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Tree cover transitions and food security in Southeast Asia

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ABSTRACT

Trees are sources of food, especially fruits, critical for healthy diets. Trees also modify microclimate, water and nutrient flows for crops and livestock, and are a source of income, allowing forest-edge communities to be food-sufficient through trade without cutting down forests. Opportunities for ecological intensification, utilizing trees in agricultural landscapes, vary along stages of a tree cover transition of forest alteration and deforestation followed by agroforestation. The nonlinear forest transition curve can provide both a theory of change (similarity of processes) and a theory of place (configuration of state variables). We reviewed local perspectives on food security for four configurations of the forest and landscape transition in Southeast Asia, with local human population densities ranging from less than 10 to 900 km^{-2} to explore how current generic 'theories of change' on how to achieve global food security need more explicit 'theories of place' that take such differences into account.

1. Introduction

Food security, forests, poverty and sustainable development are terms that have relevance across all scales from local through national to global. Yet the meanings of these terms change significantly at different scales. In this article, we hope to disentangle the discussion on their interactions in the context of the elusive sustainable development goals for 'a future we want,' as agreed by world leaders in the Rio+20 meeting (http://www.uncsd2012.org/). Maslow (1943) suggested that multiple needs of individuals can be represented as a pyramid, with physical security as basis and identity and self-articulation at the top. Food relates to all levels of this pyramid, from basic needs to identity. Recently, van Noordwijk et al. (2014a) suggested that a similar pyramid applies at the scale of a national government, which sees territorial integrity, physical security, caloric food and water security as basic needs, but also articulates identity in food terms.

Trees provide resins and fruits, some of which are caloric staple foods and many are important dietary sources of vitamins (Jamnadass et al., 2013). Siegel et al. (2014) compared availability of fruits and vegetables with what is considered necessary for a healthy diet and found a global deficit of 22%, with 58% in low-income and −2% in high-income countries. This deficit in (tree-based) fruit and vegetable supply coexists with oversupply (relative to a healthy diet) of protein sources and caloric staple foods that are more easily stored and traded over long distances. Trees and forests also support local livelihoods, agricultural production and food security as they are major providers of environmental services (here interpreted as ecosystem services minus the provisioning services, following van Noordwijk et al. (2012a)). Food security, in all its aspects, in a world at risk of exceeding planetary boundaries through its human appropriation and modification of vegetation, climate, water and nutrient cycles (Rockström et al., 2009) implies a focus on quality and diversity of food, beyond calorific quantity, and on explicit choices to adjust desirable to affordable diets for the expected population size and welfare targets. On the supply side it requires the closing of both yield and efficiency gaps (van Noordwijk and Brussaard, 2014; Bommarco et al., 2013). Yield gaps are defined as the difference between actual and potential yield – acknowledging that there are many ways to define the latter in operational terms (van Ittersum et al., 2013). Efficiency gaps are similarly defined as the difference between actual and potential resource use efficiency, with similar challenges in defining 'potential' operationally. As technically inefficient ways of closing yield gaps can be economically rational for farmers in the absence of internalized environmental costs, policies to increase food security by reducing input prices have downside risks for the provision of environmental services. Yet, the Borlaug hypothesis that has been popular for the past two decades expects that by reducing

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yield gaps, agricultural intensification contributes to reduced pressure ('land sparing') on the remaining forests (Tomich et al., 2005; Lusiana et al., 2012). There thus may be a trade-off between the local environmental costs of intensification versus the opportunities it provides to conserve forests elsewhere. As first approximation, agroforestry is used as a term that indicates a combination of agriculture and forestry as land use sectors, but also as a way of combining functions and objectives (Mbow et al., 2014).

Forest-edge communities typically employ a dual economy where primary staples are self-produced and trade is focused on non-food items (Dove, 2011). The term intensification is widely used for changes in agricultural practice, but its definition as a change in a state variable 'intensity' often remains implicit, with notable exceptions (Giller et al., 1997; Tscharntke et al., 2005). Where land use intensity is commonly quantified on the basis of outputs or the magnitude of the yield gap (difference between actual and potential yield), the need for intensification to meet increasing demand is a tautology. Van Noordwijk and Budidarsono (2008) extended the Ruthenberg index that indicates the fraction of time (and space) that land is cropped in a swidden-to-fallow-to-permanent cropping series, with additional terms in an index based on efforts to modify the water and nutrient cycles, controlling weeds, pests and diseases, substituting human labour by fossil energy-based mechanization and removing remnant refugia for biota from a landscape. These various aspects of intensification can be compared on their effectiveness in increasing yield as well as affecting environmental services allowing tradeoffs to be made between the farm-level decisions that jointly determine land use intensity. Various adjectives are used in combination with 'intensification,' with terms such as 'sustainable' and 'climate-smart' indicating goals rather than methods, and 'ecological' currently preferred for efforts to close yield and efficiency gaps simultaneously (van Noordwijk and Brussaard, 2014).

