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Surveys

Economic and ecological trade-offs of agricultural specialization at different spatial scales

Stephan Klasen [a], Katrin M. Meyer [b,*], Claudia Dislich [b], Michael Euler [c], Heiko Faust [d], Marcel Gatto [e], Elisabeth Hettig [b,f], Dian N. Melati [g], I. Nengah Surati Jaya [h], Fenna Otten [d], César Pérez-Cruzado [g], Stefanie Steinebach [i], Suria Tarigan [j], Kerstin Wiegand [b]

[a] *Department of Economics, University of Göttingen, Platz der Göttinger Sieben 3, 37073 Göttingen, Germany*
[b] *Ecosystem Modelling, University of Göttingen, Büsgenweg 4, 37077 Göttingen, Germany*
[c] *Department of Agricultural Economics and Rural Development, University of Göttingen, Platz der Goettinger Sieben 5, 37073 Goettingen, Germany*
[d] *Department of Human Geography, University of Göttingen, Goldschmidtstr. 5, 37077 Göttingen, Germany*
[e] *Department of Agricultural Economics and Rural Development, University of Goettingen, Platz der Göttingen Sieben 5, 37073 Göttingen, Germany*
[f] *GIGA German Institute of Global and Area Studies, Institute of Asian Studies (IAS), Neuer Jungfernstieg 21, 20354 Hamburg*
[g] *Forest Inventory and Remote Sensing, University of Göttingen, Büsgenweg 5, 37077 Göttingen, Germany*
[h] *Forest Resources Inventory and Remote Sensing, Bogor Agricultural University, Kampus IPB Darmaga, 16680 Bogor, Indonesia*
[i] *Institute of Social and Cultural Anthropology, University of Göttingen, Theaterplatz 15, 37073 Göttingen, Germany*
[j] *Department of Soil Sciences and Natural Resource Management, Bogor Agricultural University, Indonesia*

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ABSTRACT

Specialization in agricultural systems can lead to trade-offs between economic gains and ecosystem functions. We suggest and explore a conceptual framework in which economic gains can be maximized when production activities are specialized at increasingly broader scales (from the household to the village, region or above), particularly when markets for outputs and inputs function well. Conversely, more specialization likely reduces biodiversity and significantly limits ecosystem functions. When agricultural specialization increases and moves to broader scales as a result of improved infrastructure and markets or other drivers, ecosystem functions can also be endangered at broader spatial scales. Policies to improve agricultural incomes may influence the level of specialization at different scales and thus affect the severity of the trade-offs. This paper takes Jambi province in Indonesia, a current hotspot of rubber and oil palm monoculture, as a case study to illustrate these issues. We empirically show that the level of specialization differs across scales with higher specialization at household and village levels and higher diversification towards the province level. We discuss ways to resolve trade-offs between economic gains and ecological costs, including landscape design, targeted policies, and adoption of long-term perspectives.

1. Introduction

For poor smallholder households that depend largely on the use of natural resources for their livelihood, increasing agricultural incomes is critical to escape poverty (Lipton, 2005; World Bank, 2007; Klasen et al., 2013). In an environment of well-functioning markets and infrastructure, a possible economic option to increase incomes is to specialize on the most profitable crop for given soil, climate, and weather conditions (Lambin and Meyfroidt, 2011; Ruiz-Perez et al., 2004).

At the same time, there are some costs and constraints to complete specialization which partly relate to land tenure, farm size, social capital stocks, and idiosyncratic decision making of farmers, and partly relate to the availability, access, and functioning of markets for inputs, outputs, labor, and credit. For example, complete specialization often requires highly seasonal labor demand which often cannot be procured locally; similarly, concentration on one crop exposes farmers to high risk against which they can only imperfectly insure themselves (Di Falco and Chavas, 2008; Abson et al., 2013); third, jointness in production can also lead to advantages of diversified production (Allen and Lueck, 1998; Ballivian and Sickles, 1994; Klasen and Waibel, 2012; Kurosaki, 2003).

However, the better labor, capital, insurance, input, and output markets function, the lower are these constraints to specialization. If, for

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* Corresponding author.
E-mail addresses: sklasen@uni-goettingen.de (S. Klasen), kmeyer5@uni-goettingen.de (K.M. Meyer), cdislic@uni-goettingen.de (C. Dislich), michael.euler@agr.uni-goettingen.de (M. Euler), hfaust@uni-goettingen.de (H. Faust), mgatto@uni-goettingen.de (M. Gatto), elisabeth.hettig@giga-hamburg.de (E. Hettig), dmelati@uni-goettingen.de (D.N. Melati), ins-jaya@cbn.net.id (I.N.S. Jaya), fotten1@uni-goettingen.de (F. Otten), cperez@gwdg.de (C. Pérez-Cruzado), ssteine@gwdg.de (S. Steinebach), surya.tarigan@yahoo.com (S. Tarigan), mail@kerstin-wiegand.de (K. Wiegand).

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example, seasonal labor demand can be met with migrant labor, farmers have access to insurance, and improved infrastructure promotes intra-regional and international trade in competitive input and output markets, these constraints to specialization at increasingly broader scales are much less serious and specialization at increasingly larger scales becomes an important route to improve farm incomes, also for smallholders (Kurosaki, 2003). In the extreme, this could lead to monocultures not only at the level of the individual household, but at the level of the village, or even region. Hence, the degree of specialization may change along spatio-organizational scales depending on market functioning (Fig. 1).

To be sure, this discussion so far focuses on the economic rationale for specialization of the individual farmer. Of course, other drivers of specialization can often also be operative and they often relate to politics and power. For example, large and politically well-connected land owners might push specialization through evicting subsistence farmers or specialization might be promoted by subsidies for particular cash crops, again benefiting particular groups of farmers (e.g. Pritchard, 2013; Binswanger and von Braun, 1991; Binswanger et al., 1995). Thus policies, politics, and power can also influence the degree of specialization either directly or indirectly via their influence on market functioning (Herath and Weersink, 2009). While these instances can be important drivers of specialization in particular circumstances, we want to focus here on the possible dilemma posed that improvements in the functioning of markets can provide increasingly powerful economic incentives for specialization even without such political interference by the powerful.

