# Economic valuation of land use change - A case study on rainforest conversion and agroforestry intensification in Central Sulawesi, Indonesia

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# Summary


Cocoa is a cash crop which is predominantly cultivated in smallholder agroforestry systems. On a global scale, the expansion of cocoa cultivation area has dominantly taken place in areas of prior primary forests, thereby contributing substantially to the loss of remaining rainforests. Tropical rainforests provide a wide range of ecosystem services benefiting local farmers as well as regional or international communities. However, the values of these services are rarely mirrored by markets and hence not included in economic accounting when these forests are converted into other land uses.

In many cocoa producing regions, the traditional cultivation under the canopy of planted or natural shade trees is increasingly switching to full-sun agroforestry systems without shade trees, with potentially detrimental effects for the agroecosystems in terms of biodiversity and ecosystem function loss. This intensification pathway is financially favourable, but risky in terms of agronomical and ecological sustainability.

Indonesia is currently the third largest cocoa producer worldwide with a persistent production increase. Central Sulawesi is a major cocoa producing region in Indonesia. At the rainforest margins around Lore Lindu National Park (LLNP) in Central Sulawesi (Indonesia), the expansion of cocoa agroforests is the main driver of regional forest conversion. Moreover, agroforestry systems are increasingly intensified by the extraction of shade trees, thereby causing further environmental degradation.

The described land use change provokes severe trade-offs between public benefits arising from ecosystem services provided by forests and sustainable agroforests, and private benefits of forest conversion and intensive cocoa production. This dilemma calls for strategies which are suitable to solve ecological-economic trade-offs of land use change. Payments for environmental services (PES) have been suggested as a promising tool for efficient nature conservation but they require sound knowledge of their economic and ecological implications, which is widely lacking in the tropics.

Against this background, this study has four main objectives:

1) To assess the structure and management of cocoa agroforestry systems in Central Sulawesi across an intensification gradient.
2) To determine the socio-economic drivers of cocoa agroforestry expansion and intensification.
3) To conduct an economic valuation of forest conversion and agroforestry intensification.
4) To analyze impacts of PES schemes on forest conversion and agroforestry intensification by applying a dynamic ex-ante modelling approach at farm household level.

Empirical data on cocoa agroforestry management were gathered on 144 cocoa plots and the corresponding farming households (one cocoa plot of each of 12 households per village, 12 villages in the vicinity of LLNP). The cocoa agroforestry plots were systematically chosen to represent the entire intensification gradient of high to low canopy closure (CC) values. Plots were characterised in terms of plot history and structure including cocoa tree density, intercrops and shade trees. Farmers were contracted to prepare weekly records on yields and several yield determining factors from January to December 2007. Surveyed parameters include capital and labour used for management activities and input (e.g., fertilizer, pesticides) as well as output in terms of dry cocoa bean yield. For Chapter II and IV, cocoa agroforestry data are complemented by socio-economic farm and household data from panel surveys conducted in 2001, 2004 and 2006 (van Edig and Schwarze). These panel data stem from a 13 village random sample (Zeller et al. 2002), which overlapped with the cocoa agroforestry sample (n=144) in 80 cocoa farming households. However, basic socio-economic characteristics were surveyed for the complete cocoa agroforestry sample. Furthermore, results from various ecological studies and from other socio-economic surveys conducted in the project area were used in Chapter III and IV.

This study reveals that cocoa plots in the LLNP region are mostly established by converting natural forest lands, and they are increasingly intensified by the removal of shade trees. Canopy closure decreased by 20% on average between 2007 and 2008. The soil nutrient status is mostly sufficient but total phosphor availability and stagnant soil water conditions limit yields. Substantial improvements are required in terms of pest and disease management, soil amelioration and replanting. Marketing of cocoa beans takes place mostly via small traders from the same village. Farm gate prices account for around 70% of world market prices. Cocoa bean yield varies strongly by season. Agroforestry intensification and labour input are positively correlated with yields. Structural agroforestry intensification is correlated with expenses for material inputs and with biophysical parameters (rainfall and soil phosphor content).

Cocoa area expansion and intensification are basically affected by the same set of driving factors. Both processes are not poverty driven. In tendency, better-off households dominate both, the intensification pathway and the extension of cocoa area. Both developments are constrained by labour availability and aging households. Most significantly, migrant households are triggering both, the intensification and the expansion of cocoa agroforests. In summary, expansion and intensification of cocoa agroforests is rather driven by economic factors indicating a commodity and market oriented livelihood strategy which is likely to cause further cocoa area expansion (neoclassical theory) than a subsistence based strategy (impoverishment theory). Hence, a land-sparing effect of agricultural intensification is implausible for this case of cash crop production. Rather, cocoa intensification and area extension are likely to go hand in hand.

When natural forests or production forest are converted into agroforestry systems, marginal changes in private net benefits from cocoa production and timber harvest are always positive. In contrast, values for public goods and services, including carbon sequestration and avoided emission, pollination services as well as biodiversity values show net losses when switching to a more intensive land use in all cases. Public goods and services do not provide sufficient net benefits to offset returns from conversion to cocoa agroforests. A carbon sequestration project at current carbon prices is not sufficient to offset returns from intensively managed cocoa agroforests. The high private returns resulting from forest conversion to cocoa agroforests and the increasing profitability of cocoa agroforests along the intensification gradient raises trade-offs in the provision of ecosystem services provided by forests and extensive agroforestry systems.

A dynamic non-linear mathematical programming model was developed at farm household level in order to asses the impacts of two PES schemes: The introduction of a price premium for shade-grown cocoa, including a main shade premium and a pre-premium component, and the introduction of a carbon project, including an afforestation (agroforestry) and a REDD (Reducing emissions from deforestation and degradation) component. The two PES scenarios are compared to a baseline scenario without PES. The model basically optimizes cocoa productivity by allocating additional family labour to this cash crop, whereas wet rice and maize cultivation decrease in the model. The shade premium is directly related to the productivity of the cocoa system by increasing its output price, thereby affecting overall production structure to a larger extent than carbon credits, which are rather dedicated to the whole cocoa system as a per hectare payment. The rate of farm area extension by deforestation is effectively reduced only in the shade premium scenario. The shade premium also provides a good incentive to stabilize canopy openness, but it is adopted only by about half of the households. Adoption and income from the shade premium is positively correlated with larger wet rice area and local ethnicity. The REDD component within the carbon project is not suitable to prevent deforestation in the project area. The current REDD scheme is also not well targeted when the aim is to benefit the relatively poor farmers. Households adopting REDD are likely to be those who would not convert forests anyway because they have sufficient farm area and off-farm income sources. In both PES scenarios, farmers receive slightly increased total farm revenues when compared to the baseline scenario.

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# Abbreviations

| | |
|---|---|
| AFS | Agroforestry System |
| AI | Agricultural Intensity (weighted index) |
| AME | Adult Male Equivalent |
| BL | Baseline Scenario |
| BPD | Black Pod Disease (*Phytophtora palmivora*) |
| CA | Carbon project scenario |
| CBA | Cost-Benefit Analysis |
| CC | Canopy Closure |
| CDM | Clean Development Mechanism |
| CDPF | Cobb-Douglas Production Function |
| CER | Certified Emissions Reductions |
| $CO_2e$ | Carbon Dioxide Equivalent |
| COPAL | Cocoa Producers' Alliance |
| CPB | Cocoa Pod Borer (*Conomorpha cramerella*) |
| DR | Discount Rate |

| | |
|---|---|
| ENSO | El Niño Southern Oscillation |
| ES | Ecosystem Service |
| FAO | Food and Agriculture Organisation of the United Nations |
| FOB | Free On Board |
| GM | Gross Margin |
| HH | Household |
| ICCO | International Cocoa Organisation |
| IDR | Indonesian Rupiah |
| IFOAM | International Federation of Organic Agriculture Movements |
| LLNP | Lore Lindu National Park |
| LP | Linear Programming |
| LUCC | Land use/land cover change |
| m a.s.l | Meter above sea level |
| MI | Management Index (non-weighted index) |
| MP | Mathematical Programming |
| NF | Natural Forest |
| NLP | Non-Linear Programming |
| NPV | Net Present Value |
| NTFP | Non-Timber Forest Products |
| OECD | Organisation for Economic Co-operation and Development |
| OLS | Ordinary Least Squares |
| OP | Canopy Openness |
| PCA | Principal Component Analysis |
| PES | Payments for Environmental Services |
| PF | Production Forest |
| REDD | Reducing Emissions from Deforestation and Degradation |
| SAN | Sustainable Agriculture Network |
| SD | Sekolah Dasar (Primary School) |
| SMBC | Smithsonian Migratory Bird Centre |
| SMS | Safe Minimum Standard |
| SP | Shade Premium scenario |
| STORMA | Stability of Rainforest Margins (Sonderforschungsbereich 552) |

| | |
|---|---|
| tCER | Temporary Certified Emissions Reductions |
| TFR | Total Farm net Revenue |
| TNC | The Nature Conservancy |
| UNFCCC | United Nations Framework Convention on Climate Change |
| USAID | United States Agency for International Development |
| USD | US Dollar |
| WCED | World Commission on Environment and Development |
| WTP | Willingness-To-Pay |
| yr | year |

# Introduction

## Background

Land-use and land cover change belong to the major driving forces of global environmental change, impacting landscapes and environments in manifold ways (Lambin et al. 2000). Expansion and intensification of agriculture are among the predominant global changes of this century (Matson et al. 1997). They form the main proximate causes to land use and land cover change, which are regularly accompanied by habitat fragmentation and destruction (Perrings 2001, Geist and Lambin 2002). In consequence, agricultural expansion is also considered as the major proximate cause of biodiversity loss (Perrings, 2001, Matson et al. 1997). In tropical regions, agricultural expansion is by far the dominant cause for deforestation (Geist and Lambin 2002). During the last 30 years, 288 million hectares (21%) of tropical forest areas have been cleared, mainly driven by rapid economic growth in several tropical areas (Bawa et al. 2004).

Another prevalent form of land-use modification is agricultural intensification, which led to substantial increases in food production since the 1950ies (Matson et al. 1997). Agricultural intensification plays a crucial role within the 'critical triangle' of development goals: agricultural growth, poverty alleviation and sustainable resource use (Vosti and Reardon 1997). Intensive farming systems are often considered as a means to reduce deforestation (Palerm 1955, Bandy et al. 1993 as cited in Shriar 2000). In cases where agricultural intensification is able to take pressure off forests, this offers a policy entry point for win-win-win situations within the critical triangle goals (Angelsen et al. 2001, Lee et al. 2001, Cattaneo 2001, Vosti et al. 2002).

Determining the drivers of land cover and land use change is a complex and disputed issue. Many approaches place population dynamics and poverty in the centre of the causal chain of land use change. Additionally, in recent years, economic opportunities related to institutions as well as global forces were increasingly discussed as major drivers of land cover and land use change worldwide (Lambin et al. 2001). This argument is, for instance, repeatedly mentioned in the context of cash crop production. Cash cropping has become increasingly important during the last decades and is now often deemed a much stronger driver of land use change than for instance population growth, since farmers pay close attention to signals of market development and adapt their land use to it (Brookfield 2001).

The cash crop cocoa belongs to the major global agricultural commodities (Franzen and Borgerhoff Mulder 2007, Talbot 2002). It is cultivated in agroforestry systems displaying a wide spectrum of production intensities (Rice and Greenberg 2000). In many tropical landscapes, cocoa agroforestry constitutes the first step in a conversion process from forest to agricultural land-use. The expansion of cacao production has replaced substantial areas of primary forest in West Africa and on the Indonesian islands of Borneo and Sulawesi (Rice and Greenberg 2000).

