from 63 to 34% (Zhang and Cao 1995). Today, forests remain primarily in nature reserves and state forests, while previously forested lands have been largely converted into rubber plantations. Rubber was not introduced to Xishuangbanna until 1940, when a Chinese settler returning from Thailand planted it in trials. After the 1949 Revolution, the new government of China saw rubber as an important strategic resource. To ensure the availability of natural rubber for national defense and industrial construction in the face of an international embargo, the Decision on Cultivating Rubber Trees was passed in 1951. This decision moved to establish rubber plantations in the tropical regions of China as rapidly as possible. The state organized a feasibility mission for establishing rubber plantations in 1953. Both Xishuangbanna in southern Yunnan and Hainan Island were identified as potential sites for rubber plantation.

In 1955, the first state rubber farm was established by researchers and staffed by Han Chinese from the inland province of Hunan and retired soldiers who formed the main labor force for the expansion of state farms. The first rubber planting by local farmers was in 1963, encouraged with technical support from state rubber farms – rubber spread quickly into most of the hilly areas of Xishuangbanna. The pace of rubber expansion has been particularly rapid since 1990s: the area under rubber increased from 87,226 ha in 1992 to 153,613 ha in 2002 and 349,965 ha in 2010, representing an increase of over 100% during the period from 2002 to 2010. Currently, rubber covers 18.3% of Xishuangbanna's landscape, and the expansion of its area continues (Xu and Grumbine[13]).

In line with the prevailing ideology in China, the state was keen to establish large-scale uniform rubber plantations in Xishuangbanna; monoculture rubber replaced large forest at foothills during 1960s and swidden-fallow mosaic landscapes in the uplands after 1990s. Rubber trees were either counted by the forest agency as forest cover or by the agricultural agency as agricultural production. Rubber plantation, as advanced productive forces, was considered as an approach to poverty alleviation or replacement of shifting cultivation. In this way, local farmers converted large areas of fallow forests (secondary forests) into smallholder rubber farms. Thus, a second wave of rubber planting followed in the 1980s, in tandem with the continued development of rural industry. This planting resulted in a mixed landscape including composite swidden together with a number of different crops and different management practices; generally, rubber replaced rice, or agroforestry systems included young rubber intercropped with pineapple (*Ananas comosus* (L.) Merr.), upland rice, or vegetables.

Consequences in China: Locally Driven Integration Versus State-Driven Segregation

While there is virtually no mixed agroforestry of rubber in Xishuangbanna, Chinese rubber production started with monoculture plantation operated at first by state industry and later followed by smallholders. Smallholders often manage rubber more intensively while the rubber price is high and less intensively while the price is low. By comparison with state rubber farms, they are also more flexible in terms of size, land tenure, and land-use practices such as the ability to intercrop with other annual crops depending on market fluctuations (Xu 2006).

Since the 1950s, the government of China has implemented numerous – sometimes conflicting – policies affecting agriculture and forestlands. Spatial segregation is the key approach to developing such policies. The common practice of segregation is called "state simplifications" described by Scott (1998) for constructing a "legible landscape." In effect, this is an attempt by the state to transform the local people and even the landscape with some common quantifiable standards to enable, as Scott (1998) puts it, a synoptic view. Rubber was a perfect crop for productive plantations for several reasons: it served the state interest to build China into a socialist country, made China self-sufficient in a period of international embargo, transformed agricultural-based production to an industrial mode of production, and produced a "legible landscape" for the state (Xu 2006). At its most literal sense, this "legibility" was a physical expression of organizing nature – even-aged rubber trees are planted in evenly spaced straight rows and managed by paid state labor. Furthermore, these crops were not only important products in their own right, but since they required some level of industrial processing, they furthered the state objective of creating and enhancing the role of a proletariat in rural industries.

The spatial segregation for large-field agriculture, monoculture plantations, and demarcation of natural forest (often as nature reserve) agreed well with the socialist model of collective operations. In comparison to culturally diverse smallholder farmers, the uniform collective was perceived to be superior. Following this logic, collectivization became the strategy that would free peasants from the constraints of a "peasant mentality," characterized by individualism, ignorance, poverty, and vulnerability to natural disasters. Since the mid-1980s, the government has also been putting pressure on the upland minorities to stop swidden agriculture in favor of crops such as rubber (Xu et al. 2009).