This can pose a dilemma since, at the same time, there can be substantial ecological and also socio-cultural costs in terms of reduced ecosystem functions and services if such monoculture agricultural systems emerge at the level of a village or an entire region. Ecosystem functions are the capacity of natural processes to provide goods and services that directly or indirectly satisfy human needs (De Groot et al., 2002). There might be losses in plant and animal biodiversity (Foster et al., 2011), but also reduction of pollination services (Priess et al., 2007) or biological pest control (Stamps and Linit, 1997) as well as hydrological functions (Comte et al., 2012; Nedkov and Burkhard, 2012; Ojea et al., 2012). Decomposition services and carbon sequestration may possibly be impaired, too. Furthermore, information functions or cultural services may be lost (Gasparatos et al., 2011; Millennium Ecosystem Assessment, 2005). These losses crucially depend on the level of scale at which specialization on monoculture crops occurs, with specialization at broader scales generating more problems. There can also be a mismatch on a temporal scale: In the short term, the progressive loss of ecosystem functions and associated services may only have a small impact on the profitability of specialized monocultures; in the longer-term, the sharp reduction or entire disappearance of important functions might, however, undermine the profitability of monocultures at broader spatial scales.

The economic, socio-ecological, and cultural consequences depend therefore, to a large extent, on the spatial scale at which specialization occurs. For example, specialization within a village at the level of an individual farm might already generate some benefits of specialization for the respective farmer with few ecological costs compared to broader-scale specialization if the diversity of crops remains high within a village. Fig. 1 illustrates this point by showing two scenarios: one where poorly functioning markets allow only specialization at the household level; economic benefits of specialization are low but ecosystem functions are high. In scenario two, well-developed markets allow specialization at the regional level generating higher benefits but specialization at this broader scale reduces ecosystem services (see also Timmer, 1997). This development of specialization can also be driven or exacerbated by policies, politics and power. For example, policies can actively promote monocultures through supporting and subsidizing the development of cash crops in particular regions; in the case of Indonesia discussed below, the promotion of the palm oil sector was supported by various policies of the government, including migration policies, land policies, or infrastructure (McCarthy and Cramb, 2009). In addition, however, policies aimed primarily at promoting growth and poverty reduction may also affect this trade-off between economic benefits and socio-ecological and cultural consequences of specialization. For example, policies to improve access and functioning of markets (e.g. through improved infrastructure, information systems) are likely to increase the economic benefits of specialization as they may increase the scope for specialization for poor producers, but such policies might cause harm from an ecological point of view as they push specialization to a broader spatial scale.

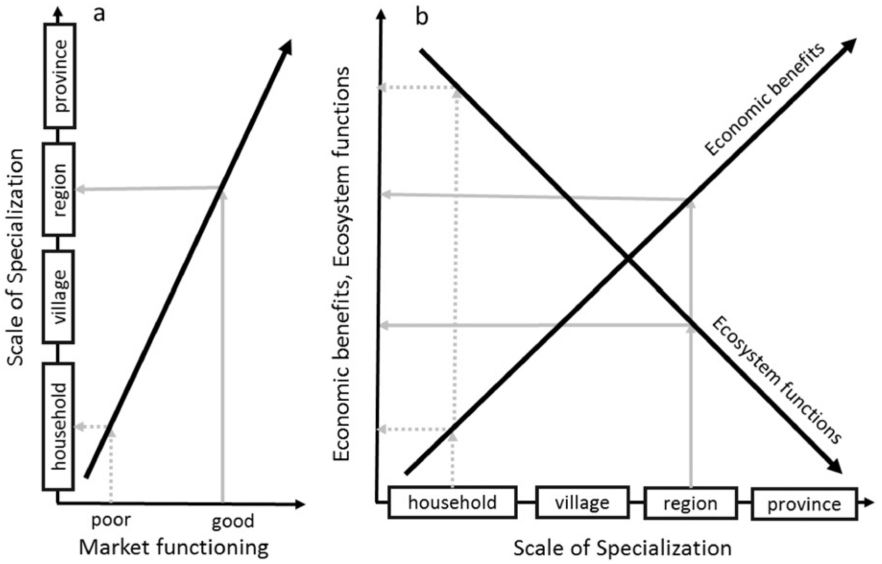

Fig. 1. Market functioning can drive the level of scale at which specialization occurs (a), which in turn drives economic benefits and ecosystem functions (b; black arrows). Other drivers (not depicted here) such as policies, politics and power may influence the scale of specialization either directly or via their influence on market functioning. Two scenarios are illustrated (grey arrows): In the poor market functioning scenario (dotted grey arrows), specialization is only possible at the household level (see a) which leads to low economic benefits and high ecosystem functionality (see b). In the scenario with good market functioning (solid grey arrows), specialization is possible at broader scales such as the region (see a). This leads to loss of ecosystem functions and high economic benefits compared to the poor market functioning scenario (see b). Note that in this illustration the location of the crossing of the arrows is arbitrary. The general message is that there is a scale-dependent trade-off between specialization and ecosystem functions driven by market functioning.

Some of these issues have been studied individually in both the economics (e.g. Belcher et al., 2004; Hazell and Wood, 2008; Kurosaki, 2003; Ruiz-Perez et al., 2004; Timmer, 1997) and ecological (e.g. Lambin and Meyfroidt, 2011; Smith et al., 2008) literature. Many studies have also commented on the general trade-offs between intensive agricultural production and the loss of ecosystem services (e.g. Evans, 2009; Hazell and Wood, 2008; Lambin and Meyfroidt, 2011; Millennium Ecosystem Assessment, 2005). However, the interplay of specialization and ecosystem functions and services at different spatial scales, and how they are influenced by markets and policy has not been studied at any level of detail so far. The purpose of this conceptual paper is to lay out these issues and the ensuing trade-offs between economic benefits and ecosystem functions at different scales and illustrate them with examples from the literature and with on-going research on oil palm plantations in the province of Jambi in Indonesia.