Nevertheless, during the last decade agroforestry systems have repeatedly been evaluated with respect to conservation aspects since they are deemed to provide options for a sustainable intensification that will increase production without causing unacceptable harm to the natural resource base (Shriar 2000). This is an interesting option particularly at tropical rainforest margins, where sustainable agroforestry systems can contribute substantially to the stability of the transition zone from natural forests to intensive agriculture (Tscharntke et al. 2007, Perfecto et al. 2007, Schroth and Harvey 2007). While the traditional way of cocoa production is the cultivation under a canopy of planted or natural shade trees, intensive cocoa systems are nearly devoid of shade trees and they are becoming increasingly common in the main cocoa growing regions. This trend in various parts of the tropics has potentially detrimental effects for the agroecosystem in terms of biodiversity and ecosystem function loss (Ruf 2007, Franzen and Borgerhoff Mulder 2007, Steffan-Dewenter et al. 2007).

Tropical rainforests, but also many tropical agroforestry systems provide a wide range of goods and services (ecosystem services) resulting from ecosystem functioning. Particularly, shaded agroforestry systems can maintain a considerable part of original ecosystem services and some of the original rainforest biodiversity not found elsewhere in farmed landscapes (McNeely and Schroth 2006, Perfecto et al. 1996, Moguel and Toledo 1999, Steffan-Dewenter et al. 2007). Many ecosystem services (e.g. carbon sequestration) deliver benefits on national or even global scales with no or little direct benefit to the farmer on the local scale. Under these circumstances, incentives play a key role when the aim is to support sustainable agriculture systems (Tilman et al. 2002). Payments for environmental services (PES) have often been suggested as a promising incentive tool for solving ecological-economic trade-offs of land use change and for efficiently contributing to nature conservation. However, such schemes require sound knowledge of their economic and ecological impacts, which still remain widely untested in the tropics (Wunder 2006).

Against this background, the thesis aims at contributing knowledge to the dynamics of land cover and land use change in the tropics within the context of the globally important cash crop cocoa. This case study from Central Sulawesi (Indonesia) is focussing on two prevailing pathways in land use and land cover change (LUCC): rainforest conversion to cocoa agroforestry systems and the intensification of cocoa agroforests. Both processes will be assessed with respect to their driving forces. Also, by analysing the regional gradient in land use intensity, ecology-economy trade offs resulting from LUCC are quantified. The trade-off analysis contributes to new insights on the total economic consequences of LUCC, which are notoriously scarce for any tropical rainforest ecosystem (Balmford et al. 2002). Moreover, when it comes to the design of incentives, such as Payments for Environmental Services

(PES), policy makers often lack sound knowledge of the specific socio-economic and ecological implications of such schemes. Therefore, the study also aims at providing new evidence in this context from by using an ex-ante modelling approach for the study region.

The study was conducted as part of the DFG-financed SFB 552 “Stability of rainforest margins-STORMA”- subproject A5: “Welfare Economic Assessment of Forest Encroachment and ENSO effects in the face of personal capital and social capital dynamics”.

## Research Objectives

In detail, the thesis has four main research objectives:

**Objective 1: To assess the structure and management of cocoa agroforestry systems in Central Sulawesi across an intensification gradient**.

This study aims at assessing the basic socio-economic and soil properties of cocoa agroforestry systems in Lore Lindu National Park (LLNP) region, where cocoa is the dominant cash crop. In January 2007, 144 cocoa plots in 12 villages covering an intensification gradient were selected for a 1-year cocoa management study including a subset of 48 plots for extended soil analyses in order to describe basic characteristics of cocoa production and marketing, plot maintenance, particularly in terms of shade canopy management and yield determinants (see Chapter 1).

**Objective 2: To determine the socio-economic drivers of cocoa agroforestry expansion and intensification.**

In this study, both the causes of cocoa agroforestry expansion and intensification are examined by applying two different regression models and using empirical data from the cocoa management study and from a socioeconomic panel survey (see Chapter 2).

**Objective 3: To conduct an economic valuation of forest conversion and agroforestry intensification.**

In order to quantify potential trade-offs resulting from ongoing land use change in the LLNP area, we calculate marginal net benefits arising from various ecosystem services for a gradient in land use intensity. Using cost-benefit analysis within an impact pathway framework, we assess the following land use alternatives: natural forest, production forest, and four cocoa agroforestry systems of differing management intensities. Using various data sources from the project area, we focus on several important ecosystem services, including the provision of timber, rattan, cocoa income and biodiversity, the supporting services from pollination and soil fertility and the regulation of atmospheric carbon dioxide (see Chapter 3).

**Objective 4: To analyze impacts of PES schemes on forest conversion and agroforestry intensification using a dynamic ex-ante modelling approach at the farm household level.**

In this study, a dynamic and disaggregated farming household model based on mathematical programming is formulated to ex-ante analyze agricultural production and resource use patterns of smallholder cocoa farmers in Indonesia subject to the introduction of different PES schemes. Impacts of two different PES scenarios are tested across a regional intensification gradient in cocoa agroforestry: the introduction of a price premium for shade-grown cocoa and the introduction of a carbon project (see Chapter 4).

## Theoretical Framework

A theoretical framework of household behaviour is applied where profit maximisation is the basic driver of dynamic decision-making. Profit maximization is limited by biophysical and economic constraints and shaped by household preferences and consumption patterns (Vosti et al. 2002). The underlying hypothesis is that small-scale farmers tend to make efficient use of their resources in the way that it produces the highest possible net return, although their productivity is often constrained by location-specific attributes, limited resources and low access to improved technologies (Schultz 1964 as cited in Schreinemachers and Berger 2006, Lambin et al. 2000). With this theoretical background, we apply a framework of causal relationships underlying land-use change (cf. Kaimowitz and Angelsen 1998, Crissman et al. 2001). This basic framework is adaptive to all four research objectives (=four chapters) (Fig. 1).

Six categories of factors dominate the causal relationship underlying LUCC:

1. *Macro-level variables* influence the decision parameters, but not directly agent decisions. They are considered exogenous (e.g. demographics, government policies, world market prices) and are not considered in this study.
2. *Decision parameters of agents* directly influence agent' decisions. They are regarded as exogenous (e.g. output and input prices, labour costs, accessibility, available technology/ information, risk, property regime, environmental factors, government restrictions, other constraints on factor use) (Chapter 2, Chapter 4).
3. *Agents of land-use change*: Cocoa producing smallholders, their decision making and household characteristics (knowledge, culture, objectives, preferences, resource endowments) (Chapter 2, Chapter 4).
4. *Choice variables*: activities about which agents make decisions. They are by definition endogenous (e.g. land, labour and capital allocation; migration, consumption, and management/technology) (Chapter 1, Chapter 2, Chapter 4).
5. *Magnitude of land-use change* in terms of forest conversion and agroforestry intensification and agricultural output (e.g. cocoa yields) (Chapter 1, Chapter 2, Chapter 4).
6. *Private and public (social) costs and benefits* resulting from environmental change and the trade-offs emerging among them (Chapter 3).

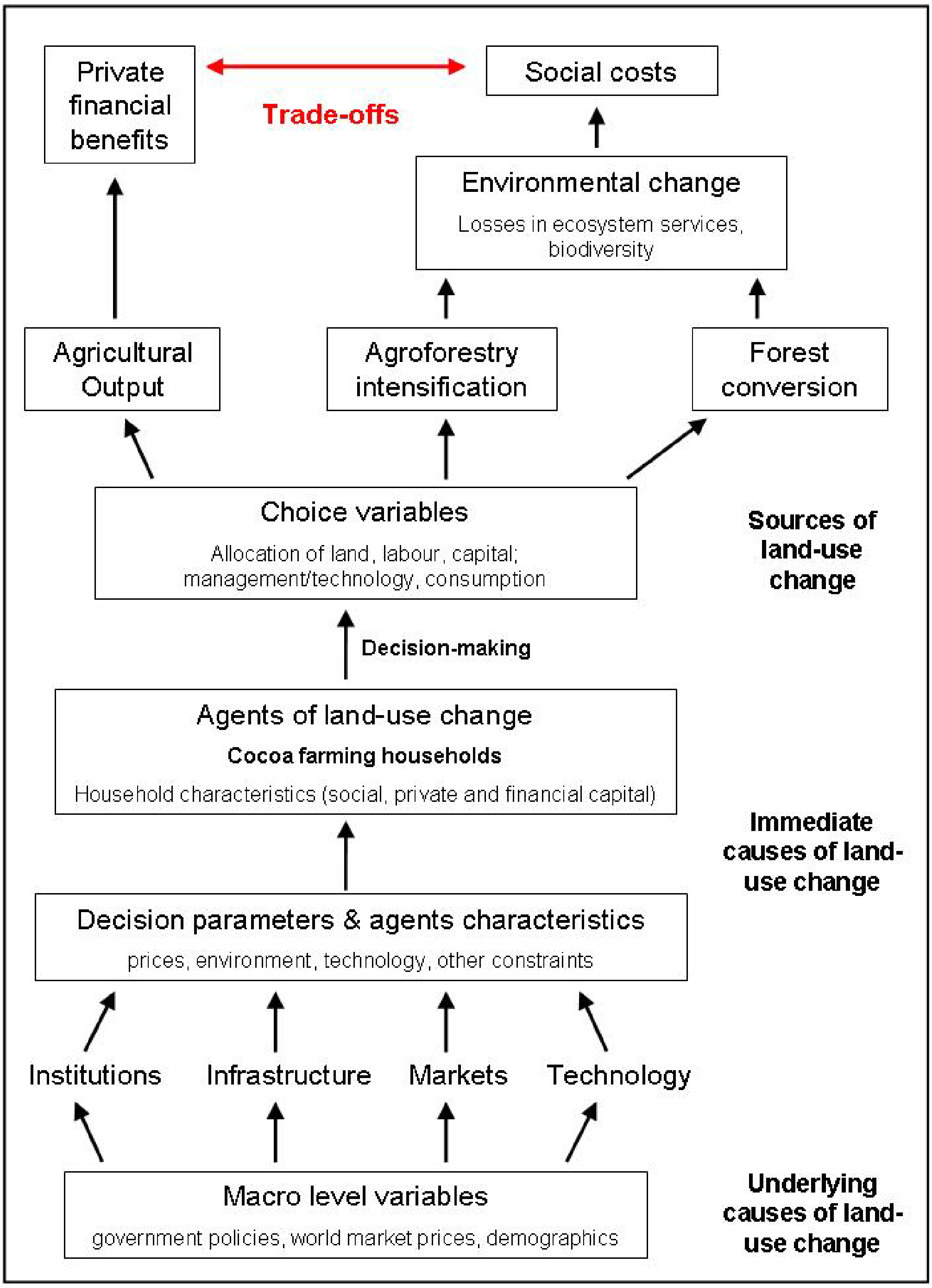


Figure 1. Framework of causal relationship underlying land-use change (adapted from Kaimowitz and Angelsen (1998) and Crissman et al. (2001)).

The starting points of the framework are the agents (cocoa producing households of the LLNP region). They make decisions about choice variables, leading to activities that are direct causes of land use change. Agent decisions are based on their own characteristics concerning resource endowments (factor use constraints) and exogenous decision parameters (prices, environmental factors etc.), which together form the set of immediate causes of deforestation. Broader economic, political, cultural demographic and technological forces determine agent characteristics and decision parameters. These factors belong to the underlying causes of deforestation (Lambin et al. 2001).