The drastic quantitative increases in food production and associated human population size in the past 10,000 years since the start of agriculture (Miller, 2008), with variable effects on qualitative aspects of food security, has been obtained at substantial environmental cost, with the green revolution as recent manifestation of what agricultural technology can achieve (Fig. 1). Four overarching goals have been agreed for international agricultural research, with increased rural income, increased food production and enhanced food security as a group aimed at continuing current developmental trends, while goal four, improved natural resource management requiring an escape from the trade-off with the first group. From the current position at the origin of the coordinate system in Fig. 1, there is a range of trajectories: continuation of a traditional focus on

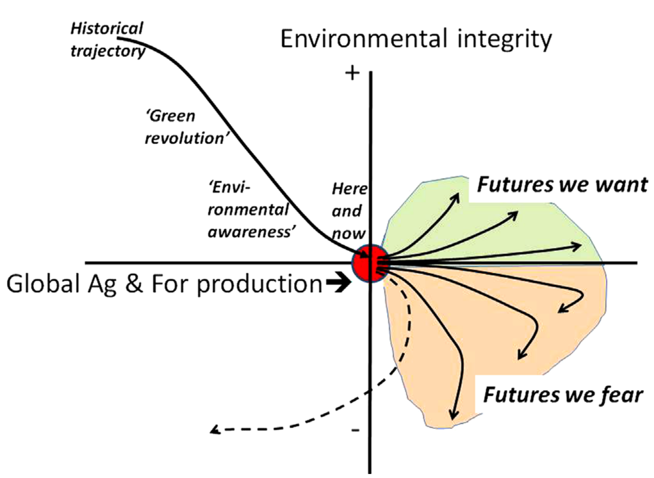

Fig. 1. Historical trajectory of humanity and its future options in the tradeoff between environmental services and agricultural and forest production that enhances income, food supply and food security.

supply alone may cross planetary boundaries and lead to a 'collapse' scenario. Simultaneous closing of yield and efficiency gaps may allow an escape into the desirable upper right quadrant of a recovery of environmental services alongside modest increases along the X-axis. The single goal of food security thus needs to be reframed as an imperative to navigate tradeoffs among two major axes, with yield and efficiency gaps as proxies. As yield and efficiency gap scale by different rules (van Noordwijk, 1999), the trade-off depends on scale (van Noordwijk and Brussaard, 2014).

With the 'theory of change' language becoming prominent in development circles, it is pertinent that 'forest transition theory' provides both a theory of (non-linear) change (similarity of processes, prominence of actors and agency, direction of change) and a theory of place (configuration of state variables) (van Noordwijk and Villamor, 2014). In this context a theory of change can be defined as 'Implementable, rational pathways, aligned with documented experience, to achieve change that is deemed desirable by funders and acceptable by gatekeepers.' A theory of place can be defined as a 'Framework for articulating, describing and analysing the spatial and contextual aspects of current livelihoods, the business-as-usual projection of ongoing change, and the identity and sense of belonging associated with these.'

We can recognize four configurations of forest, agroforestry and agriculture in the way landscapes relate to the four stated objectives (Fig. 2; van Noordwijk et al., 2015). These differ in actual land cover (fractions of various degrees of tree cover; spatial configuration), but also in institutional aspects of forest versus agricultural categories of land, and in the way livelihoods and food security are perceived (Carney, 1998; Jackson et al., 2010).

In configuration I swidden/fallow rotations (also known as shifting cultivation) are the major source of local livelihoods. As a land use system, swiddens are both forest and agriculture, as the swidden allows both crop production and a start of forest rejuvenation. The four objectives are addressed simultaneously.

In configuration II, institutional processes that segregate forest from village land associated with agriculture prevail and forest and agriculture become entities that are seen to complement each other in terms of human wellbeing. However, they also engage in an area trade-off: growth of agricultural area implies less forest, and forest conservation necessitates a more productive form of agriculture. The land sparing discourse that builds on the Borlaug hypothesis typically refers to this configuration.

Configuration III, which can develop out of the first if institutional pressures towards segregation are less strong, acknowledges an intermediate-tree-cover land use type, labelled as agroforestry. The agroforestry part of the landscape is intermediate between forest and agriculture in the functions and services it provides, and the theoretical framework for the resulting landscape transitions is one of land sharing (van Noordwijk et al., 2012b).

Finally, in configuration IV a distinct role of natural forest is recognized that supports landscapes in which an agriculture–agroforestry transition takes care of (nearly) all provisioning services (including food), with abundant use of trees on farm. The supporting and regulating role of forests allows the agriculture plus agroforestry parts of the landscape to provide for income, food supply and food security.