2. Optimal Specialization from an Economic Perspective

Economic benefits of specialization are very closely linked with the presence of economies of scale in production. Economies of scale are defined as the advantage of large-scale production that results in lower costs per unit of output (Kislev and Peterson, 1996). Hence, the total production costs are spread over more units of output. Economists tend to distinguish between internal economies of scale and external economies of scale (Hallam, 1991; Marshall, 1920). Internal economies of scale are cost advantages due to conditions inside the production unit (e.g. the farm or the firm), while external economies of scale are cost advantages from greater production of a sector or region (or even an entire economy, Caballero and Lyons, 1990). In the case of agriculture, both internal as well as external economies of scale can be present.

For the case of cash crop agriculture, we identify four most relevant *internal* economies of scale. Firstly, the increasing scale of production can reduce outlays per unit of output, for example in purchasing chemical inputs or in reducing transportation and processing costs - especially, if distance to input and output markets is high. Second, internal economies of scale can result through the indivisibility of machines since the use of a more powerful machine, e.g. a tractor, is only profitable for larger plantations. Third, larger production units can sometimes employ workers with more specialized knowledge, for example in the application of chemical inputs (even though this seems not to be the case in our example in Jambi, see Section 4). Lastly, a finer division of labor is possible which might increase the efficiencies of performing tasks and facilitate the monitoring of labor in completing these tasks.

Given these potentially large internal economies of scale, the question of optimal farm size arises. If these economies of scale are so substantial, why does cash crop production not take place exclusively on large plantations? And why do smallholders survive in the face of the cost advantages of large plantations? This is because large production units in agriculture also have to contend with substantial diseconomies of scale (e.g. Allen and Lueck, 1998; Binswanger et al., 1995; Lipton, 2005). They are due to the need for large farms to rely on hired labor where principal-agent problems (Levinthal, 1988), information and incentive problems might lead to high costs of monitoring labor and/or low labor effort and productivity. As a result, the family farm has remained a competitive production unit where these information and incentive problems are much less prevalent. As argued by Binswanger et al. (1995), large plantations will prevail if the economies of scale in processing are substantial (as is the case, for example, with bananas and tea) and/or when smallholders cannot easily be linked to larger processing facilities, as is possible in some cases in our case study (see Section 4). A key message emerging from this discussion is that internal economies of scale generate substantial benefits for farms to specialize on one output, even if it is not optimal for production to take place exclusively on large plantations (see also Herath and Weersink, 2009).

A key driver for *external* economies of scale in cash crop agriculture is the total growth of the respective crop industry in a particular region. This facilitates the development of local processing industries and the development of transportation facilities; both reduce transport costs and promote trade. Growth of the industry in a local area can also help develop and improve the functioning of input, output, and factor markets by ensuring more volume of transactions in these markets which will increase the number of participating actors, thus promoting competition as well as lowering transaction costs. Lowered transaction costs further promote trade and allow an increasing separation between production and consumption of agricultural households (Timmer, 1997): production is specialized on the most profitable crop given soil and climatic conditions, while consumption of food and other needs is procured through trade.

Despite these substantial scale advantages in production, there are barriers and limits to specialization on one output. One limit can be product-specific. For example, joint production of several outputs can be technically optimal (e.g. in the case of inter-cropping or crop rotation to optimally use existing soil resources or preserve/improve soil fertility, e.g. Ballivian and Sickles, 1994). It may also be the case that local heterogeneity of soil, water, and weather conditions recommend a more diversified portfolio of optimally adapted outputs. Second, resilience in production over time is usually a key concern of smallholders (Chuku and Okoye, 2009). A resilience-oriented strategy would promote a diversified output portfolio. Third, there may be an intrinsic value attached to maintaining a diversified portfolio of output, particularly also if these portfolios ensure adequate provisioning of households with the most important necessities and/or the diversified portfolio has itself ethnic or cultural significance (Laird et al., 2011). Socio-cultural ecosystem services have been recognized in many studies (de Groot et al., 2002; Millennium Ecosystem Assessment, 2005). Nevertheless, cultural aspects too often have been neglected in the ecosystem services assessment (Chan et al., 2012; Schaich et al., 2010) and therefore the analysis of land-use and landscape development may produce misleading results. Altogether, however, non-material benefits and intrinsic values related to culture and ethnicity as well as the social embedding or sentimental attachment to places usually constitute limits to specialization.

Apart from these technical and socio-cultural limits to specialization, the main other basic constraint to complete specialization relates to the functioning of markets and the associated transaction costs of engaging heavily with input, output, and factor markets. If transport costs are high and labor markets absent, farmers will maintain a diversified portfolio of outputs at a local scale that includes all major food necessities (Timmer, 1997). Production decisions will then also be made depending on the availability of family labor; and a diversified portfolio will be beneficial if labor demands can then be spread over the year. Moreover, concentration on one crop can be risky as there are high output and price risks; in the absence of functioning markets for credit and insurance, such risks can devastate farmers if production fails or prices fall (Klasen and Waibel, 2012; Morduch, 1995; Ray, 1999; Di Falco and Chavas, 2008; Abson et al., 2013). Since poor farmers live close to subsistence, the absence of well-functioning credit and capital markets will be one reason for them to rely on a diversified production portfolio to reduce these risks (Morduch, 1995). Also choosing crops that are particularly resilient to shocks and risks will then be an important concern for farmers (Chuku and Okoye, 2009).

Conversely, this implies that improvements in the functioning of these markets could reduce those constraints to specialization, which could enable also smallholder farmers, including poor ones, to specialize much more. They can then increasingly rely on credit and insurance markets to deal with production and price risks, they can rely on labor markets to deal with seasonal labor demand problems, and they can ensure reliable access to food and other needs through trade. With well-functioning markets, potential competitive advantages due to local environmental conditions favoring one particular crop can be realized at the level of scale that shares these conditions. If the local or regional variability in environmental and soil conditions is low, or a particularly lucrative crop can profitably be grown in landscapes with some environmental and soil variety, this could lead to complete specialization at quite a broad spatial scale.