Decisions that cocoa farmers make on land use are leading to certain magnitudes in land-use change in terms of forest conversion and agroforestry intensification. This results in changing outputs, such as cocoa yields, timber harvest and non-timber forest product extraction, which affects the private net benefits of farming households. On the other hand, it leads also to environmental change affecting the provision of ecosystem services. Trade-offs occur along the land use gradient because farmers will basically choose land use options that lead to an increase in their private net benefits. However, this has often detrimental effects on ecosystem services, leading to a decrease in public (social) benefits and an increase in social costs not captured by market prices (Chapter 3).

## Study area

The research region (Fig. 2) is part of the Indonesian province Central Sulawesi, with the province capital Palu situated at the northern border of the study area. The area has a size of about 7500 $km^2$ including the Lore Lindu National Park with an area of around 2200 $km^2$. The study area is topographically diverse with mountains reaching up to 2,600 m a.s.l. It is characterized by a humid tropical climate (~ 1 degree south of the equator) with mean annual temperatures between 25 and 26°C at sea level and a high humidity (85-95%). Mean annual precipitation is more than 2,500 mm with a high local variability due to the diverse topography. The area in and around LLNP is covered by nearly 70% by tropical, mainly mountainous rainforests (Erasmi et al. 2004) providing a wide range of ecosystem goods and services. The rainforest in this area includes important habitats for the endemic flora and fauna, and is part of the *Wallacea* biodiversity 'hotspot' (Myers et al. 2000).

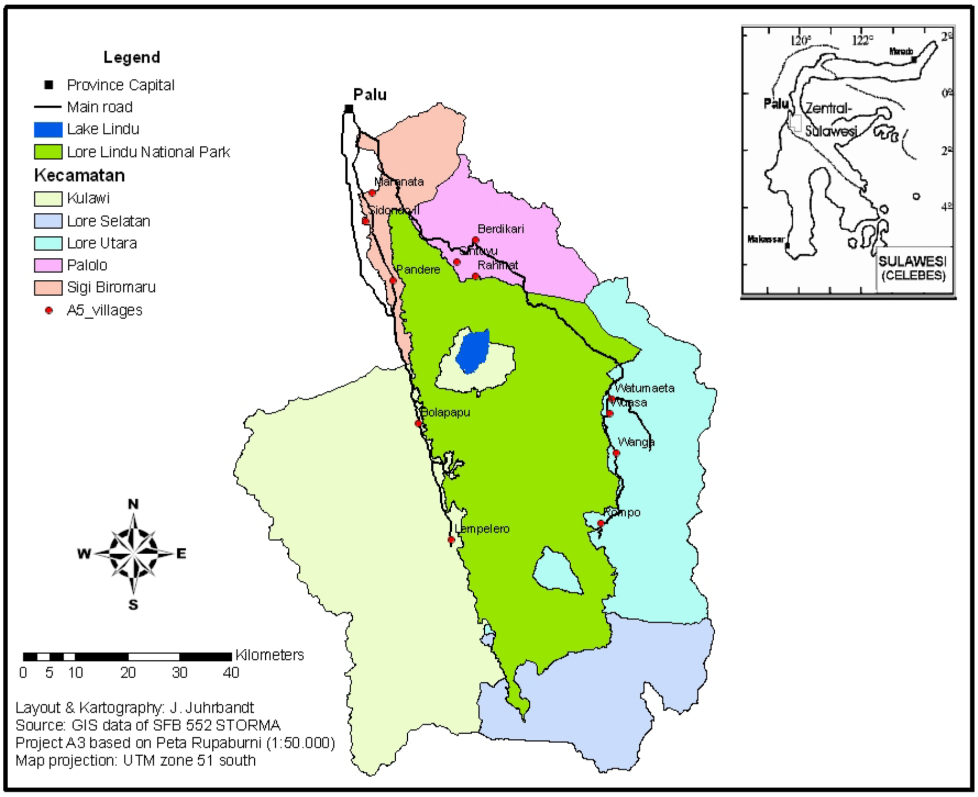


Figure 2. Study area

More than 30,000 rural households, mainly smallholder farmers, live in 119 villages in the study area. Strong dynamics prevail in demographics with a population increase of 60% between 1980 and 2001, which was in large parts driven by in-migration (Maertens 2003, Weber et al. 2007). Between 2001 and 2007, the population further increased by 14.1%, translating into an annual growth rate of 2.2%, which lies above the national level (1.3%) (Reetz 2008).

Considerable deforestation activities have been observed in the study region. Between 1972 and 2002, 17.2% of the regional forest cover was lost (0.6% annually) (Erasmi et al. 2004). Between 2001 and 2007, forest area further decreased by 4.8% (Reetz 2008).

The climate in the LLNP area permits year-round agriculture, providing near to optimal agro-climatic conditions for cocoa farming. While perennial crops such as cocoa and coffee are the prevalent land use on the slopes, paddy rice cultivation dominates the valley bottoms. Other important crops include maize, soybeans, various legumes and fruits, particularly bananas and coconut. Although, traditionally, wet rice was grown in the region, cocoa cultivation provides substantially more income (Schwarze 2004, Schwarze and Zeller 2005). Cocoa area increased from zero (1979) to approximately 18,000 hectares in 2001 (Maertens 2003). From 2001 to 2007, cocoa acreage further increased to 20,600 hectares (Reetz 2008). New cocoa plots were partly established within LLNP (Maertens 2003, Reetz 2008). Agricultural expansion of perennial cropping systems was identified as the main driver of regional forest conversion (Erasmi et al. 2004, Koch et al. 2008).

The increase of cropping area is followed by a significant intensification of cocoa systems. Multilayer agroforestry systems with diverse shade canopies are increasingly converted into sun-grown cocoa plantations. This is achieved by cutting down the initial shade canopy of residual forest trees. Oftentimes, fast-growing leguminous trees, e.g., *Glyricidia sepium*, are subsequently replacing natural forest trees (Siebert 2002). Intensification of cocoa agroforestry systems appears as a financially favoured strategy as yields can nearly be doubled when decreasing canopy cover from medium (50-65%) to zero-shade conditions, at least in the short run (Steffan-Dewenter et al. 2007, Schneider et al. 2007). Yet intensive sun-grown plantations are generally assumed to coincide with high losses of biodiversity and ecological functioning, thereby raising severe ecological-economic trade-offs along the intensification gradient (Siebert 2002, Steffan-Dewenter et al. 2007).

## Theories of land cover- and land use change

*Rainforest conversion*

Deforestation is a land cover change which generally describes ‘situations of complete long-term removal of tree cover’ (Kaimowitz and Angelsen 1998). Indonesia globally displays the second highest annual net loss in forest area (2% annual forest loss between 2000 and 2005, FAO 2006). Deforestation patterns are often affected by infrastructural development (roads) and by government policies on migration and settlement. This is particularly true for the Indonesian ‘transmigrasi’ policy, which brought some 3.7 million people from Java and Bali to the outer islands during the 1960s, 1970s and 1980s (Perrings 2001).

Deforestation is the major proximate cause of biodiversity loss (Perrings 2001, Pagiola et al. 1997). It often also results in downstream damage in form of sedimentation and changing flow peaks (Chomitz and Kumari 1998, Pagiola and Holden 2001). Moreover, tropical deforestation is globally considered the single most important source of carbon dioxide emissions (Duxbury 1995). When including subsequent land uses into the calculation, deforestation accounted annually for about 25% of all anthropogenic emissions of greenhouse gases during the 1990ies (Houghton 2005). In the past, population change and subsequent demand for land for food production were regularly mentioned as causal factors for deforestation. However, “population growth is never the sole and often not even the major cause for tropical deforestation” (Angelsen and Kaimowitz 1999, Geist and Lambin 2002). Besides agricultural expansion as the most important proximate cause for deforestation, wood extraction and infrastructure expansion are likewise relevant. These parameters are driven by underlying causes, e.g. economic and institutional factors, including national policies (Geist and Lambin 2002, Vosti et al. 2002). Deforestation was in the past also frequently connected to poverty-induced pressure in order to meet basic needs (e.g. Brundtland Report, WCED 1987, Reardon and Vosti 1995).

In the deforestation literature, three main approaches aim at explaining the phenomenon of forest loss: The impoverishment approach, the political ecology approach and the neoclassical approach (Wunder 2005). While the impoverishment approach refers to a combination of poverty and demographics (‘vicious cycle’) as the main cause for deforestation, the political ecology approach points to the role of external drivers such as capitalist investors. Contrarily, the neoclassical approach assumes deforestation agents to be optimizers reacting to economic opportunities whether they are poor or not. The main causal factor of the latter theory is the quasi-open-access conditions of forest with ill-defined property rights (Wunder 2005).

Deforestation is increasingly believed to be driven by a complex set of regionally distinct causes, where the relative profitability of agriculture, connected to political,

social and infrastructural changes, can play an important role (Angelsen and Kaimowitz 1999, Geist and Lambin 2002, Lambin et al. 2001, Vosti et al. 2002).
In contrast to the earlier favoured view of the subsistence farmer who is forced to deforestation to make a living in face of severe agronomic and market constraints, the new perspective tends to consider also strengthening market links in most forest margins. This mostly enhances income opportunities for local farmers, but it is not necessarily advantageous for remaining forests (Vosti et al. 2002).
Rainforest conversion is a land cover change of special concern in frontier regions, as these areas often contain the last undisturbed closed forests within a region or country (Pichon 1997; Moran 1993 and Collins 1986 as cited in Shriar 2000). Particular characteristics of frontier regions comprise land abundance and labour scarcity, imperfect credit markets, generally poor market conditions and infrastructure, land tenure insecurity and limited presence of extension services. Frontier farming systems display high levels of systems dynamics, high variability in production strategies and prices over time and space. They are placed in a general economic context of expanding but yet incomplete links between farmers and regional markets and regional and broader markets (Vosti et al. 2002, Shriar 2000). The LLNP region can be basically considered a frontier region, although legally acquirable land is getting scarcer and labour availability increases due to population growth and in-migration (Reetz 2008, Maertens et al. 2006).

*Agricultural Intensification*

While in the past, research focused mainly on land cover change meanwhile the importance of the more subtle processes of land use change have been recognised. Agricultural intensification is usually defined as a process of raising land productivity over time through increases in inputs on a per unit area basis (Shriar 2000, Ellis 2000, Brookfield 1993) within the context of the prevailing social and economic drivers (Lambin et al. 2000). Generally viewed, agricultural intensification may lead to changes in cropping regimes, which result in altered agroecosystems. These modified systems often display a reduced genetic and species diversity. This makes them more susceptible to exogenous shocks or environmental changes due to a lower adaptive capacity (Perrings 2001, Lee et al. 2001).

Early intensification theories suggest that switching from extension of crop area to production intensification may not be profitable for a farmer until beginning scarcity of land and/or ecosystem services is constraining land extension (Boserup 1965, Holden 1993, cf. Lee et al. 2001). Later on, these early theories were criticised for their limited view on demographic factors (Brookfield 2001), and for paying little attention to the economic drivers of land-use change (Bilsborrow and Carr 2001).