This combination of ideologies reconstructed natural landscapes all over China, including in Xishuangbanna. Shifting cultivators such as the Lahu, the Hani, and the Jinuo were thought to be more backward, representing a primitive mode of production. Based on this appraisal, ideologically driven planners concluded that state rubber farms needed to be staffed by people whom they saw as more "educated" and "advanced" peasants, that is, by Han Chinese farmers resettled to the border frontier of Xishuangbanna from inland China. Those "advanced" peasants were organized collectively throughout rubber plantations to become state workers representative of "advanced" productive forces in the socialist model. This reflected a general trend toward managed, "legible" landscape. As a result of this transformation, segregated landscape with clear boundaries has replaced integrated landscape (Xu 2006). Referring back to the three system levels in Fig. 1b, the policy level C clearly dominates in the context of China.

Segregate-or-Integrate Theory

Both the Sumatra and Xishuangbanna case studies are currently moving toward coarser-grained segregated landscape configurations in which there is little role for integrated agroforests that combine biodiversity conservation and profitability for farmers. Integration and segregation of functions in landscapes can be achieved in between the extremes of full allocation to a single function. Perpendicular to the single axis of deforestation/reforestation, we can compare complete segregation and complete integration of trees in a landscape as two extremes of a "spatial pattern" axis (Fig. 8). Agroforestation is associated with more integrated systems, while a coarse mosaic of "fields + forests" forms the alternative, at potentially the same total tree cover and associated properties such as carbon stock.

From a public policy perspective where multiple functions have value and a political platform in society, how can these options of more or less (natural) forest and more or less integration be rationalized? Formal analysis of intercropping experiments

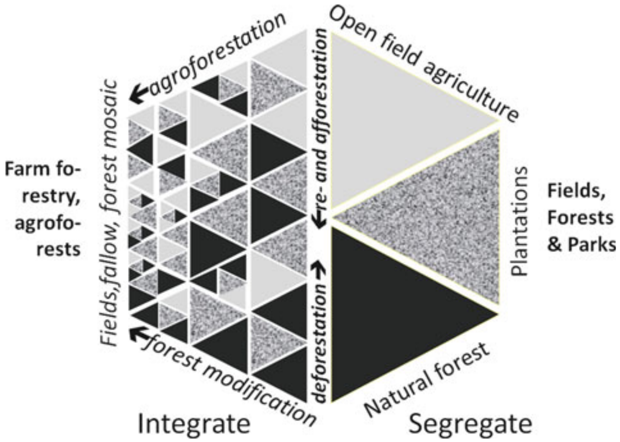

Fig. 8 Two basic approaches to multifunctionality (here represented by three *gray tones*): spatial segregation (*right*) and integration (*left*), in combination with variation in tree cover (*vertical axis*)

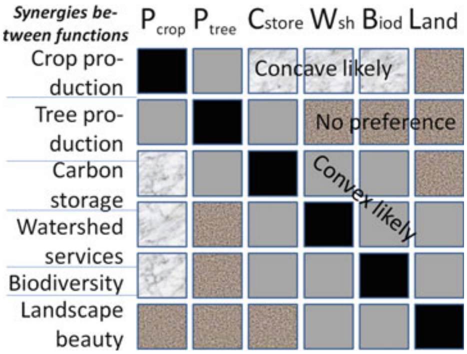

Fig. 9 Tentative summary of hypotheses on the potential for synergy and competition between landscape functions, indicating pairs where low compatibility or competition is likely to lead to concave trade-offs and pairs where convex synergy curves can be expected; formal reviews of literature exist for only a few of the pairs

introduced by De Wit (1960) has shown that "yield advantages" or "reduced land area equivalents" can only be expected for components that have a concave rather than convex trade-off relationship. The biophysical, niche-differentiation aspects of convex relations have been well studied for productivity of annual and perennial components of temperate and tropical agroecosystems and agroforestry (Cannell et al. 1996; Vandermeer et al. 1998; van Noordwijk et al. 2004a). van Noordwijk et al. (1995b, 1997, 2004b), and van Noordwijk and Ong (1999) applied similar analysis to the combination of biodiversity conservation and agricultural productivity in landscapes. Convex trade-off curves between "relative ecological functionality" and "relative agronomic functionality" lead to a potential efficiency advantage in "multifunctionality" solutions, while concave trade-off curves imply that segregation and simplification will pay off (Fig. 9).