Where the four configurations currently coexist in Southeast Asia, we need to be aware that current change can be different from historical patterns elsewhere, with mutual influences in an increasingly connected world. The remainder of this contribution to the debate will review four case studies from Southeast Asia (Table 1) that represent the four configurations of Fig. 2. The four configurations are broadly aligned with the generic relationship between human population density and remaining forest cover (Köthke et al., 2013), with a major difference between the dominance of natural forest in configuration II and of agroforest in configuration III (Fig. 3).

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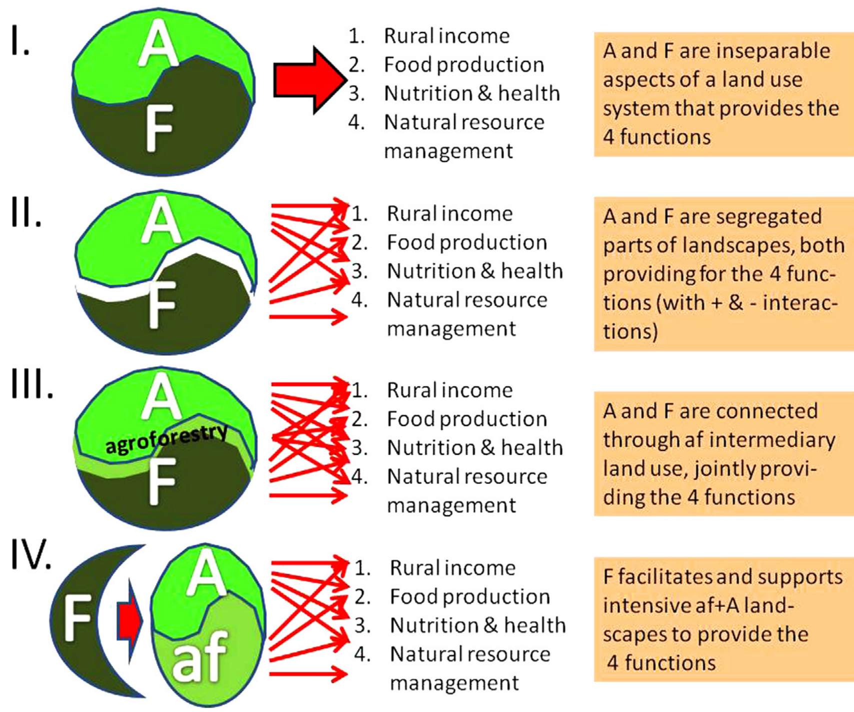

Fig. 2. Four configurations in forest and landscape transitions with consequences to the way the four functions that correspond with CGIAR system level objectives are achieved; A=agriculture, F=forests, af=agroforestry (van Noordwijk et al., 2015).

Table 1
Basic statistics of demography and land use in the four case study areas around 2010 (HDI data: 2005).
Source: National bureaus of statistics and Spatial analysis unit, World Agroforestry Centre.

	I. Katingan, C.Kalimantan (Indonesia)	II. Mae Chaem, Northern Thailand	III. Bungo and other foothill districts, Jambi (Indonesia)	IV. Wonosobo, C. Java (Indonesia)
Human population density, km^{-2}	8.4	20.9	52.2	881
Human development index	71.3	65.4	71.0	67.6
Forest fraction	0.690	0.801	0.330	0.059
(ha per capita)	*(8.231)*	*(3.948)*	*(0.632)*	*(0.007)*
Agroforest & tree crops	0.175	0.005	0.568	0.469
(ha per capita)	*(2.090)*	*(0.024)*	*(1.088)*	*(0.053)*
Rice-field (paddy) fraction	0.018	0.016	0.023	0.185
(ha per capita)	*(0.216)*	*(0.080)*	*(0.045)*	*(0.021)*
Crop (non-paddy) lands	0.003	0.167	0.020	0.188
(ha per capita)	*(0.034)*	*(0.821)*	*(0.038)*	*(0.021)*
Other land	0.099	0.003	0.034	0.031
(ha per capita)	*(1.182)*	*(0.017)*	*(0.066)*	*(0.004)*
Settlement	0.010	0.008	0.034	0.068
(ha per capita)	*(0.116)*	*(0.037)*	*(0.064)*	*(0.008)*

For each configuration we set out to answer:

- What does food security mean to local people in this context?
- What roles do trees and forests play in food security?
- How are productivity growth and environmental services related?