The induced intensification thesis (Turner and Ali 1996) explains changes in agricultural intensity by variations in farmer behaviour concerning production goals and rules of labour and capital allocation. Two types of production strategies can be distinguished: A subsistence or consumption oriented and a commodity/market oriented strategy (Shriar 2005). In a subsistence economy, risk minimization and labour saving strategies are of prior importance. As intensification usually implies an increase in labour demand, farmers will hesitate to intensify unless an urgent need (population change/ land pressure change) forces them to. In contrast, the model of an ideal market implies a ‘commodity behaviour’ in that small-holders increasingly move into market production, thereby changing social structures and aspirations which transform behaviour (Turner and Ali 1996). This ‘market approach’ is based on open-economy models and explains agricultural expansion caused by the profitability of agriculture, mainly resulting from increasing producer prices, decreasing transportation costs and technical improvements (Kaimowitz and Angelsen 1998). However, farmers might be constrained in fully responding to market signals due to limiting factors such as poverty and geographical isolation, particularly at high levels of risk. Moreover, farmers may also fail to respond to it because their production goals are not completely market-oriented, causing ‘hybrid’ farming behaviour which ranges along a continuum of the two ideal models and may prevail in a single farm. These ‘dual farmers’ combine the risk-avoidance of food-cropping with the market risk implied by cash cropping (Turner and Ali 1996).

In order to meet the critical triangle goals, ‘sustainable agricultural intensification’ is widely being discussed as a potential solution. Sustainable intensification refers to an increase of agricultural production with a simultaneous maintenance or enhancement

of the natural resource base (Ruben et al. 2001). This is to be achieved by a combination of adequate technologies, policy incentives and institutional reforms which are suitable for bringing in line the short term welfare objectives of farmers with long-term regional sustainability criteria (Reardon 1995 as cited in Ruben et al. 2001). Sustainable intensification aims at providing land use solutions that balance the preservation of forests, the livelihood needs of inhabitants and the growth requirements of regional and national policy makers (Tilman et al. 2002, Vosti et al. 2002). However, sustainable agricultural practices are oftentimes knowledge-intensive and thus require proper investments for development and dissemination (Tilman et al. 2002).
Agroforests are generally deemed to provide opportunities for a sustainable intensification (Gockowski et al. 2001, Tomich et al. 2001). However, the way cocoa agroforestry intensification is currently proceeding in LLNP region, has probably to be considered rather unsustainable (Siebert 2002, Steffan-Dewenter et al. 2007).

## Cocoa as a commodity

Cocoa is a perennial cash crop which is mainly produced in Latin America (Belize, Mexico, Ecuador, Peru, Costa Rica and Brazil), West Africa (Cote d'Ivoire, Cameroon, Ghana, Nigeria, and Sao Tome), and Indonesia (Sulawesi, Central Sumatra) (Franzen and Borgerhoff Mulder 2007). Between 2001 and 2005, world cocoa production increased by 5.8% per year on average. From 2005 to 2008, the production was stagnating, but with high fluctuations (ICCO 2008b, ICCO 2010a).
Cocoa is predominantly a smallholder crop, as more than 90% of world cocoa production originates from small farms. Cocoa plays a very important economic role for small farmers. As a cash crop it can provide necessary income for the purchase of food (Bentley et al. 2004), which is especially important in areas where food security has been a problem (Belsky and Siebert 2003). Cocoa is cultivated in agroforestry systems which are known to be part of small farmers' low risk and low cost strategies in the humid tropics (Deheuvels et al. 2007).
The typical value chain is described by Talbot (2002) as follows: After harvesting, cocoa pods are opened and cocoa beans are extracted, selected, fermented and dried,

which is usually done by the producer. Subsequently, cocoa beans are collected by a village-level trader and then acquired by a national trader (a state marketing authority or an export organization), who realises grades and controls the bean quality before export. To a very small extent, cocoa beans are processed into intermediate products (cocoa liquor, butter, or powder) in the country of origin. The product gets traded in the world commodity market or it is directly taken over by an international trader or processor. Buyers and sellers enter into contracts about future deliveries of cocoa beans in the so-called futures market, which determine the world market price of cocoa (e.g. at the London International Financial Futures and Options Exchange [LIFFE]). The chocolate manufacturer arranges the retailing of the finished product.

Cocoa is a typical primary commodity with world market prices subject to high volatility. A considerable increase in concentration has taken place along the cocoa supply chain; especially in processing (Archer Daniels Midland -ADM, Cargill Inc, Barry Callebaut and Nestle) and manufacturing (Nestle, Hershey, Cadbury, Mars and Philip Morris). The number of large specialized cocoa traders fell from about 50 in 1980 to only two in 2002 (Losch 2002). As a consequence, cocoa producers currently face a monopsony situation on the sale side, meaning there are only a few buyers that they can sell to (Haque 2004).

On the global scale cocoa production is subject to boom-and-bust-cycles resulting in a geographic shifting of production centres. The profitability of tree crops usually is highest if they are grown in newly deforested areas, which provides an incentive for farmers to establish new plantations in primary forest as it is available rather than to replant already cultivated land which is labour- or capital-intensive (Ruf et al. 1996, Angelsen and Kaimowitz 2004, Ruf and Schroth 2004)

## Cocoa production in Indonesia

Between 1980 and 1994, Indonesia experienced a ‘cocoa boom’ with production increasing at an average rate of 26 percent p.a. Presently, Indonesia is the third largest producer of cocoa after Ivory Coast and Ghana with over 490.000 metric tons (MT) produced 2008/2009 (14% of global production; (ICCO 2010a). Smallholders from Central Sulawesi, Southeast Sulawesi and South Sulawesi provinces produce nearly 75 percent of the national cocoa bean output (Akiyama and Nishio 1996, COPAL 2008) providing the main source of income for over 400.000 farming households (Panlibuton and Meyer 2004).

The favourable soil-climate combination, cheap inputs and plenty of labour force made yields of up to 3000 kilogram per hectare possible during the 1990ies. Low taxation and efficiently working local cocoa marketing channels result in high producer prices in comparison to other cocoa producing regions (Panlibuton and Meyer 2004, Ruf 1995). The biggest competitive advantages of Sulawesi's cocoa production include its low costs, high production capacity, efficient infrastructure and the open trading and marketing system.

Since there exists just a single market for almost all levels of bean quality, with little price differentiation, smallholder farmers have no incentives to invest in improved quality of cocoa beans by enhanced production and processing measures, such as a solid fermentation process (Panlibuton and Meyer 2004). Sulawesi cocoa is traded on the global market as unfermented, fat, bulk bean ('Sulawesi FAQ') and due to its lower costs it is used as filler in chocolate production, blended with other fermented beans to add flavour. Global demand for these bulk beans is not significantly affected by changes in price. Main quality losses are caused by high infestation rates of Cocoa Pod Borer (CPB) *(Conopomorpha cramerella)*, followed by poor production practices (Panlibuton and Meyer 2004). Following this pattern, the Indonesian cocoa sector had been rapidly expanding under near free-trade conditions, followed by declining profitability due to pest infestations since 2003/04 (Neilson 2007).

In Sulawesi as the recent "pioneer front", farmers initially benefited from a 'forest rent', associated with good soil fertility and low levels of pests and diseases. This rent declines over time. During the last few years, first indications of declining yields arose in Sulawesi, mainly due to severe pest and disease infestation, above all by CPB. Reacting to the declined productivity, farmers are more likely to convert new forest lands into cocoa plantations than to replant cocoa seedlings on the old plantations (Ruf 1995). In consequence, local cocoa production tends to be unsustainable. Knowledge on plant protection and replanting is weak because only a limited number of cocoa farmers has had access to training and extension activities as of now (Neilson 2007).

Still, cocoa is the most profitable crop in the LLNP region. Despite the financial crisis, producer prices were increasing during the last 3 years (~18% annually) (ICCO 2010b) and global demand is likewise still on the rise with an increase of the world chocolate consumption of 2-3% per year (ICCO 2008a). Hence, the expansion of cocoa production and the intensification of cocoa agroforests is likely to continue.

The remainder of the thesis is organized as follows: Chapter 1 assesses the structure and management of cocoa agroforestry systems in the LLNP region in terms of socio-economic and soil properties across an agricultural intensification gradient. In Chapter 2, we determine the socio-economic drivers of cocoa agroforestry expansion and intensification by using regression analysis techniques. Chapter 3 is a comprehensive trade-off analysis that quantifies the marginal changes in the total economic value of forest conversion and agroforestry intensification by deploying a cost-benefit approach. In Chapter 4, the impacts of PES schemes on forest conversion and agroforestry intensification are estimated using a dynamic ex-ante modelling approach at the farm household level. Finally, some overall conclusions derived from the results of the four chapters are given in a closing section.

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# 1 Chapter

## Structure and management of cocoa agroforestry systems in Central Sulawesi across an intensification gradient

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**Summary**

Central Sulawesi is a major cocoa producing region in Indonesia. Nevertheless, very little is known about the basic socio-economic and pedological properties of cocoa agroforestry systems in the region. In the vicinity of Lore Lindu National Park (LLNP), 144 cocoa plots covering an intensification gradient were selected for an intensive 1-year cocoa management study including a subset of 48 plots for extended soil analyses.

Local cocoa plots are mostly established by converting natural forest lands, and they are increasingly intensified by removal of their natural shade tree cover. Soil nutrient status is mostly sufficient but total P availability and stagnant soil water conditions limit yields. Phytosanitary and soil amelioration management are often suboptimal and may need to be improved. Marketing of cocoa beans takes place mostly via small traders from the same village. Farm gate prices account for around 70% of world market prices. No price incentives exist for enhancing bean quality by better processing.

Cocoa bean yield varies strongly by season. A structural intensification index integrating data on canopy closure, cocoa tree density, number of native forest trees and number of intercrops, was positively correlated with yields. Labour input also increases yield. Labour input was not correlated with the structural intensification index but expenses for material inputs and hired labour as well as biophysical parameters as rainfall and phosphor content were. The strong economic incentive for farmers to intensify cocoa agroforests threatens local biodiversity and ecosystem functioning.

*Keywords*

*Cocoa agroforests, plot structure, shade management, yields, yield determinants, intensification, soil analysis*

## 1.1 Introduction

Although already introduced to Java at the beginning of the $18^{th}$ century and to Northern Sulawesi in the late $18^{th}$ century, Indonesian cocoa did not play a major role at world markets until the 1990ies (Durand 1995, Pomp and Burger 1995). Between 1980 and 1994, Indonesia's cocoa production increased at an average rate of 26 percent p.a. Presently, Indonesia is the third largest producer of cocoa after Ivory Coast and Ghana with over 480.000 metric tons produced 2007/2008 (13% of global production; ICCO 2008). Recent production increases are in bulk cocoa produced by cocoa hybrid lines (FAO 2003). Smallholders from Central Sulawesi, Southeast Sulawesi and South Sulawesi provinces produce nearly 75 percent of the national cocoa bean output (Akiyama and Nishio 1996, COPAL 2008) providing the main source of income for over 400.000 farming households (Panlibuton and Meyer 2004).

Indonesia’s cocoa expansion was favoured by the availability of suitable land providing "forest rents" (high initial soil fertility and low levels of pests and abundance of pollinators), low production cost, a relatively good transport infrastructure, favourable macroeconomic policies, and the entrepreneurship of smallholders (Akiyama and Nishio 1996, Ruf et al. 1995). Low taxation and efficiently working local cocoa marketing channels result in relatively high producer ('farm gate') prices.