Of course, these markets will never function perfectly and not all farmers may benefit from improved physical access to markets due to unfavorable power relations, prevailing societal structures or high transaction costs for access (Poulton et al., 2010), but the point to emphasize here is that as the functioning of these markets improves, specialization may become economically more attractive. Moreover, specialization can then move to a broader spatial scale. In particular, if input, output, and labor markets improve substantially, complete specialization on one cash crop may move from the household and the village level to the regional or even national level.

A related point of note is that policies that improve the functioning of input, output, labor, capital, and insurance markets are likely to promote this specialization at an increasingly broader scale. Thus, while these policies may be beneficial to smallholder producers as they promote higher and more stable incomes (while also providing benefits to traders and international investors), they will come at a cost of increasing specialization and monocultures at broader spatial scales with important consequences for ecosystem functions and services.

3. Ecological Consequences of Specialization

Specialization leads to monocultures, and monocultures are usually less beneficial for ecosystem services and associated biodiversity than more diverse polycultures. In addition, specialization often leads to intensification which is typically accompanied by higher inputs and the removal of remnant vegetation, and may lead to ecosystem simplification and loss of quantity and quality of products and services (Günter et al., 2012). A range of provisioning, regulating and supporting ecosystem services can potentially be affected by the reduction of crop diversity towards monocultures. Provisioning services such as crop production may suffer significant losses due to reduced crop diversity (Di Falco et al., 2007; Smith et al., 2008). In the long run, high fertilizer inputs may lead to eutrophication (Tilman et al., 2001) and altered soil physical characteristics and microbial communities. This may also reduce production services. Mediated by reduced crop production following low crop diversity, specialization could thus even threaten food security (see also Palmer and Di Falco, 2012), at least for subsistence farmers and at local scales unless product markets are, as discussed above, able to provide sufficient food diversity at affordable costs. Regulating ecosystem services such as biological pest control may also be more efficient in polycultures or when remnant vegetation is present. For instance, most insect herbivore species have lower densities in polycultures than in monocultures (review on 287 species in 209 studies by Andow, 1991). Complex agronomic multicropping systems have lower pest insect populations than simpler systems (Stamps and Linit, 1997). Temperate forests that consist of multiple tree species have fewer pest outbreaks than single-species stands (Stamps and Linit, 1997). However, supporting services such as soil fertility and regulating services such as nitrogen-use efficiency have been shown to depend more on management than on crop diversity (Snapp et al., 2010). A reduction of coffee yields due to declining pollination services under diversity loss due to deforestation may be counteracted by preserving patches of forest (Priess et al., 2007). Hence, specialization can have positive or neutral effects on some ecosystem services, but in most cases, specialization reduces ecosystem services.

Associated biodiversity is often, but not always enhanced in polycultures as compared to monocultures. For instance, polycultures of different annual crops harbored greater weed species richness than monocultures of these crops (Palmer and Maurer, 1997). However, in Malaysia, bird species richness was found to be higher in monoculture oil palm plantations than in polycultures (Azhar et al., 2014), probably due to higher human disturbance during weeding and harvesting in polycultures.

With increasingly broader spatial scales at which specialization occurs, the spatial extent of the resulting monocultures and their ecological effects will likely also be scaled up. This means that not only crop diversity may be lost over larger areas, but also that landscape configuration might be affected. For instance, technological and environmental factors (e.g. road access, topography) may cause the few crop types to be clustered in space. This causes large-scale heterogeneity in the landscape and may augment the loss of associated diversity because species that depend on a certain uncommon crop type are less likely to find the remnants of this crop type. Moreover, landscape fragmentation has non-linear effects on species survival, with extinction setting in long before the last remnants of this crop type have vanished (Bascompte and Sole, 1996). Thus, specialization at broad scales may exacerbate the ecological consequences of specialization at local scales.

4. Illustrating Specialization Trade-Offs in Jambi, Indonesia

4.1. The Case Study of Jambi

Indonesia is the country with the largest increase in forest cover loss from 2000 to 2012 (Hansen et al., 2013). At the same time, monoculture cash crops expand rapidly. Since 2007, Indonesia has been the largest palm oil producer in the world (Coordinating Ministry of Economic Affairs, 2011), and it is also the second largest producer of natural rubber. Seventy percent of the palm oil area in Indonesia is located in Sumatra and approximately 42% of palm oil land is managed by smallholders (Coordinating Ministry of Economic Affairs, 2011: 53) of which more than 50% have some kind of contract with a company. Similarly, the majority of the rubber production is produced by smallholders (Coordinating Ministry of Economic Affairs, 2011: 57). The province of Jambi has a total land area of 5,300,000 ha (BPS Provinsi Jambi, 2011: 3; Fig. 2) and is a showcase of high dependency on the agricultural sector. The total area under oil palm and rubber cultivation are approximately 936,500 ha and 1,284,000 ha, respectively (BPS Provinsi Jambi, 2011, updated after personal communication with an Indonesian government representative). The average per capita income in Jambi province is roughly 17.5 million RP/year (equivalent to about 1200 USD/year; BPS Provinsi Jambi, 2011), which is substantially below the national average of 26.8 million RP/year (equivalent to about 1850 USD/year; Kopp et al., 2014: 2). Fifty-two percent of the workforce in Jambi is employed in the agricultural sector. An increase in the number of large plantations has contributed to reducing the area of farmland accessible to smallholders. Government promotion of the forestry and later the oil palm sector has contributed to agricultural intensification (Potter, 2001) and induced an agricultural transition towards oil palm (Rigg, 2005). More specifically, subsistence strategies of smallholders in the province shifted from extensive swidden farming to cash crop production. But this specialization has also been supported by rising global demand for cash crops, especially for oil palm, improved access and infrastructure, and the suitability of this crop to the area. Rubber remains the second most-important cash crop and currently, 99.6% of the rubber in Jambi province is cultivated by smallholders (Estate Crop Services of Jambi Province, 2012).