This is followed by a discussion in which the four configurations are compared (Table 2) for lessons learnt and emergence of

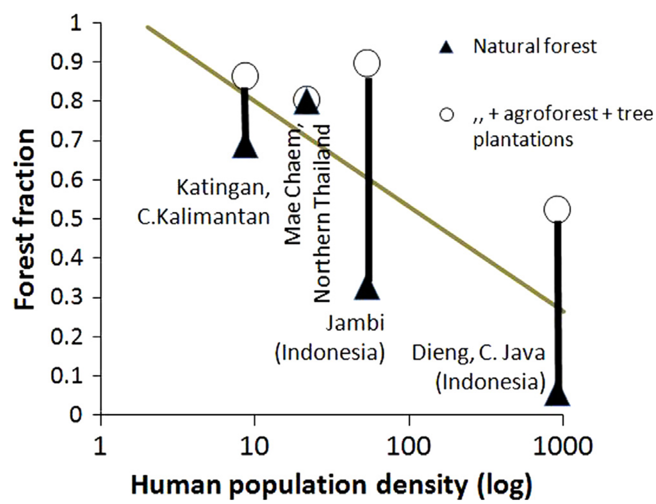

Fig. 3. Relationship between human population density and forest cover (remaining natural forest as closed triangles, forests plus agroforest and plantation forests in the open circles) of the four landscapes discussed; the line indicates the average relationship at national scale in FAO data discussed by Köthke et al. (2013).

new perspectives and issues that are researchable, urgent and interesting.

2. Food security issues in different configurations of landscape transition

2.1. Configuration I: Swiddening, rattan and gradual market integration

A major transition from swiddening historically has been when the non-cropped phase ('fallow') became a source of tradable goods, potentially overtaking the crop phase in contributions to local livelihoods (Van Noordwijk et al., 2008). The rattan gardens

Table 2
Summary of the four case studies in relation to direct and indirect ecosystem services.

	Configuration I Kalimantan	Configuration II N. Thailand	Configuration III Sumatra	Configuration IV Java
Direct (provisioning) ecosystem services increasing food security	Upstream swiddens provide ¾ of food needs, supplemented by market exchange for forest and agroforest products (rattan) and mining; downstream market-based food security has taken over; supplementary food from hunting and fishing	Spatial segregation of protected forest and intensive food crops provides income and market-based food security	Selectively retained native forest trees provide dietary diversity, while staple food is mostly bought (through outsourcing). Local people enjoy the diversity of fruits from agroforests as source of nutrition	Market-based food security, little direct roles left for forest, except for drinking water
Indirect environmental services increasing food security	Spawning grounds for fish in riparian vegetation. Deforestation upstream has reduced buffering of river flow and has made crop production more risky.	Steepest slopes have protective tree cover, riparian forests regulating stream flow are mostly converted	Forests are the source of seed rain of desirable trees in the agroforest; hillslope agroforests regulate water flows and protect local rice paddies	Forests protect hilltops but a more distributed tree cover on slopes is needed for soil protection, supporting ecosystem services for commercialized commodities (i.e., soil fertility and nutrient).
Yield gap issues	High crop and cultivar diversity in staple foods spreads risks, but reduces average yield	Intensive horticulture is associated with high input use and above-standards pesticide residues on marketed products	Unselected rubber germplasm has only 25% of yield of selected clones	High input use; yield reduced by episodic crop loss
Efficiency gap issues, environmental impacts	Recent start of fertilizer use; main pollution of rivers due to small-scale mining for gold	Intensification leads to environmental damage, pollution concerns and high chemical residues of marketed crops	Shifting staple food production to other areas ('outsourcing') with a marketable surplus externalizes pressure on forests; current trends to intensify and simplify leads to loss of on-site biodiversity	Slope stability, erosion, and fertilizer residues are major issues, affecting downstream lives

of Kalimantan, with a production cycle starting in a rice-based swidden, are an example of this configuration. They have long been proven to be a suitable land-use option that successfully integrates the cultivation of staple foods (rice, maize, or cassava) for primarily subsistence purposes and cash crop production, and at the same time allows for ecological services by using forest analogues as major land use (Fried, 2000; Godoy, 1990; Joshi et al., 2003; Mulyoutami et al., 2009). Like other agroforestry systems rattan gardens provide diverse ecosystem services, such as hydrological regulation, soil protection, carbon sequestration and biodiversity conservation (Matius, 2004).

In recent years, however, rattan management has changed and rattan gardens have been converted to mainly rubber and palm oil, in consequence of an unfavourable political economy of rattan that depresses farmgate prices in support of domestic processing (Belcher et al., 2004; Bizard, 2013; Pambudhi et al., 2004). A recently conducted comparative study amongst Ngaju Dayak rattan farmers in Katingan district in Central Kalimantan documented these changes and their consequences for local food production and consumption (Bizard, 2013).