In the past three decades, cocoa area increased from zero (1979) to ~18.000 ha around and inside Lore Lindu National Park (LLNP) in Central Sulawesi (Maertens 2003), which is part of the Wallacea biodiversity 'hotspot' (Myers et al. 2000). Agricultural expansion of perennial cropping systems - mainly cocoa - often after illegal slashing of natural forest were identified as the main drivers of regional forest conversion (Erasmi et al. 2004, Koch et al. 2008). Although, traditionally, wet rice is grown around LLNP, cocoa agroforestry provides substantially more income (Schwarze 2004). Intensification of cocoa agroforestry systems appears as a financially favoured strategy, as yields can nearly be doubled when decreasing canopy cover from medium (50-65%) to zero-shade conditions (Steffan-Dewenter et al. 2007, Schneider et al. 2007). Consequently, a shift takes place from multilayer agroforestry systems with diverse shade canopies to rather simply structured cocoa plantations with only one or two planted shade tree species (Siebert 2002, Steffan-Dewenter et al. 2007).

Although data availability on long term cocoa agroforestry performance under different management intensities is scarce, declining cocoa yields in sun-grown systems are known, for example, from Ghana. Pest and disease pressures are usually mounting a few years after the introduction of wide-spread, intensified cocoa cropping (Ahenkorah et al. 1974, Ahenkorah et al. 1987). In the project region, intensification may also put soil fertility and sustainable production at risk (Belsky and Siebert 2003). With regard to soil fertility, local cocoa agroforestry appears less demanding than annual upland crops (Dechert et al. 2004). First reports of partly dramatic yield losses have appeared in recent years from Sulawesi, however (Reuters 2009).

During the last decade, agroforestry systems have repeatedly been investigated with respect to conservation aspects. Shaded coffee agroforestry systems with natural forest trees can maintain some of the original rainforest biodiversity (Perfecto et al. 1996, Moguel and Toledo 1999). Recent results from the LLNP area indicate that this is partly also true for shaded cocoa agroforestry systems (Steffan-Dewenter et al. 2007). Although substantial loss in specialized forest species takes place during the initial conversion of rainforests to agroforests, high to intermediate shade cocoa plots may still serve as important habitat for the native flora and fauna. A further shift to intensive, low shade plots is expected to result in high additional biodiversity losses (Steffan-Dewenter et al. 2007).

Previous studies of agriculture in the LLNP region focused on the intermediate section of the intensification gradient (Steffan-Dewenter et al. 2007). In order to analyse the implications of the ongoing intensification process as well as pro-biodiversity policy options requiring high shade cocoa agroforestry systems, data across the entire intensification gradient are necessary, though. Thus, we designed and conducted a detailed, one-year cocoa management study that documents plot establishment and structure, soil nutrient status, pest and disease pressure, as well as plot management, yields, processing and marketing. In this contribution, we focus on descriptive data and bivariate correlations between plot and management variables including cocoa yield. This is the first step in a comprehensive set of analyses on ecology-economy trade-offs in cocoa cropping around LLNP. With the initial "forest rents" (Ruf 1995) steadily declining, such knowledge is indispensable for a systematic search for sustainable land use options that improve rural incomes without unnecessarily jeopardizing biological diversity.

## 1.2 Methods

### 1.2.1 Study area and sampling

The study was conducted in 12 villages in the vicinity of LLNP in Central Sulawesi, Indonesia. The selected villages are part of a 13 village random sample (Zeller et al. 2002). The villages are located in four valleys covering altitudes from 75 to 1275 m a.s.l.: Palu valley (Maranata, Pandere and Sidondo II), Palolo Valley (Berdikari, Bulili and Sintuwu), Napu valley (Watumaeta, Wuasa, Wanga and Rompo) and Kulawi valley (Bolapapu and Lempelero). This region provides near optimal agro-climatic conditions for cocoa farming, which include an annual precipitation of 1500-2000 mm, a dry season of not more than 3 months, and temperatures with 30-32°C mean maximum and 18-21°C mean minimum. Soil depth should not be less than 1.5 m and soil pH should be between 6.0 and 7.5 (Wood 1985a). In mountainous regions of LLNP, annual average precipitation reaches 2500 mm (Berlage 1949 in Leemhuis 2005). In the sampled villages, rainfall varies between 1215 mm (Sigimpu, 640 m a.s.l.) and 1900 mm (Talabosa, 1090 m a.s.l.). Mean annual temperatures range from 21°C (Wuasa, 1133 m a.s.l.) to 27.4°C (Pandere, 93.3 m a.s.l.) (daily meteorological data from 2002-2006, STORMA-B1, H. Kreilein).

In each of the 12 villages, a sample of one cocoa plot of each of 12 cocoa producing households was selected, resulting in a total sample size of 144 plots. The cocoa agroforestry plots were not randomly selected but systematically chosen to represent the entire intensification gradient of high to low canopy closure (CC) values. Canopy closure is the proportion of the sky hemisphere obscured by vegetation when viewed from a single point (Jennings et al. 1999). Plot selection was accomplished in two waves in 2006 guided by German researchers with prior experience in the project region, and supported by local staff. Site selection was conducted based on farmer assessments of plot canopy closure and on-site verifications by hemispherical convex densiometer measurements (Model-C, Robert E. Lemmon). Per village, three plots were identified for each of 4 *a priori* defined shading categories: (near) natural forest cover (>85% CC; category "1"), dense shade cover (>65% CC; "2"); medium shade cover (>35% CC; "3"); low to zero shade (0-35% CC; "4"). For all plots, structural and management data were sampled (1.2.2, 1.2.3). Soil analysis was conducted for a subset of 48 plots (1.2.4).

### 1.2.2 Agroforest structure

Plots were characterised in terms of plot history and structure including cocoa tree density, intercrops and shade trees. Plots were geo-referenced and photographed, and their layout sketched. Shade tree cover, i.e. CC, was monitored three times from 2006 to 2008. We measured CC as the average of 8-16 randomly selected points per plot using a hemispherical convex densiometer.

Canopy closure itself can already be viewed as a proxy for intensification in cocoa agroforestry (Juhrbandt and Barkmann 2008). However, intercrops such as banana or coconut also contribute to CC, and a dense upper canopy may even consist of trees of a single planted shade tree species without conservation value (e.g., *Glyricidia sp*.). Specifically for analyses in a biodiversity conservation context, CC is a very rough an indicator. For a compact albeit more comprehensive inclusion of structural plot parameters, we turned to a Management Intensity Index (MI) suggested by Mas and Dietsch (2003). Adapting their concept, our MI includes the planting density of cocoa trees as well as the total number of native forest tree species and intercrop species per plot besides CC. Each of the four components of the index was normalised, and values added. Resulting MI scores range from 0 to 4 with 4 indicating the most intensive system.

### 1.2.3 Agroforest management

Farmers were contracted to prepare weekly records on yields and several yield determining factors from January to December 2007. In each village, one particularly collaborative farmer was employed to support the preparation of the records. Every month, local university graduates collected and checked the management record sheets. Surveyed parameters include capital and labour used for: plot management activities (including phytosanitary measures), cocoa pod and bean processing, for changes in plot structure, intercropping, fertilizer input, pesticide input, fungicide and herbicide input. Finally, yield of fresh pods and proceeds from dry bean marketing were recorded.

Adoption of agricultural innovations as well as farmer perceptions on soil fertility, and on the impact of pests, diseases, dryness and tree age on cocoa production were surveyed additionally. Particularly, farmer statements on the year of the first occurrence of Cocoa Pod Borer (CPB) *(Conopomorpha cramerella)* and Black Pod Disease (BPD) *(Phytophthora palmivora* L.*)* on their cocoa plot were captured and yield losses due to these two species documented for the beginning of infestation and in 2007.

### 1.2.4 Soil analyses

One plot per shading category in each village was selected for soil analyses, resulting in a subset of 48 cocoa plots. Accessible and homogeneous plots were preferentially selected. In order to locate the soil sampling plot, 6 to 15 Pürckhauer profiles were analyzed for each of the 48 plots. Based on this on-site analysis, a representative 20m x 20m sampling plot was chosen. Within the sampling plot a 1m x 1m x 1m soil profile was excavated.

Soils were classified into two water condition categories:

0= Dry to fresh sites: Groundwater level 2-3m, soil profile shows no stagnant moisture.

1= Moist and groundwater sites: Groundwater level 1m or less, close to rivers, or flooded after heavy rainfall; soil profile showed strong stagnant moisture or gleyic conditions.

Within the sampling plot, three 5m x 5m subplots were defined surrounding the soil profile. Mixed samples were taken at three depths (0-10cm, 10-30cm, 30-50cm) by five Pürckhauer profiles per subplot. These depths cover the main distribution of roots and soil nutrient stocks in previously investigated cocoa agroforestry systems (Hartemink 2005).

Measured soil parameters, which are essential to judge soil nutrient status in the tropics, include: the total amount of Carbon ($C_t$), Nitrogen ($N_t$) and Phosphorus ($P_t$), the amount of available Phosphorus ($P_{av}$) (cf. Bray and Kurtz 1945), exchangeable Calcium ($Ca_{ex}$), Potassium ($K_{ex}$), Magnesium ($Mg_{ex}$) and Aluminium ($Al_{ex}$), and the effective Cation Exchange Capacity ($CEC_{eff}$). Lanfer (2003) provides a simple classification scheme in terms of general soil nutrient status (Tab. 1). The classification scheme is based on a synthesis of several dedicated studies. Nutrient concentrations were converted into kg ha$^{-1}$ (sampled thickness [m] x bulk density [kg m$^{-3}$] x nutrient concentration [kg kg$^{-1}$] x area [m² ha$^{-1}$]). For this classification, the first 30 cm of the topsoil are considered. All units are kg ha$^{-1}$·0.3m$^{-1}$ except $CEC_{eff}$ [kmol ha$^{-1}$ 0.3m$^{-1}$]; av. = available, ex. = exchangeable.

Table 1. Classification for different soil parameters, derived from different studies (see below).

| Parameter Level | $C_t$ | $N_t$ | $P_{av}$ | $Ca_{ex}$ | $K_{ex}$ | $Mg_{ex}$ | $Al_{ex}$ | $CEC_{eff}$ |
|---|---|---|---|---|---|---|---|---|
| Low | <1.5 | <0.10 | <3 | <0.4 | <0.15 | <0.2 | <0.3 | <4 |
| Medium | 1.5-4.5 | 0.10-0.15 | 3-7 | 0.4-4 | 0.15-0.3 | 0.2-0.8 | 0.3-1.0 | 4-8 |
| High | >4.5 | >0.15 | >7 | >4 | >0.3 | >0.8 | >1.0 | >8 |
| Source | (1) | (2) | (1), (4) | (1) | (1) | (1) | (3) | (1) |

(1) Cochrane & Sanchez (1982), (2) Guamán (1999), (3) Iniap, (in Lanfer 2003). (4) Bray 1945. $P_t$ is not included in this classification system.
$C_t$ and $N_t$ in [%], $P_{av}$ in [ppm] and $Ca_{ex}$, Kex, $Mg_{ex}$, $Al_{ex}$ and $CEC_{eff}$ in [cmol kg$^{-1}$].

### 1.2.5 Data analyses

Labour, capital, inputs and outputs were aggregated at a monthly and yearly level for further analyses. All parameters were expressed on per hectare basis, except the number of native forest tree species and the number of intercrops. As most species are not homogeneously distributed, species richness is not increasing continuously with area, so that an up- or downscaling of species richness with area would lead to biased results. Cocoa yields are calculated as kilograms sun-dried cocoa beans per hectare sold to small traders, middlemen or collection centres.