Table 3 Relationship between land-use category and policy objectives under fully segregated (only diagonal cells are nonzero) and fully integrated (no cells are zero) extremes

	Policy objective				
Land-use category	A Resource extraction	B Economic growth	C Center-based welfare	D Decentralized welfare	E Environmental integrity
Segregated land-use plan					
f(A)	*A*	0	0	0	0
f(B)	0	*B*	0	0	0
f(C)	0	0	*C*	0	0
f(D)	0	0	0	*D*	0
f(E)	0	0	0	0	*E*
Integrated land-use plan					
1	f(1,a)	f(1,b)	f(1,c)	f(1,d)	f(1,e)
2	f(2,a)	f(2,b)	f(2,c)	f(2,d)	f(2,e)
3	f(3,a)	f(3,b)	f(3,c)	f(3,d)	f(3,e)
4	f(4,a)	f(4,b)	f(4,c)	f(4,d)	f(4,e)
5	f(5,a)	f(5,b)	f(5,c)	f(5,d)	f(5,e)
Total	$\Sigma f(i,a)$	$\Sigma f(i,b)$	$\Sigma f(i,c)$	$\Sigma f(i,d)$	$\Sigma f(i,e)$
Equivalence requirement	$\Sigma f(i,a)=A$	$\Sigma f(i,b)=B$	$\Sigma f(i,c)=C$	$\Sigma f(i,d)=D$	$\Sigma f(i,e)=E$
Multifunctionality advantage if there is asset of f(i) for which	$\Sigma f(i)<(f(A)+f(B)+f(C)+f(D)+f(E))$				

The Tinbergen (1952) rule that the number of policy objectives and number of policy instruments have to match follows from basic matrix algebra where the number of equations has to match the number of unknowns for a problem to be solvable. The “fully segregated” and “fully integrated” options are extremes of a wide range of partial integration solutions (Table 3). In the upper part of the table, a highly reduced matrix shows that each policy-relevant objective has its own part of the landscape. Synergy between objectives in such configuration is minimal, but policy makers can rapidly switch land-use allocations if objectives change in weight. In the lower half of the table, all land-use types potentially contribute to all objectives, and land-use planning has to find a solution that satisfies the minimum requirements for each function and maximizes the aggregate benefit beyond this minimum condition. Under certain parameter conditions, a multifunctional approach as in the lower part of the table can achieve more overall functionality on the same land area; the table provides a formal criterion for such outcome. Configurations in the lower half of the table can be strongly interlinked, in which case all functions may be buffered, but the flip side of this may be that the status quo is too resilient.

Another way of analyzing the relevance of the shape of bifunction trade-off curves (Fig. 10) is to consider the economic value that has to be assigned to the

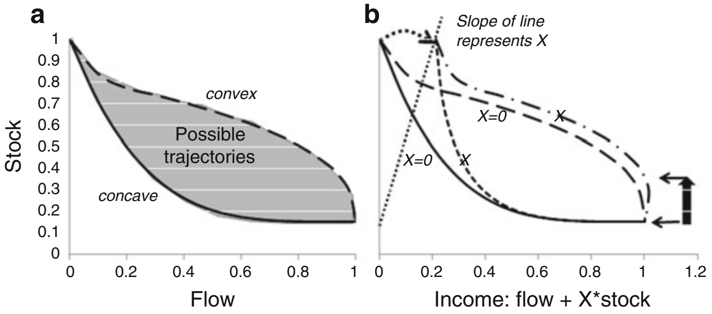

Fig. 10 (**a**) Concave and convex shapes of trade-off curves between flow (e.g., income) and stock (e.g., biodiversity or C-stock) of land-use systems; (**b**) total income based on the flows plus X times the stock, for concave and convex trade-off curves; *arrows* indicate income-maximizing solutions and the upward shift of stocks at income-maximizing land-use choices

secondary function relative to the primary function before optimization can lead to a choice for a mixed system. For concave curves, there is no such solution, and optimality implies a choice between the two functions; for convex curves, intermediate solutions exist for any nonzero value of the value ratio. Adding income value to landscape-level carbon and/or biodiversity stocks effectively means tilting the Y-axis of the biplot (Income = Flow + X*Stock) and may shift the point of maximum economic return to a higher carbon stock trajectory. Depending on the ratio between stock and derived income stream and the shape of the stock-flow trade-off curve, reward systems for environmental services related to carbon or biodiversity stocks can be expected to shift farmer decisions only where convex trade-off curves are involved.