2.1.1. *Local meaning of food security*

In the upland village of Tumbang Malawan, so-called rattan swiddens (*taya uwei*) form an integral part of people's land management, and thus local food security. Apart from providing rice, maize, cassava and vegetables for subsistence consumption for one or two seasons, after 7–10 years, rattan harvesting allows farmers to obtain cash income for buying goods – provided that the rattan price is attractive. Young rattan shoots are cooked as vegetable; fruits are edible. Rattan swiddens moreover contribute to people's diet and health as they serve as hunting ground and for collecting fuel wood, forest foods, and medicinal plants. Even though harvests vary from season to season, Bizard (2013) found that 79% of all households could cover their rice needs on a subsistence basis during the 2012/2013 cycle. In addition to securing staple foods and vegetables, during land preparation and planting farmers collect all kinds of foods (e.g., mushrooms, fruits, rattan and bamboo shoots and other vegetables), pig fodder, medicinal plants, seedlings for transplanting and fuel wood. In a similar way, fallow lands directly and indirectly contribute to people's diet throughout the year. The importance of swiddening for local food security is frequently expressed by villagers by saying, "If we don't practice swiddening, we don't eat" (*Amun dia malan, dia kuman*).

This contrasts the situation in the downstream village of Tumbang Runen. Here, local rattan farmers "have been practicing swiddening on trading vessels for decades", i.e., to cover their rice needs people have since long been dependent on market purchase, with money earned by rattan sales (Bizard, 2013). In 1960s and the beginning of 1970s, people were still engaging in swidden activities along the shallow alluvial soils along riverbanks that usually involved the establishment of rattan gardens. From the 1970s onwards, however, swiddening increasingly came under pressure owing to scarcity of fertile soils in an environment of mainly peatland and the unpredictable flooding and recurrent fires in consequence of upriver and in situ logging. People's dependence on cash income and the market increased. While throughout 1980s and the beginning of 1990s villagers could make a living from rattan yields, from the mid-1990s till 2006 needs were met with income from logging. Nowadays, most people live of fishing and palm oil wage labour. Apart from small plots of maize, cassava and vegetables swidden activities as well as rattan labour hardly contribute to food security in Tumbang Runen. Although established rattan gardens remain largely unmanaged in face of a low rattan price and alternative livelihood options, they still are important for local food security as a source of other resources. Flooded rattan gardens serve as a spawning ground for fish populations that are the most important source of both protein and cash. Just as any other kind of cash labour, fishing yields translate for villagers into food security, because "[i]f you don't work, you don't eat" (*Amun dia bagawi, dia kuman*).

2.1.2. *Role of trees and forests in food security*

While rattan has been mostly discussed as a non-timber forest product, policy-makers have started recognizing the significant role that swiddening can still play for environmental services (Bruun et al., 2009). First steps must include the acknowledgement of swiddening as potentially rational land management rather than as a land use of the past that needs to be rapidly abolished (Ellen, 2012; van Noordwijk et al., 2008). Rattan agroforests start to be recognized as managed garden systems with forest-based biodiversity in many taxa compatible with natural forest. The current policy framework on international rattan exports needs revision as it regulates and taxes all rattan as forest product, regardless of its origin.

2.1.3. Interactions of productivity growth and environmental services

The conversion of these land management systems to rubber and palm oil monocultures (with very low levels of forest-based biodiversity) means the loss of both ecosystem services and availability and diversity of local food sources, and changes the traditional food consumption pattern, not to mention the socio-cultural repercussions that such a transition may have when being enforced rather than evolving (van Noordwijk et al., 2008).

2.2. Configuration II: short-fallow rotations and permanent agriculture interacting with forests

In contrast to the intensification patterns where the fallow phase becomes the major source of income through forest resources and/or as grazing land, there are many places where the cropping phase allowed market integration and commercialized agriculture, often leading to a shortening of the fallow, with consequences for soil fertility, weeds and pest and disease pressure. Our example of this phase, Northern Thailand, is part of montane mainland Southeast Asia.

2.2.1. Local meaning of food security

Upland rice as a staple crop became historically combined with opium as high value-per-unit-weight cash crop, suitable for remote locations, out of reach of effective political control. In the past few decades, however, semi-permanent and permanent commercial agricultural practices growing cash crops such as cabbage, corn (mostly for animal feed), soybean, and recently rubber have gradually replaced the swiddens (Thomas et al., 2002). Food security is largely seen to depend on income security, with the reach of markets substantially increased in recent decades. In the Mae Chaem study area in North Thailand, crop production with short fallow periods (3–5 years) replaced swiddening with fallow periods of more than 10 years. Wangpakapattanawong (2001) reported that a fallow period of 5 years was still sufficient for soil fertility in the first year of cropping, but there are no published studies on shorter fallow periods than 5 years. Tienboon et al. (2008) compared food security and child health in swidden/fallow systems with short (5 years) and long (12 years) fallow periods. With rice as the staple food, other food groups provide the main fat and protein sources from elsewhere in the landscape and/or obtained by trade. A number of health and nutrition problems exist, such as second-degree malnutrition, insufficient iron and vitamin A, parasitic infestation, and poor sanitation (Tienboon et al., 2008). The commercial agricultural system with more market integration was shown to be more food secure, with less health and nutrition problems. The commercial farmers, however, might be facing other forms of health problems, such as mother-to-child transfer of harmful chemicals through breast feeding (Stuetz et al., 2001). This could also be the case with recent land-use intensification with corn and rubber.