Gross margins (USD per ha) are calculated as the differences between revenues (sale of cocoa beans and intercrops) and variable input costs. Variable costs include expenses for pesticides and fertilizers, transport costs, paid labour, seeds and other material. Returns to labour are calculated as USD (average exchange rate 2007) gross margin per hour of total working time.
Pearson correlation analysis and regression analysis were used to identify linear relationships between canopy closure and several CC-dependant variables as well as between yields and several yield determining factors. For linear regression analysis, ordinary least squares (OLS) analysis was used. Influential observations were excluded using Cook's distance measures (>4/sample size are influential observations). One-way ANOVA with Tukey post-hoc tests were applied to determine group differences in marketing analysis. All statistical analyses were carried out either with SPSS 16.0 or Stata 9.2.

## 1.3 Results

### 1.3.1 Structure and management of cocoa plots

**Plot establishment**

35.4% of the farmers reported that they established their cocoa plots by converting natural forest land. Cocoa agroforestry usually follows a few seasons of dry land agricultural crops. 22.9% reported to have converted other perennial cropping systems (coconut or coffee), and 25% that they converted land with annual crops. 28.5% of the plots were purchased as established cocoa plots between 1970 and 2005. Between 1995 and 2005, the average price was 582.8 USD $ha^{-1}$. Even after adjustment for inflation, plot prices significantly increased since 1995 ($P < 0.001$, inflation adjusted according to International Monetary Fund, World Economic Outlook Database, April 2009).

**Plot structure**

The entire CC gradient was covered although zero shade plots were found in the Palu valley where cocoa plots are often grown under coconut trees. CC ranged from 1.6% to 98.6% in 2008 (average CC 42.4% in 2008). Cocoa plot size was between 0.4 and 3.3 ha (0.63 ha on average) with 75% of the plots smaller than 1 ha. With substantial variability, mean planting density was 854 (STD 346.2) cocoa trees per ha. Planting density was highest in Palolo. Cocoa tree age varied between 3 and 27 years. In Palolo, cocoa trees were slightly older on average reflecting a longer cocoa cropping history.

We found high variability of intercrops and shade trees. Native forest trees were present on 66% of the plots with up to 9 different species per plot. A high share of forest trees was found in Kulawi valley plots. A total of 80 different native forest tree species were identified by farmers. 91 % of the plots were intercropped with 1 to 5 intercrops (mean 1.8). In total, 20 different intercrops were found. Intercrops were predominantly bananas and perennials such as fruit trees, coconut or coffee. Vanilla or vegetables were also frequently grown. The highest diversity of intercrops was found in Palu valley.

**Pest and disease pressure**

Cocoa Pod Borer (CPB) *(Conopomorpha cramerella)* and Black Pod Disease (BPD) *(Phytophthora palmivora* L.*)* spread rapidly: Farmers reported that BPD and CPB arrived in their villages around the year 2000 or later. In 2007 BPD and CPB occurred on 100% and on 99% of all plots respectively. Farmers estimated yield losses of 24.3% on average due to CPB (median 20%, maximum 70%), and 20.5% due to BPD. BPD and CPB induced yield losses are correlated ($r = 0.45$, $P < 0.001$). Plots farther away from the forest edge showed lower CPB yield losses ($r = -0.215$, $P = 0.01$). Yield losses due to BPD decreased with higher altitude ($r = -0.32$, $P < 0.001$).

Recommended cultural control techniques to combat CPB and BPD include 4 major steps: frequent harvest (at 14 days interval), cocoa pruning, sanitation of pod husks (removal, burning or burying of affected pods) and fertilization (ACDI/VOCA 2005). None of the household applied all 4 steps, and only 8.4% reported employing 3 steps. Whereas 37.8% of farmers practiced sanitation of pod husks, not a single household harvested at a 14-day-interval. In contrast 51.7% of the farmers used pesticides. Farmers who had suffered high yield losses already when CPB first occurred at their plots, reported spraying pesticides more frequently later (r=0.28, P=0.013). About half of the households stated that they were able to reduce yield losses occurring by CPB (51%) and BPD (53.8%) attacks since begin of infestation. More frequent pruning of cocoa trees helped reducing BPD (r= -0.177, P=0.041), higher fertilizing and pesticide application frequency reduced CPB yield losses (r= -0.2, P=0.018 and r= -0.176, P=0.038 respectively), whereas an increase in CC between 2007 and 2008 led to increasing CPB yield losses (r=0.279, P=0.001).

**Soil characterization**

Cocoa plots are located on lower slopes, alluvial fans and at the border of the alluvial basins, resulting in geologically young topsoil. According to the WRB/FAO (2007) soil classification, the following soil types were found: Cambisols, Gleysols, Phaeozemes, Stagnosols and Fluvisols. Cambisol was found on 30 of 48 plantations in different specifications (gleyic, eutric, stagnic, fluvic, endoskeletic). The following catena of soil types was identified from the slope to the basin: Cambisol followed by stagnic/ gleyic Cambisol and in the basins Gleysol, and fluvic/ gleyic Cambisol. A comprehensive characterisation of the stocks and available nutrients from the 48 investigated plots is provided in Tab. 2.

Table 2. Stocks and available nutrients within the first 30 cm of the topsoil.

| | $C_t$ | $N_t$ | $P_t$ | $P_{av}$ | $Ca_{ex}$ | $K_{ex}$ | $Mg_{ex}$ | $Al_{ex}$ | $CEC_{eff}$ |
|---|---|---|---|---|---|---|---|---|---|
| n | 44 | 48 | 44 | 40 | 40 | 40 | 40 | 40 | 48 |
| Mean | 52.068 | 5.024 | 2.193 | 12 | 6.889 | 664 | 1.148 | 301 | 341 |
| SD | 15.831 | 1.752 | 1.312 | 10 | 2.904 | 292 | 773 | 333 | 137 |
| Max | 98.914 | 8.612 | 7.279 | 41 | 13.132 | 1.515 | 3.357 | 1.463 | 648 |
| Median | 49.902 | 4.992 | 1.856 | 10 | 6.168 | 636 | 765 | 202 | 298 |
| Min | 25.257 | 1.756 | 458 | 1 | 1.578 | 247 | 407 | 42 | 130 |

All units are kg $ha^{-1}\cdot0.3m^{-1}$ except $CEC_{eff}$ [kmol $ha^{-1}$ $0.3m^{-1}$]; av. = available, ex. = exchangeable. Many plots are classified as low nutrient plots mainly for C and $P_{av}$. For $N_t$ and exchangeable Al, plots are evenly distributed across all three categories. For the remaining nutrients and $CEC_{eff}$, most plots attain a medium to high nutrient status (Tab. 3).

Table 3. Nutrient status distribution of cocoa plots according to Lanfer (2003); Numbers of cocoa plots in each category (low to high); numbers vary due to data gaps (missing analyses).

| | $C_t$ | $N_t$ | $P_{av}$ | $Ca_{ex}$ | $K_{ex}$ | $Mg_{ex}$ | $Al_{ex}$ | $CEC_{eff}$ |
|---|---|---|---|---|---|---|---|---|
| n | 44 | 48 | 44 | 40 | 40 | 40 | 40 | 48 |
| Low | 38 | 18 | 34 | 1 | 0 | 1 | 12 | 1 |
| Medium | 6 | 19 | 6 | 3 | 12 | 0 | 12 | 29 |
| High | 0 | 11 | 4 | 36 | 28 | 39 | 16 | 10 |

Only 43% of surveyed households ever fertilized their cocoa plots, and in 2007 even only 27.3% did so. 30.1% of farmers stated that soil fertility was already reduced compared to the time when they started to manage the plot. There is no correlation between plot fertilization and cocoa yields.

**Cocoa yields**

2007 yields showed a broad range (7-1613 kg $ha^{-1}$) with an average of 476.9 kg $ha^{-1}$ and pronounced seasonality (Fig. 3).

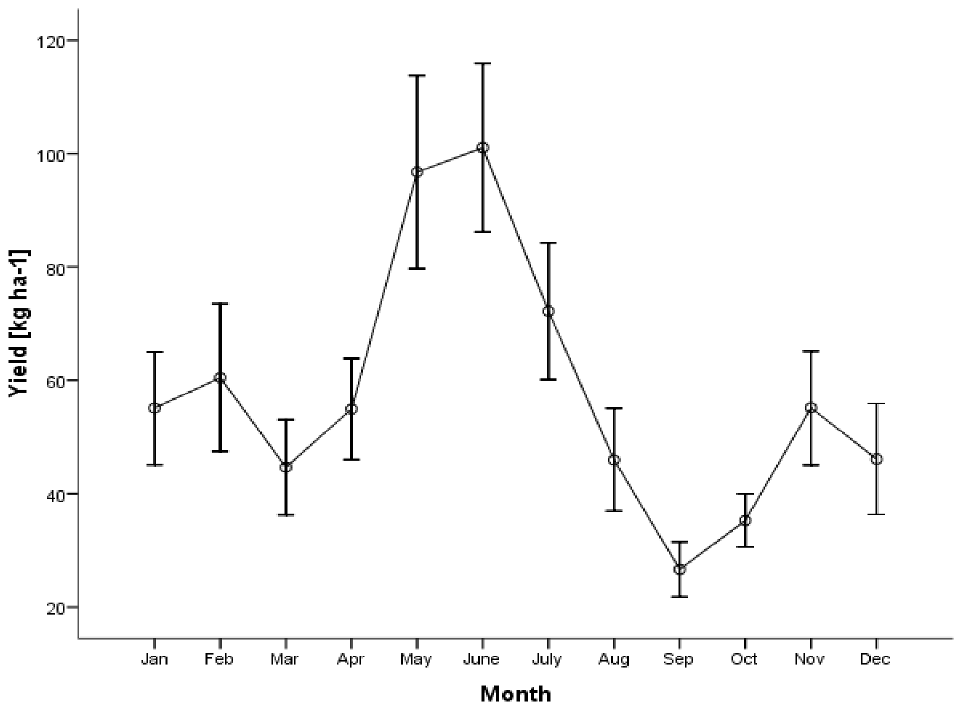


Figure 3. Average monthly yields in 2007 (n=143, error bars show standard deviations).

Canopy closure, presence of stagnant soil water conditions, number of native forest tree species and number of intercrops were correlated – in this order – with decreasing yields (Tab. 4). Increasing yields were correlated with cocoa tree density and labour input. Among themselves, plot structural parameters were frequently correlated. Aggregated in a Management Index (MI) as a proxy for plot structure intensification, they revealed substantial explanatory power for cocoa yield variation (Fig. 4).

Table 4. Correlation of plot structure parameters and cocoa yields (n=143).

| | Cocoa yield [kg $ha^{-1}$ $yr^{-1}$] | Planting density of cocoa trees [ $ha^{-1}$] | No. forest tree species per plot | No. intercrops per plot | Canopy cover [%] | Material input expenses [IDR $ha^{-1}$] | Total work time [h $ha^{-1}$ $yr^{-1}$] |
|---|---|---|---|---|---|---|---|
| Cocoa yield [kg $ha^{-1}$ $yr^{-1}$] | 1 | | | | | | |
| Planting density [cocoa trees $ha^{-1}$] | 0.337** | 1 | | | | | |
| No. forest tree species per plot | -0.205* | n.s. | 1 | | | | |
| No. intercrops per plot | -0.197* | -0.226** | n.s. | 1 | | | |
| Canopy cover [%] | -0.396** | -0.169* | 0.182* | 0.279** | 1 | | |
| Material input expenses [IDR $ha^{-1}$] | n.s. | n.s. | n.s. | n.s. | -0.141 | 1 | |
| Total work time [h $ha^{-1}$ $yr^{-1}$] | 0.248** | 0.191* | n.s. | n.s. | n.s. | n.s. | 1 |

Pearson correlations; n.s.: not significant; displayed correlation coefficients significant at p<=0.1; *: p<=0.05; **: p<=0.01.