Transformation of the Jambi lowland forests started in the 19th century when the Dutch colonial power exploited the natural resources in the region. In the early-1970s, the Indonesian state sold almost the entire lowland rainforests of Jambi Province as logging concessions. While the earlier concessions exploited already existing timber resources, the current concessions accommodate cash crop plantations, primarily oil palm and industrial timber. This change from a predominantly extracting economy to a production economy resulted in the establishment of an agricultural frontier zone where government-led transmigration programs were implemented from 1983 to 2002 to meet the demand for labor force on oil palm plantations (Hauser-Schäublin and Steinebach, 2014). Migration resulted either from state-organized transmigration projects or from 'informal rural migrants' (Bock, 2012)

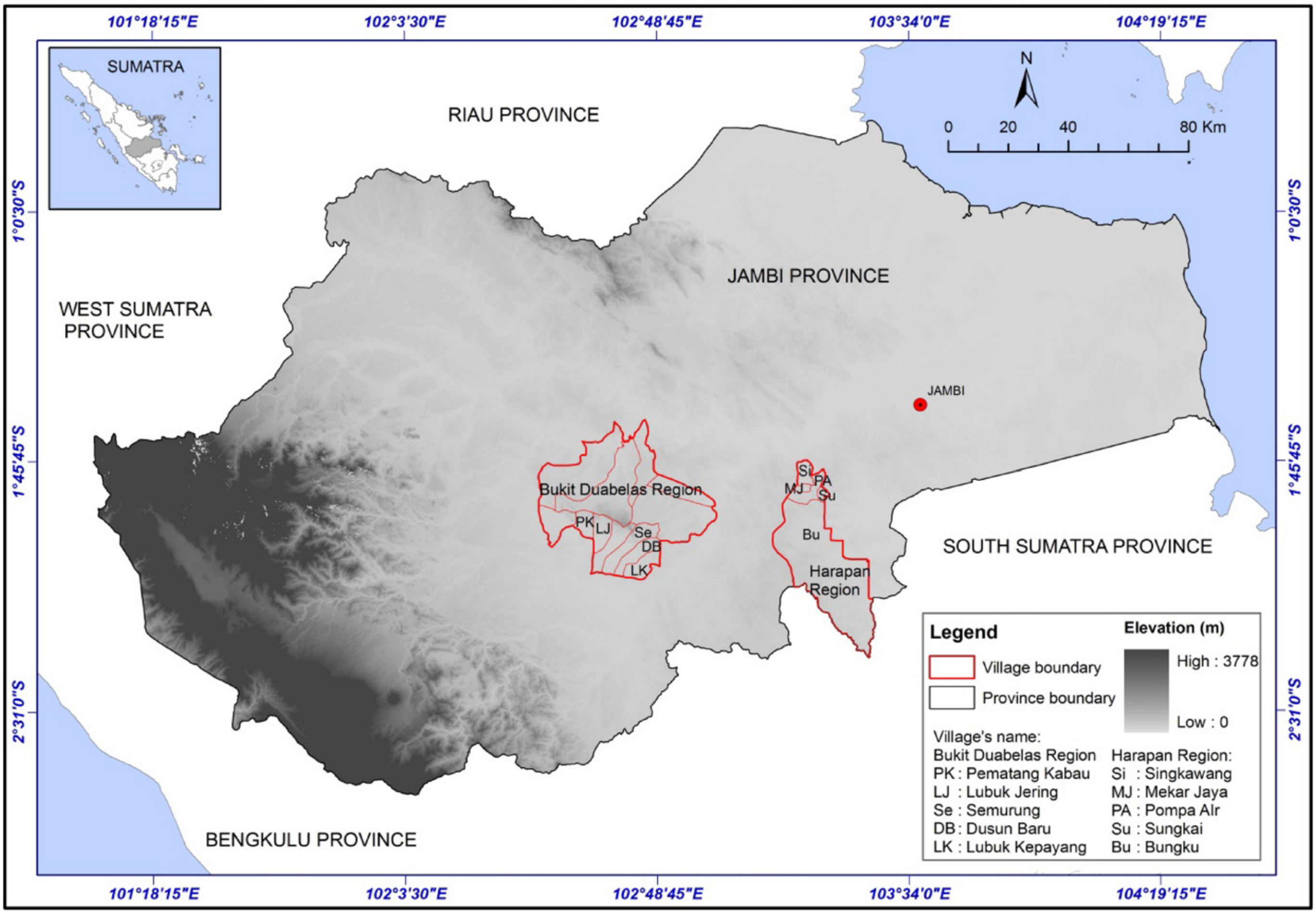

Fig. 2. Map of Jambi province on Sumatra, Indonesia, where our case study was conducted, indicating the locations of the two example regions Bukit Duabelas and Harapan and the official boundaries of the five example villages per region selected for the specialization-scale study whose results are reported in Fig. 3.

and led to strong increases in population size. The population in Jambi grew from 1.1 million people in 1971 (16 people/km^2) to 2.4 million people in 2000 and reached 3.4 million in 2014 (63 people/km^2) (Drake, 1981: 473; BPS Provinsi Jambi, 2013: 136–137). Between 1967 and 2007 reportedly 96,401 families or 394,802 people were resettled to Jambi by transmigration projects as a measure of poverty alleviation and regional economic development (Pemerintah Provinsi Jambi, 2008). These households received parcels of land (about 2.5 ha each) and contracts with agribusiness companies to cultivate oil palm within a smallholder-contract-system. In summary, land-use transformation in Jambi province is closely linked to immigration because immigration is essentially triggered by the rising agro-business and oil palm economy to which migrants either act as a workforce for plantations or hope to be set up with land and begin production by themselves. In 2012 the share of residents with migratory background reached about 80% (Suara Pembaruan, 2012).

In the case of Jambi, specialization on oil palm or rubber plantations has been considered the (economically) best land-use option because returns to land and labor are higher compared to rubber agroforests (Feintrenie and Levang, 2009) and other non-commercial land-use systems (Zen et al., 2005). While Belcher et al. (2004) found higher returns to land in oil palm plantations compared to rubber agroforests and rubber plantations in East Kalimantan, Feintrenie et al. (2010a, b) observed the opposite in Jambi where returns to land are higher in rubber plantations than in palm oil plantations and rubber agroforests. All authors found higher returns to labor in oil palm than in rubber plantations. However, these plantations rarely provide any non-material benefits or other cultural services, nor do they provide intrinsic values. Interestingly, this coincides with the fact that in the native habitat of oil palms in Western Africa, socio-cultural importance is not related to monocultures but to the palm individual, or parts of it (Atinmo and Bakre, 2003).