2.2.2. Role of trees and forests in food security

In the local knowledge and institutions, there are multiple types of forests, some of which are a part of the swidden cycle, others, such as the 'forests above rice-fields' and 'sacred forests' explicitly not (van Noordwijk et al., 2004). The swidden/fallow practices with medium (5–10 years)-to-long (more than 10 years) fallows have recently been recognized in Thai policy discourse as environment friendly as they do not exploit the soils too heavily and they require little extra chemical inputs.

2.2.3. Interactions of productivity growth and environmental services

While total forest cover did not change much, the type and spatial distribution of forests did, with a noted coarsening of the previously fine-grained spatial pattern. Large blocks of 'agriculture' now alternate with blocks of 'forest' in a spatially segregated landscape (Castella et al., 2013; Hoang et al., 2014). The segregation of forest and agriculture happened in response to an institutional split, with a forest authority allowing intensive logging, but excluding swiddening. The reduction in length and subsequent abandonment of fallowing implied and was only possible through the technical substitution by chemical fertilizer of the 'supporting service' of soil fertility replenishment that the forests previously provided. The roles of forests in regulating water flow for local food production became less important with the spatial segregation as well (van Noordwijk et al., 2004; Thanapakpawin et al., 2007). Dams and reservoirs provided a technical substitute for landscape-based buffering of water flows for downstream users. As reservoirs are managed, however, to be full at the expected end of the rainy season, they have no buffer capacity left at that time of the year and additional rainfall can lead to downstream flooding. The new addition of monocultural rubber plantation to this landscape is likely to complicate the issues on land management. Rubber trees require constant water availability throughout the year as they are potentially evergreen. Montane mainland of Southeast Asia annually faces water shortage in the dry season.

2.3. Configuration III: agroforests and changes in integrated agriculture–agroforestry–forest transitions

The transition from an enriched forest fallow that provides a source of additional income to an agroforest that is the primary source of livelihoods through income that allows purchase of the staple food, described above as recent change along the Katingan river, took place in Jambi province (Sumatra) in the first two decades of the 20th century, during the post-World War rubber boom (van Noordwijk et al., 2012b).

2.3.1. Local meaning of food security

While some local rice production persisted and maintained a gender-differentiated social value as source of food security (Van Noordwijk et al., 2008; Villamor et al., 2014a), economic rationality suggested in most years that the rubber:rice price ratio allowed reliance on rice imported from elsewhere. Rubber agroforests in combination with reliance on trade for more than half of the staple food (rice) needs have been maintained for a long time as the agroforests provide tradable goods, such as rubber latex, and local needs such as timber, firewood, fruits, vegetable and medicine (Tata et al., 2008). The role of rubber agroforests in providing food (including hunting) was well recognized by farmers in three villages in Jambi as part of a global comparison of landscape mosaics (Pfund et al., 2011). Tata et al. (2008) reported that 64% of tree species occurring in rubber agroforestry in Jambi belong to species with edible parts, while such trees form only 18% of the forest vegetation. Selective retention of trees considered useful is the basis of this difference, while the surrounding forest has, at least until recently, provided a sufficiently diverse 'seed rain' allowing farmers to obtain a diverse agroforest rich in local fruit trees without planting efforts. Food tree species included species with edible fruits, species that produce edible nuts and those that produce spices. Trees with commercially viable gums are also part of the agroforest, obtained by selective retention of saplings and pole-sized trees from a forest seed source.

2.3.2. *Role of trees and forests in food security*

Rubber agroforests maintain hydrological functions of the river as quantified in the flow-persistence metric (van Noordwijk et al., 2011). Rubber agroforests have a threefold lower latex productivity per unit area than rubber monoculture with selected clones and good management (Wibawa et al., 2005), but returns to labour are similar and risk of establishment failure is less (Joshi et al., 2003). The potential intensification of rubber agroforests is thus a prime example for the spare-or-share, segregate-or-integrate discussion (van Noordwijk et al., 2012b, 1997). The high biodiversity of agroforests can be maintained alongside acceptable returns-to-labour for rubber tapping (Joshi et al., 2003; Tata et al., 2008) and opportunistic harvest and sale of other products when in season. Conversion of agroforests to rubber monoculture and oil palm is constrained by lack of investment capital and (perceived) risks of failure. Agroforests may survive in the landscape only if external stakeholders of global biodiversity, such as European and North American consumers of processed rubber in the form of car tyres and other products, economically appreciate the biodiversity-friendly rubber production systems (Pfund et al., 2011), which ongoing action research and agent-based modelling is trying to achieve (Villamor et al., 2014a).