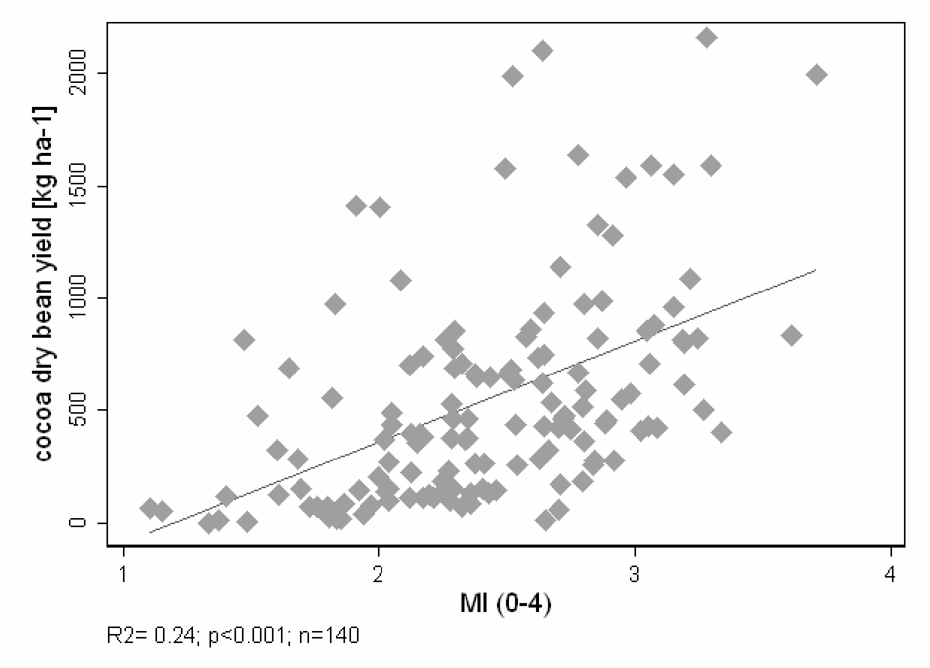


Figure 4. Cocoa dry bean yield 2007 in relation to a Management Index MI (0-4) composed of plot structural parameters.

Influences of soil parameters surveyed on a subset of plots (n=48) on cocoa yields are not very strong. In regression analysis, only total soil phosphor content is a yield determinant (Tab. 5). The model improves when a dummy for stagnant soil water conditions is included, which has a negative influence on yields.

Table 5. Regression analysis, dependant variable: cocoa yield (n=43).

| Cocoa dry bean yield [kg ha$^{-1}$] vs. | $R^2$ | p | Coeff. total soil P | Coeff. stagnant water |
|---|---|---|---|---|
| Total soil P [kg ha$^{-1}$] | 0.21 | 0.002 | 0.456 (p=0.002) | |
| Total soil P [kg ha$^{-1}$], stagnant water (0/1) | 0.27 | 0.002 | 0.453 (p=0.002) | -0.25 (p=0.07) |

**Processing and marketing**

Of four main post-harvest activities, cracking of the cocoa husk followed by extraction of the beans require, by far, most labour per hectare (Fig. 5).

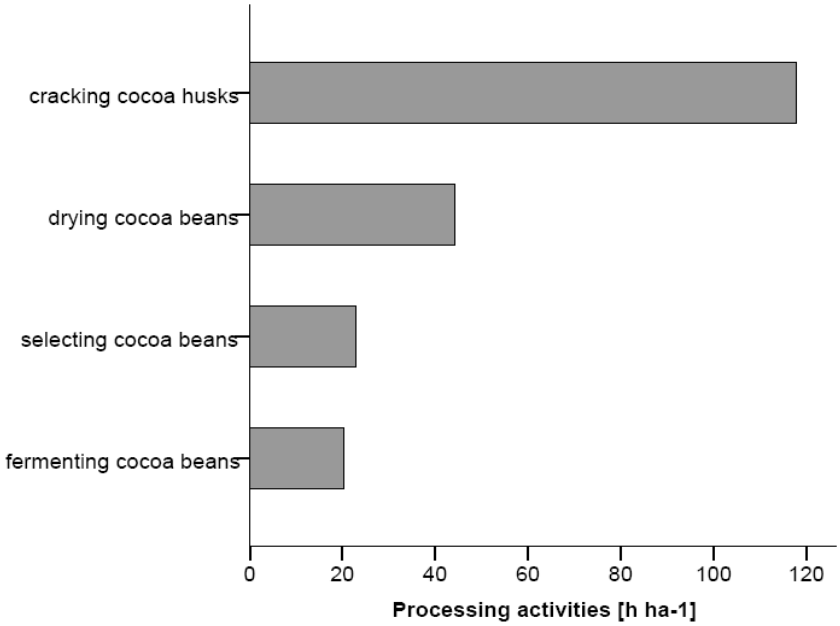


Figure 5. Labour requirement for cocoa bean processing (means of n=144 plots).

71.8% of all cocoa beans were sold within the same village, mostly to small traders or middlemen. Only 14.4% of sales were done at a cocoa collection centre in the province capital Palu.

Producer prices at farm gate rose quickly in early 2007, and peaked in July (Fig.6) closely following world market price (FOB, ICCO monthly averages; ICCO 2008). Farmers of the project region received on average 70.2% (minimum: 62.4%, maximum 77.4%) of the world market price. The linear correlation between local and world market prices is very high (r=0.834, P=0.01).

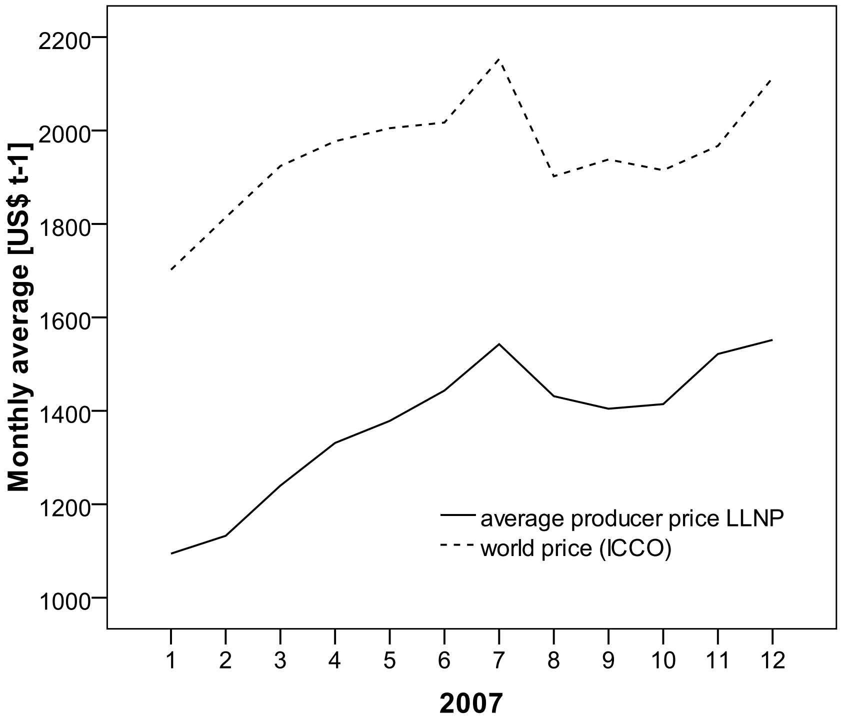


Figure 6. Cocoa producer prices in the LLNP region and world market prices in 2007 (monthly averages in USD $t^{-1}$ dry beans; world prices according to ICCO 2008).

One-way-ANOVA with Tukey post-hoc tests showed the following significant cocoa price differences ($p<0.01$): Prices were higher when cocoa beans were sold directly in Palu compared to sales in the neighbour village (+11.1%) or at the home village (+16.2%). Higher prices were also achieved by selling directly to a big merchant compared to selling to a middleman (+13.7%) or to a small trader (+15.5%). Prices gained in Palolo valley were significantly higher than in the other valleys (+6.4%).

### 1.3.2 Shade management and Intensification

**Shade Management**

From 2006 to 2008, a reduction in CC was measured on 72% of all cocoa plots. For example, 65% of the households eliminated shade trees on their cocoa plots in 2007 alone. Plots with initially high CC in 2006 tended to show the highest decreases. In contrast, nearly shade-free plots in 2006 tended to increased in CC (Fig.7). Between

2007 and 2008 alone, canopy closure decreased from 64.3% to a mere 42.3% on average.

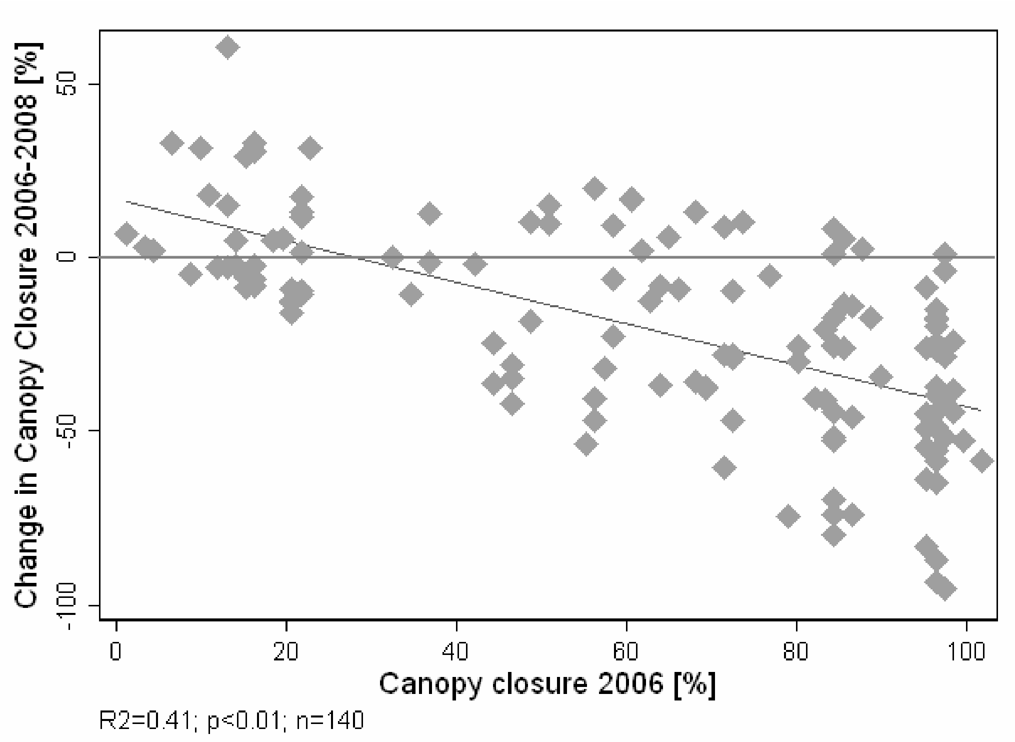


Figure 7. Change in Canopy closure from 2006-2008 in relation to initial CC 2006 in % ($R^2$=0.412, P=0.05).