On the contrary, non-financial considerations such as ethnic (and thus also migratory) background can play an important role (Belcher et al., 2004): ethnic-specific perceptions of the environment apparently have a serious impact on land and resource management (Manik et al., 2013; Pfund et al., 2011; Reenberg and Paarup-Laursen, 1997; Steinebach, 2013). Indigenous households often also depended to a much greater extent on a diverse range of habitats and species than non-indigenous households (Laird et al., 2011). Differences in livelihood dependency on forest can cause varying conservation attitudes (Mainusch, 2010). In Jambi province, the local indigenous communities of Orang Rimba and Batin Sembilan feel that they have suffered from large-scale land transformation due to their historically strong livelihood dependency on forest resources (Manik et al., 2013). Such livelihood dependency on prevailing land-use systems constitutes an important factor determining land use and specialization.

4.2. Specialization Across Scales in Jambi

As predicted by our conceptual framework, the level of specialization differs by the level of scale considered (Fig. 3). To assess scale dependence, we analyze land-use types based on the Land Use/Land Cover (LULC) maps derived by visual interpretation (*GOFC-GOLD*, 2013; Liu et al., 2005) of the most cloud-free mosaics of Landsat and RapidEye images with the guideline of land cover mapping produced

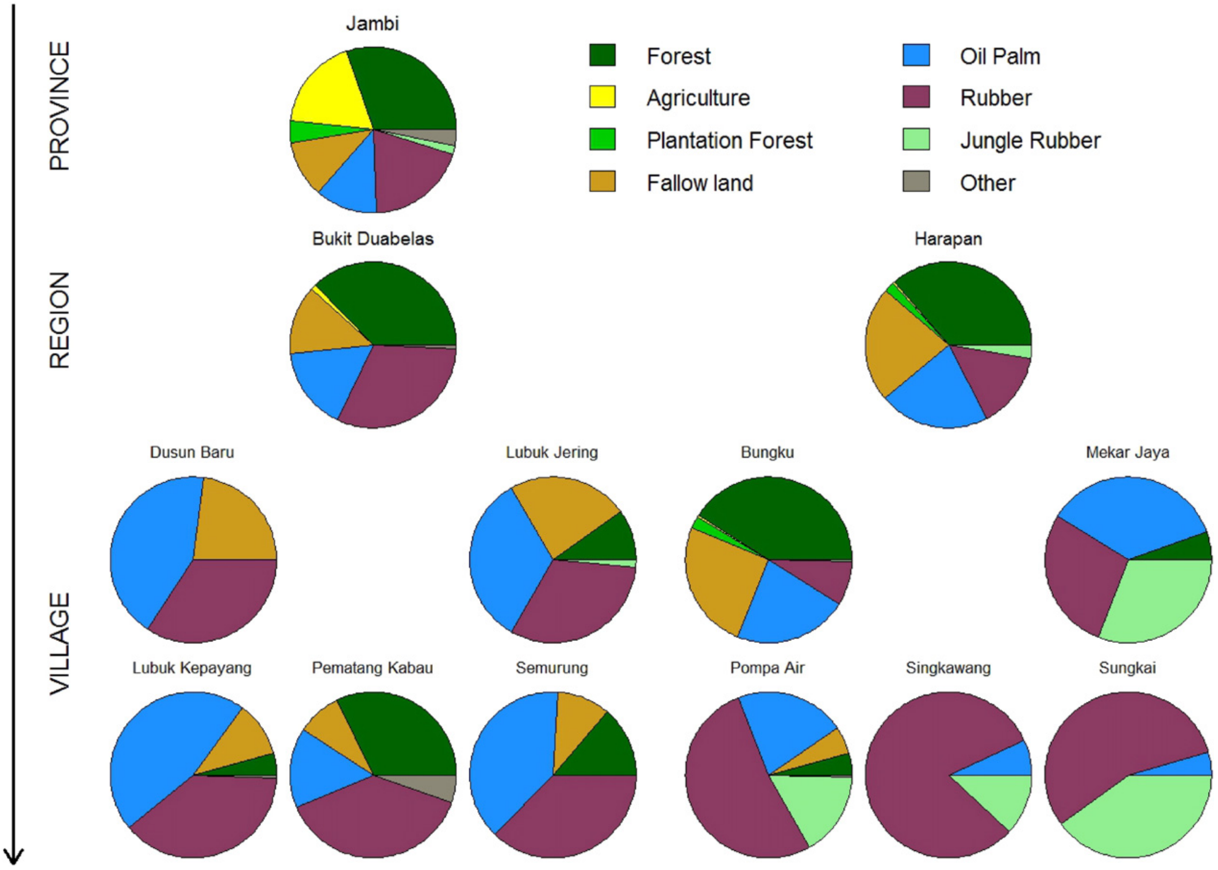

Fig. 3. Land-use types in the province of Jambi in Indonesia in 2011 show that specialization decreases from the fine to the broad scale, i.e. from the village level (five example villages per region, bottom rows) to the region level (two example regions Bukit Duabelas and Harapan, second row) to Jambi province (top row; see also map in Fig. 2). Data source: Landsat and RapidEye images analyzed according to Indonesian ministry guidelines (Ministry of Forestry, 2008).

by the Indonesian Ministry of Forestry (Ministry of Forestry, 2008, Fig. 3). This analysis does not cover the household level, but the village, region, and province levels. We find that specialization on one or a few crops is strongest at the village level, whereas differentiation increases at the region level and is highest at the province level (Fig. 3).

More detailed data are available for the household and village levels from a household survey (N = 701 smallholder households in 45 villages) and a village survey (N = 98, containing the 45 villages of the household survey) conducted in 2012 in the province of Jambi with structured interviews (Faust et al., 2013). For the present study, we analyze the main land-use types in the area, i.e. oil palm, rubber, paddy, fruits, and vegetables. At the household level, we find very strong specialization (Fig. 4a). Most households specialize on a single crop and only very few grow two or three crops. Most cultivated land is owned by pure rubber farmers and by households that focus on rubber and oil palm plantations. Similarly, at the village level, there are more villages that specialize on one or two crops than villages with more land uses (Fig. 4b). However, specialization is much weaker at the village level than at the household level.