2.3.3. *Interactions of productivity growth and environmental services*

Currently Jambi is in a next transition configuration of the landscape from complex agroforest to simpler agroforest and monocultural plantations of rubber and oil palm (Villamor et al., 2014a). In the 1990s the net change was that forests were lost and rubber monoculture and oil palm plantation increased while rubber agroforest area remained constant. More recently, agroforests became the main target of conversion, as remaining forests were better protected (Dewi et al., 2013). Nowadays, when farmers have more financial capital to invest, they tend to shift from mixed rubber (complex) agroforests (Joshi et al., 2003) to monoculture rubber and oil palm (Pfund et al., 2011, van Noordwijk et al., 2012b). This shift increases the outsourcing of local food needs from rice to more perishable components of the local diet.

2.4. *Configuration IV: permanent agriculture finding the limits to intensification*

Configuration four represents further landscape intensification, generally associated with higher human population density. Our example of configuration four represents further landscape intensification and much higher human population density. In this part of the forest transition curve environmental disaster scenarios can lead to shock effects that precede change. Forest remnants, mostly at high elevation, play some role in landslide prevention, but do not have much effect on the neighbouring crop fields, as could be observed during the past decades on the densely populated island of Java in Indonesia with its volcanic activity and fertile, geologically young soils. The Dieng Plateau of Wonosobo District is well known as a production centre of potatoes in Indonesia, supplying the urban markets. Growth in potato production in Asia in the 1990s has averaged 5.1 per cent per year, as demand for potatoes increased along with the changes of urban lifestyles. Potato now represents more than half of the Gross Regional Domestic Product of Wonosobo district. It reaches urban markets all over Java, enriching urban diets.

2.4.1. *Local meaning of food security*

A detailed land use history of the area (Sumedi, 2010) showed two waves of human occupation: a phase from 8th to 13th century when all current temple ruins were created, followed by abandonment and reoccupation starting around 1800. Local informants reconstructed the local land use history as follows: in 1980, potato was introduced by the traders from West Java who previously mostly bought cabbages from local Dieng farmers. At that particular time, the Dieng farmers cultivated tobacco, *pitrem* (local white lily flower) and vegetables, such as cabbage, onion and peanuts. Market integration has had a long history here, providing sufficient income to buy the preferred staple (rice) from lower-elevation landscapes. The West Java traders rented and bought lands from the local farmers, moving to Dieng because the potato productivity in West Java had decreased. This experiment from West Java farmers proved successful as potato productivity was higher than in West Java. Faced with the success, local Dieng farmers took over the ownership. High financial income in this landscape does not seem to be correlated with local food security. As an example, local news reported that there were at least 23 babies and toddlers suffering poor nutrition in Kayugiyang, a village in Wonosobo.

2.4.2. *Role of trees and forests in food security*

On the Dieng Plateau forest declined from 22% in 1991 to 13% in 2001 and 6% in 2006, with ‘shrubland’ increasing from 20% to 30% of the area and agriculture approximately constant at 52% (Rudiarto and Doppler, 2013). The recent peak of forest clearing in the area can be directly traced to the sedimentation pattern of a major reservoir downstream (Lavigne and Gunnell, 2006). Various attempts to protect the forests in the area failed to contain encroachment, as potato production proved to be highly profitable. Episodic catastrophes with human victims due to volcanic gas eruption do not stop people from returning as soon as immediate danger seems to be reduced. With most of the potentially arable land already utilized, input-based intensification is reaching its technical or even economic limits and soil degradation becomes a central issue; soil loss from agricultural lands, shrubland and forest in the area are estimated to be 303, 101 and 2 $t\,ha^{-1}\,yr^{-1}$, respectively (Rudiarto and Doppler, 2013). During intensive rainfall episodes major landslides and in-field erosion on slopes without deep-rooted tree cover have led to loss of soil fertility and downstream mudflow damage. In 2009, 126 landslides were recorded, more than double the number of 57 landslides in 2007. While remaining forests in strategic landscape positions can play some role in avoiding worst-case scenarios at this stage of land use intensification, it cannot compensate for in-field erosion in the vegetable production systems. Contour hedgerow systems that control erosion will reduce the direct farmer income.

2.4.3. *Interactions of productivity growth and environmental services*

Efforts to control erosion rely on a combination of persuasion and land use regulations. Economic incentives for land use systems that effectively conserve soils on the slopes are beyond the financial reach of the local government, as opportunity costs are high. Elsewhere on Java, however, watershed rehabilitation efforts have had success in returning tree cover to landscapes and in achieving a more buffered river flow, as in Kali Konto (Lavigne and Gunnell, 2006; Lusiana et al., 2012).