What Incentives Could Keep Complex Agroforests in the Landscape?

Two competing perspectives are as follows: complex agroforests may have had their role in the past but have become obstacles to progress (Pfund et al. 2011), or they will remain an important part of the agricultural matrix and form a future paradigm for conservation (Vandermeer and Perfecto 2007). Local appreciation for parts of forest biodiversity and the way it persists in complex rubber agroforests in Sumatra is noticeable but not sufficient to keep rubber agroforests as an important component of the landscape. Concerns over the loss of integrated systems and their replacement by rubber monocultures are expressed in terms of both biodiversity loss and hydrological disturbance, with different groups of stakeholders concerned about the two issues.

Four approaches have been attempted to reverse the trends toward specialization and loss of ecosystem function "co-benefits":

A. Support for "ecological intensification"[4] by attempts to introduce more productive rubber clones in an agroforest context (Williams et al. 2001; Joshi et al. 2003), high-value timber trees (Tata et al.[10]; Tata et al. 2010a), and semidomesticated local fruit trees. The smallholder timber option is technically and economically feasible but still faces policy constraints in easing market access for legally produced timber.
B. Direct outcome-based payments for biodiversity conservation, although the initial responses of biodiversity conservation agencies have been disappointing; they focus on the last remaining parts of natural forest rather than agroforest landscapes (Kuncoro et al. 2006; Leimona et al. 2009); their attention may be more easily captured in landscapes that have rubber agroforests as well as orangutan populations (Tata et al. 2010b).
C. External co-investment (Arifin 2005b; Van Noordwijk and Leimona 2010) in maintenance of biodiversity-friendly modes of rubber production through forms of ecocertification and more direct farm-to-factory links for results of improved local rubber processing (Joshi et al. 2011).
D. Support for negotiations to develop "village forest" comanagement contracts between villages and forest authorities, applicable in the watershed protection forest category on slopes (Akiefnawati et al. 2010).

Overall, the efforts to keep appreciable amounts of rubber agroforests in the landscape are "rowing against the tide," and the growth of local and external appreciation for the biodiversity value that these agroforests contain may well come too late to retain more than a small fraction, in the least accessible places. By the time the overall economic level and wage rate of Sumatra will have caught up with the current level in peninsular Malaysia, oil palm and rubber farms will have a lower return to labor than urban and service sector jobs, and there may still be a small basis for recovery of diverse agroforests. In China, the monoculture rubber may have lower opportunity for ecological recovery as it does not contain saplings or poles of natural forest species and seed dispersal agents may have disappeared.

In China, rubber is regarded as forest and therefore included in state statistics as forest cover, which is supposed to be beneficial for watershed health. Establishing rubber plantations is considered to have a sound scientific basis, providing soil erosion control that is believed to be lacking in shifting cultivation – these supposed environmental benefits are a further source of legitimacy for rubber. The Chinese scientists working in Xishuangbanna have fallen into three camps since rubber plantations were introduced in 1955 (Edmonds 1994). There are those of the so-called dark-green camp who advocate turning the tropical prefecture into a nature reserve. The opposite "dark-red" view is that Xishuangbanna can be best utilized by turning the area into a tropical cash crop plantation base, particularly a rubber-tree-centered man-made agroecological community (Feng 1986). The third opinion or the "pale-green" view is that there should be some sort of mix between conservation and development (Pei 1991). The scientific research in Xishuangbanna was influenced by the political ideology and policy discourse particularly in the 1950s as well as during the Cultural Revolution (Xu 2006).

Discussion: Arguments for an "Integrate" and "Land Sharing" Approach to Multifunctionality

We can now focus on the final question framed in the introduction: in reflection on the two case studies, can integration of agricultural productivity and biodiversity conservation functions in the longer-term perspective be a valid alternative to a more segregated approach to environmental and productive land functions? Can it justify external support for maintaining complex rubber agroforests in the landscape?