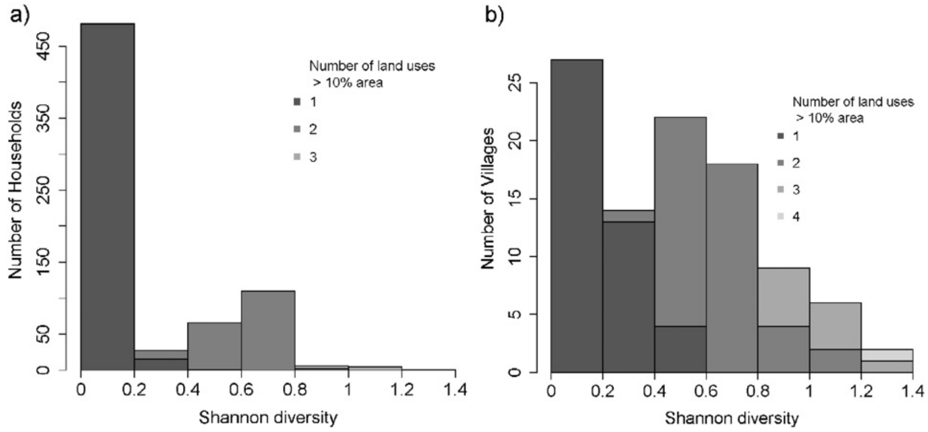

Fig. 4. Number of smallholder households (a) and villages (b) that fall into different categories of Shannon diversity (Magurran, 1988), an inverse measure of specialization. The number of land-use types with a minimum share of 10% of the total cultivated area per household or village, respectively, is indicated in grey shades. Overall, there are more households and more villages that specialize on one or two crops than households or villages that grow a more diverse portfolio of crops. Specialization is much stronger at the household level (a) than at the village level (b). Data source: own calculation.

Hence, overall, specialization decreases from household via village to province level. In itself, this is not surprising, because villages are nested in regions which are nested in provinces, so that the level of specialization can only stay constant or decrease towards broader levels of scale. However, our conceptual framework predicts that well-functioning markets lead to the possibility of high (not necessarily maximal) levels of specialization at the broadest scales. When we interpret this finding in line with our conceptual framework, this would suggest that markets are not functioning well enough (yet) to allow for a greater specialization at broader spatial scales. At the same time, there is, as expected, already considerable specialization at the household and village levels which appears to be the optimal economic strategy for households (at least in the short term). Of course, leaving our conceptual framework aside, other causes than the absence of well-functioning markets could also explain these patterns, such as heterogeneous environmental conditions (as discussed in Hanspach et al., 2014) that prevent specialization at scales broader than the household, or that there are only sizable internal but no large external economies of scale. Resilience and risk spreading strategies of individual farmers are less likely causes here, because we found very high specialization at the household level.

To investigate further to what extent economies of scale drive specialization in the Jambi case study, we take the example of oil palm cultivation and analyze both the production output and the production costs of oil palm farmers. Since output and factor costs differ across plantation age, we categorize the age in accordance to the yield cycle of oil palms into four age groups. For each age group we determine the median plot size and divide the plots into one group with smaller-than-median plot sizes and one group with larger-than-median plot sizes. As has been found in many studies (see, e.g. review by Binswanger et al., 1995; Ray, 1999), output per unit land is larger for small farms (Table 1). This is partly due to more intensive input use (especially labor, but also other inputs) on small plots (Table 1). It can also be due to more intensive and improved use of these inputs as the incentive problems afflicting large farms with hired labor are less prevalent here (see discussion in Section 2).

Production costs are investigated in the form of labor and input costs per hectare and year. Labor comprises operations such as land clearing, pits taking, seedling transportation, planting and replanting, manure and fertilizer application, chemical and manual weeding, harvesting, and pruning and marketing. Input costs refer to costs for seedlings, plant and animal waste, soil amendments, fertilizer, herbicides, machinery, and input and output transportation. Results for input and labor costs suggest lower costs for larger-sized plots (Table 1). This is especially apparent for labor costs in immature and young plantations (age groups 1 and 2). However, profits per hectare do not support cost advantages of larger farms in our study region. Only for the third age group the profit per hectare of larger plantations exceeds the profit of smaller plantations. Hence, our results for the Jambi case study suggest only weak evidence for economies of scale for larger production units.

Thus, as discussed in our conceptual framework, we can confirm the finding from many other countries that there are gains from specialization at the farm level but that this specialization does not inevitably lead to a consolidation of smallholder farms to ever-larger units; instead specialization is taking place among smallholders at the household and, as we have shown above, increasingly at broader scales such as the village level as well. However, such lower-level specialization could maintain regional diversity, and this could be valuable for sustainable development in multiple dimensions.

4.3. Policy Influence on Agricultural Specialization in the Jambi Case Study

Two main policies affected the agricultural specialization process in Jambi fundamentally, the transmigration programs and the current master plan of the Indonesian government. The Indonesian government's transmigration program played a key role for the start and spread of oil palm cultivation in Jambi and the significant involvement of smallholder farmers (Gatto et al., 2014). The oil palm cultivation was organized in so-called nucleus-estate and smallholder (PIR-NES) schemes. The government support in terms of technical and financial assistance and land titles provided to the oil palm NES schemes was instrumental for increasing the specialization of transmigrant smallholders on oil palm.