3. Discussion

The above reviews of the four configurations brought out key differences in the way the dual objectives of food security and environmental services (Fig. 1) appear to be in conflict, yet can be achieved jointly (Table 2). The opportunity for outsourcing local staple food needs through engaging in local markets that may interact with national and global ones is key to the options farmers have and the decisions they make. Externalization of activities for which other entities have a comparative advantage in a market economy can be compared to 'outsourcing' (Grossman and Helpman, 2005): it involves decisions not only to buy on the market what was previously produced in-house, but also to disinvest in associated production factors, considering the longer-term risks involved. The transition from local to externalized production of the main staple food in our configuration I example may have occurred much earlier than is generally recognized in the discourse on food security. The option of returning to local food production in times of economic shocks and political turbulence is retained in many landscapes. Gender specificity in the appreciation of locally produced food is part of the social and cultural fabric, with inheritance of rice-fields in the female line alongside male-dominated inheritance for other lands documented for parts of Sumatra by Suyanto et al. (2001). Gender-specificity of decision making may involve differences in objectives, knowledge, availability of alternatives and socially accepted choices (Villamor et al., 2014b), requiring further analysis. Food security is determined by income security in most of the Asian landscapes, even in distant forest locations and places with income earning opportunities based on specialization on (locally domesticated) forest products and introduced tree crops such as coffee, cacao, rubber, oil palm, alongside retention of useful (fruit) trees that establish spontaneously as part of the tree diversity transition (Ordonez et al., 2014).

Zomer et al. (2014) reported that over 40% of agricultural lands globally have more than 10% tree cover, with a positive trend over the past decade. Tree cover at landscape and farm level influences the micro-climatic conditions experienced by crops and livestock. The past reduction of this buffer by loss of trees due to crop-based intensification at a time that climate change increases variability and the need for buffering (van Noordwijk et al., 2014b) may well lead to a reconsideration of past choices. Tree cover and forest-based biodiversity are partially correlated, but diverge where intensive near-monocultural tree crops and plantation forestry emerge. Beyond direct interactions with annual food crops, this tree diversity may support nutritional diversity, especially of vulnerable age groups. It is tempting to interpret the results of Ickowitz et al. (2014) who found positive correlations of child nutrition and landscape-level tree cover (up to about 50%) in Africa to the dietary diversity support of local fruit production; further ground level analysis of case studies is needed (and has been initiated) to test alternative explanations.

In terms of environmental impacts the hydrological consequences of land cover change, and associated erosion/sedimentation, are likely to be the most immediately relevant for local livelihoods and food production (Lavigne and Gunnell, 2006), but biodiversity is the most compelling aspect in terms of loss of natural capital with irreversible consequences. With current global discussion on all-encompassing sustainable development goals (Mbow et al., 2014), the 'tree diversity transition' dimension of overall forest transition can be used as proxy for the wider biodiversity issues (Ordonez et al., 2014), including the diversity of local fruit trees that enrich diets and reduce malnutrition.

Meyfroidt and Lambin (2012) showed on the basis of global trade statistics that a change from net deforestation to net increase in reported forest area across all countries that have made that transition in the past decades has been accompanied by an increase in external footprint (net of export and import) of agriculture and forestry, by lowering exports and/or increasing imports. In configuration IV, intensification of agricultural land use surpasses local standards of environmental services, but taking farm land out of production to enhance conservation requires external incentives or regulation, on behalf of local public interest. Further quantification of the multiple dimensions of land use intensification, beyond the use of a single overall index (van Noordwijk and Budidarsono, 2008) is needed to clarify the choices for society at large and to fine-tune national policies that deal with food security and environmental services at a different level from the farmers we focussed on here.

4. Conclusions

Our discussion of food security aspects of land use in four configurations of agriculture, forest and agroforestry, based on landscape examples in Southeast Asia has shown a transition from local determinants of sufficiency of production, to market-based livelihood strategies where income security is the primary driver of food security, even in remote places. In parts of this transition, forests and agriculture are seen as opposites, as in the 'land sparing' discourse, but elsewhere the intermediate tree-cover land uses that are generically labelled as agroforestry offer integrated 'land sharing' options to the double objectives of food security and environmental services. The largely qualitative discussion provided here can be used to construct and test quantitative hypotheses, but the multiple faces (and associated potentially ambiguous terminology) of the primary concepts of 'food security,' 'environmental services,' 'forests,' 'agroforestry' and 'sustainable development' are a challenge. Understanding the flexibility of the human mind and livelihood strategies needs to accompany the rigorous quantification and analysis that is so far confined to partial approaches of the overall complexity of the relationship between tree cover transitions and food security in multifunctional landscapes.

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