The trade-off curves between plot-level tree diversity and profitability of tree crop production systems used to be concave in Jambi (Murdiyarso et al. 2002), supporting the conclusion that "integration" is an efficient choice at societal scale, if a society cares about its biodiversity loss. Increases in tree crop productivity, however, may stretch a concave trade-off curve into a more linear and ultimately convex shape, unless the total system productivity value is increased. Opportunities to derive more value from the "other trees" in diverse agroforests need to keep up with the increases in value of the primary tree cash crop. Active research support for "ecological intensification" may have been too little and too late to stem the tide, while the public policy support for biodiversity conservation has remained focused on the establishment of protected areas rather than the protection of biodiversity at large.

The biodiversity-rich agroforests of Sumatra developed as an ecologically more mature (K-phase) ecosystem, selected on the basis of labor use rather than land-use efficiency in a historical phase of declining rubber prices. The glamour of the earlier rubber boom had gone; the area no longer attracted migrants, but rubber remained the best option for local communities given the way the rubber value chain had emerged within the economic geographical pattern. Intensification of rubber toward rubber monocultures was technically feasible but not sufficiently attractive in a smallholder economy with its high discount rates and aversion of financial risk, linked to the risk of failure of planted rubber clones to survive. Initially, the introduction of oil palm in the landscape could only compete with smallholder rubber agroforestry where it received active government support in land-use allocations. High world market prices of rubber as well as palm oil and availability of government-supported credit have, however, triggered an Ω/α phase of shifting away from complex agroforests toward monocultural tree plantations. With lower interest rates and increasing pressure on land, the economic incentives shifted, while the loss of biodiversity and associated local goods and services was not expressed in equivalent values. Intensification in the 1920s had replaced part of local staple food (rice) production by a market exchange, but the diverse agroforests still played a role as safety nets and as providers of other goods and services for which the trade-based substitutes were not yet sufficiently attractive. In the 1990s, the land use followed a pathway toward segregation, with pressure on the "integrated" agroforests increasing in parallel with more active protection of national parks and specialized conservation areas (Ekadinata and Vincent 2011).

In terms of sustainagility, the initial preservation of a substantial share of the native tree flora in the sapling/pole stage of RAF gave farmers many options to acquire useful trees at little management cost. Only a small part of these early stages of domestication lead to organized on-farm production of semi-domesticated trees; the potential remained largely unutilized and is currently in a rapid phase of decline. One would hope that this loss occurs with free and prior informed consent (MacKay 2004) as is the current standard for all efforts to reverse the trend of ongoing losses of forests and trees from the landscape. In some villages, efforts to reverse this trend have started, but this is a minority of cases in the overall landscape as yet.

Conclusion

In conclusion, the way rubber was integrated as a productive element in smallholder mosaic landscapes in Sumatra at the start of the twentieth century is in stark contrast to the situation in China where rubber was introduced as a top-down state-driven monoculture plantation. The political economy provided context for the ecological role, similar to the current debate on oil palm where consequences of a mode of production are attributed to the tree species rather than to the way it is used. Rubber agroforests in Indonesia became an icon of environmental friendly integration, while in China the tree became associated with destruction of ecosystem services and reduction of biodiversity. While the situation in Xishuangbanna (China) has triggered public debate and a rethinking of the monoculture model of intensification in a segregated approach, the Indonesian agroforests are giving way to monocultural tree crop plantations after almost a century. In both countries, a mixed model of segregation (fully protected areas and areas of intensive agriculture) and integration (pursuing ecological intensification models in agroforest context) may be the best way to combine local livelihoods and downstream imperatives of conservation and service provision. In both countries, the current incentive structure is insufficient to support the “integration” part of this mixed solution, with government programs biased toward specific models of intensification. It might help if the market would start to differentiate between “light-green” natural rubber (as differentiated from synthetic rubber), grown in monocultural plantations, and “dark-green” rubber that is produced in biodiversity-friendly production systems. In both countries, the nature of the forest transition is influenced by government policies and current lack of market-based payment for ecosystem services or economic incentive for biodiversity conservation. Research efforts have so far focused on the monocultural systems, but there are many unexplored options for preserving forest resources in diversified agroforestry systems with species from the native flora that can support concave trade-off functions between profitability and biodiversity conservation. Without external attention and incentives, however, the route of least resistance leads to a planted monoculture and agroforests as local history of tropical land use.

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End Notes

[The authors apologize to authors quoted in these endnotes that editorial policy of this book does not allow their work to be cited.]

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