The master plan for Indonesian Economic Development designated Jambi as part of the Sumatra Economic Corridor as a ‘Center for Production and Processing of Natural Resources and as Nation's Energy Reserves’ (Coordinating Ministry of Economic Affairs, 2011: 46). The economic development strategy for the corridor focuses on three main economic activities: palm oil plantations, rubber plantations, and coal. To support the development of the main economic activities within the corridors the government will contribute around 10% of the development costs. The remaining costs will be provided by state-owned enterprises, private sector, and through public private partnership (PPP) (Coordinating Ministry of Economic Affairs, 2011: 55). Furthermore, regulatory requirements, infrastructure improvements, technology development and research activities will be supported which will

Table 1
Yearly values on mean yield, mean factor costs (costs for labor and inputs), and mean profits of oil palm plots per plot size category for plantations in different age groups. The first age group contains plantation ages 0 to 3 years, because most trees start to produce harvestable fruits in the third year. Further age groups are group 2 (4–9 years), 3 (10–17 years), and 4 (18–23 years). Standard deviations are shown in parentheses. The number of observations is given per column and per age group for small (N_S) and large (N_L) plantations in paratheses. Data source: own calculation.

	Small plantations i.e. ≤ 50% percentile				Large plantations i.e. > 50% percentile			
Plantation age group	Mean yield [MT/ha]	Mean factor costs/ha		Profit [US$/ha]	Mean yield [MT/ha]	Mean factor costs/ha		Profit [US$/ha]
		Mean labor costs [US$/ha]	Mean input costs [US$/ha]			Mean labor costs [US$/ha]	Mean input costs [US$/ha]	
	($N_S = 244$)	($N_S = 241$)	($N_S = 244$)	($N_S = 241$)	($N_L = 135$)	($N_L = 124$)	($N_L = 135$)	($N_L = 124$)
1 ($N_S = 46$, $N_L = 42$)	0.23 (1.07)	184.00 (271.56)	114.85 (121.17)	−98.24 (930.20)	0.34 (1.87)	70.28 (91.07)	103.70 (98.09)	138.75 (1631.33)
2 ($N_S = 60$, $N_L = 59$)	12.33 (9.66)	409.56 (302.89)	157.13 (131.65)	9680.01 (8095.78)	9.88 (7.65)	208.49 (239.56)	132.70 (111.86)	7997.01 (6519.13)
3 ($N_S = 87$, $N_L = 30$)	16.96 (10.42)	425.90 (403.14)	181.18 (142.43)	13,809.95 (8705.82)	17.30 (8.54)	292.64 (401.01)	203.81 (164.47)	14,597.71 (7166.60)
4 ($N_S = 51$, $N_L = 4$)	20.43 (7.50)	377.65 (363.66)	269.59 (271.02)	16,720.72 (6311.65)	14.56 (6.08)	181.01 (80.25)	94.88 (69.56)	12,100.11 (5216.16)

altogether lead to further specialization on palm oil and rubber plantations from the household to the province levels of scale.

Thus, policy has strongly supported and driven specialization directly through the economic development strategy in Jambi and indirectly through the provision of infrastructure and improvements in the functioning of markets. This has surely contributed to raising incomes in the region, but the associated specialization at increasingly broader scale is exacerbating precisely the trade-off that we have discussed above.

5. Conclusions: How can the Trade-Offs Caused by Specialization be Addressed?

Specialization causes trade-offs between economic benefit and ecosystem functions that increase with the spatial scale of specialization which, in turn, can be influenced by market functioning. When testing this concept in a smallholder landscape in Indonesia, we indeed found differences in the level of specialization across scales, but with high specialization only at household and village levels and high diversification at broader levels of scale. Beyond market functioning, other drivers such as heterogeneous environmental conditions or only weak external economies of scale in our study area could have caused this cross-scale specialization pattern. However, smallholder farmers are not the only stakeholders influencing the specialization of agricultural productions, there are also large companies, international investors, conservation managers, and politicians; those actors have tended to promote specialization through the various policy actions and initiatives we have discussed above. Since economic benefit and ecosystem functions and services are both legitimate concerns, a solution that satisfies all stakeholders is not straightforward. Such a solution must address the spatial distribution of agricultural production in the landscape, be consistent with policy goals, and should also consider long-term consequences that are not necessarily considered in specialization debates.

The concept of mosaic landscapes with intensive plantations intermingled with both agroforestry zones and high conservation value areas (Koh et al. 2009; based on earlier ideas by Noss, 1983) might illustrate how agricultural production can be distributed in the landscape across scales with both economic and ecological benefits. Intensive plantations cover areas of high specialization and high ecological costs while agroforestry would reflect areas with a greater crop- and biodiversity. Mosaic landscapes would be especially promising in areas where both large companies and smallholders are present, as is the case in Jambi. Companies with their efficient work schemes would benefit from economies of scale, could engage in intensive plantations and set some land aside for conservation (Koh et al., 2009; Tscharntke et al., 2012). Smallholders may often prefer the less specialized and more diverse agroforestry systems, also due to cultural or historical backgrounds, livelihood dependencies or sentimental attachment, and especially if supported by policy incentives.

Policies should not directly promote specialization, but rather aim at improving incomes, lowering poverty, and safeguarding ecosystem services. This might or might not lead to increased specialization at different spatial scales. Certification programs such as the Roundtable on Sustainable Palm Oil may help to reconcile economic benefits with ecological functions by supporting sustainable production modes. These might include diversification to a certain degree and at some levels of scale. Furthermore, it has been shown that the promotion of landscape heterogeneity should be included in the certification schemes to the benefits of both agricultural production and biodiversity (Azhar et al., 2015). Payment for Ecosystem Service Schemes can also more directly support the maintenance of ecosystem services. Taking the example of oil palm, lowland plantation owners could be asked to compensate upland farmers beyond 600 m elevation, where oil palm cannot grow, for water-related ecosystem services. These services, such as the provisioning of drinking water and electrical power generation, might be compromised in the lowland oil-palm plantations otherwise. Such policies might be able to turn the specialization-driven ecological-economic trade-off into win-win situations at least for some spatial scales and over longer temporal scales.

Temporal scales and especially long-term consequences of specialization were not the focus of this paper, but could provide a worthwhile perspective for future research on the topic. Specialization may have long-term costs as it may destroy vital ecosystem services required for the long-term viability of crop production. Furthermore, diversification incentives may lead to a greater sustainability also in economic terms, e.g. via improved biological pest control or pollination services, when considering sufficiently long time horizons. This would then also be in the long-term interest of smallholder producers, so that the mostly small-scale specialization-driven trade-offs between economic benefit and ecosystem functions can be converted into win-win situations.

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