Canopy closure is more closely related to the total number of intercrops on a plot (r=0.279; P=0.001) than to the number of native forest tree species (r=0.182; P=0.029). Planted shade trees which have no food usage are often times leguminous, $N_2$ fixing trees. 92.7% of all plots include planted leguminous trees, mostly *Glyricidia sp*. or *Erythrina sp.*

**Structural intensification vs. labour and material inputs**

The average annual labour input for cocoa plots was 86.2 person-days per hectare (minimum: 9.4; maximum 339.1). Weeding belongs to the most labour demanding activities accounting for up to 72.2% of the total working time (mean 19.5%). Weeding is neither correlated with MI nor with the use of herbicides. Furthermore, we found no correlation between labour for any of the activities and material inputs. In concert with increasing yields, relatively more time is used for harvesting along an increasing MI gradient ($r=0.39$, $P<0.01$).

Structural intensification according to MI goes along with higher inputs of hired labour ($r=0.18$, $p=0.04$) and expenses for material inputs such as pesticides and fertilizer ($r=0.14$, $p=0.09$). In contrast, no relationship was found between MI and total working time.

**Structural intensification vs. pest pressure**

Initial yield losses when infestation with CPB or BPD began are negatively correlated with 2008 CC (CPB: $r=-0.24$, $P=0.004$; BPD: $r=-0.17$, $P=0.04$). *Current* yield losses, in contrast, are positively correlated with higher CC for CPB ($r= 0.19$, $P=0.02$). Regression analysis reveals some evidence for yield loss due to pest pressure along the intensification gradient (BPD: $R^2=0.08$, $p=0.001$, $n=128$; CPB: $R^2=0.05$, $p=0.01$, $n=136$).

**Intensification vs. soil fertility and rainfall**

Soil fertility in terms of total phosphor ($P_t$) content is higher on more intensively managed plots (Fig. 8). For available phosphor ($P_{av}$), the relationship is even weaker ($R^2=0.07$, $p=0.08$, $n=44$). In contrast, total soil potassium ($K_t$) content is decreasing ($R^2= 0.15$, $p=0.01$, $n=46$).

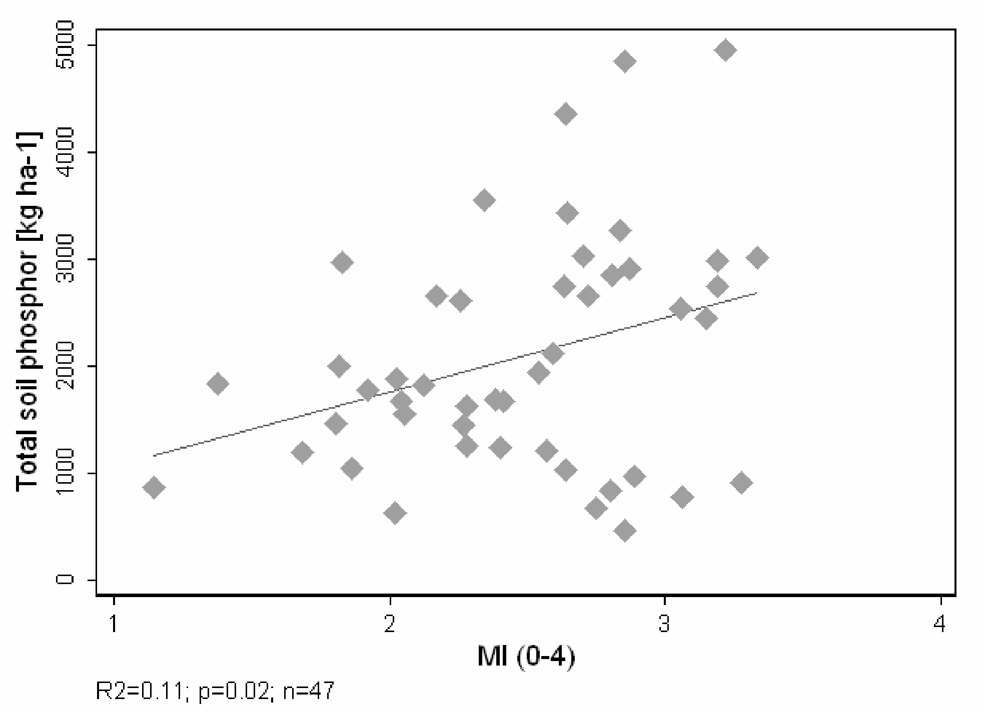


Figure 8. Total soil phosphor content in relation to MI.

Management intensity increases significantly with average yearly rainfall (Fig. 9).

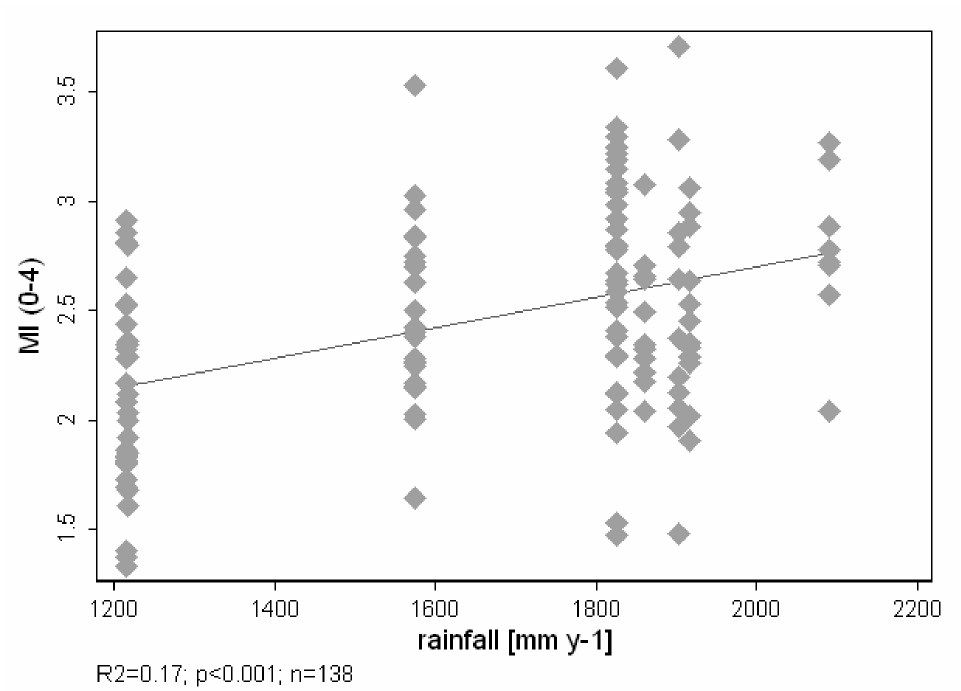


Figure 9. MI in relation to rainfall.

**Intensification vs. gross margins and returns to labour**

The share of intercrops in total revenues from cocoa plots is very small (4.6% on average), only 12% of households have a share higher than 10%. Gross margins are closely related to cocoa yields ($r=0.916$, $p<0.001$), and therefore display a similar relationship to the MI (see Fig. 4). Also when related to labour input, returns to labour are increasing along the intensification gradient (Fig. 10).

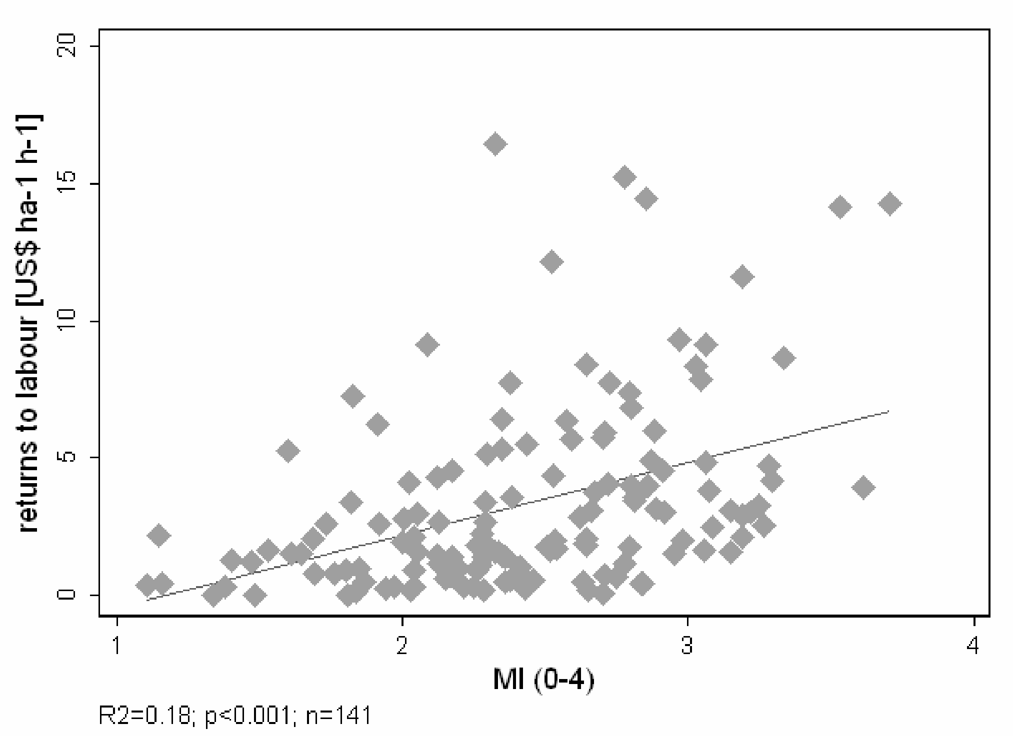


Figure 10. Returns to labour along a structural intensification (MI) gradient.

## 1.4 Discussion

With this contribution, we give a comprehensive overview on the structure and management of cocoa agroforests across virtually the entire gradient of canopy cover and management intensities found around Lore Lindu National Park in Central Sulawesi. In the following, we discuss the influence of tree age, pest pressure, management and soil fertility on cocoa yields, followed by an analysis of the special role the intensification process plays in the LLNP region and its economic and ecological impacts.

Plots surveyed in this study roughly fall within the typical range of plot sizes on Sulawesi, where 95% of the production is grown on plots of 0.5 to 1.5 ha (Taher 1996, Panlibuton and Meyer 2004). Globally, 70% of cocoa is produced by small farms (Donald 2004).

In the LLNP region, directly age-related yield declines need not be a main issue for years to come. Cocoa trees are relatively young and mostly in an early producing phase. In Malaysia, highest cocoa yields were found for trees between 15 and 20 years, but the profitable life span may reach 50 years (Montgomery 1981 in Wessel 1985). High pest and disease pressure (see below), can reduce the economically viable lifespan of cocoa trees, however (Wessel 1985, Lass 1985b).

Corroborating recent data by Neilson (2007), we found substantial self-reported CPB-related yield declines. Together with losses due to BPD, yield losses in Central Sulawesi are comparable to global average estimates of pest and disease induced yield losses of ~30% (Padwick 1956 in Duguma et al. 2001). In West Africa, for example, yield losses vary between 10-80% being highest in Cameroon (50-80%; Bakala and Kone 1998 in Duguma et al. 2001).

In spite of the pest and disease pressure and farmer trainings on integrated pest management by the Sustainable Cocoa Enterprise Solutions for Smallholders (SUCCESS) Alliance in 2005 (ACDI/VOCA 2005) in the same region, our results indicate a low level of adoption of integrated pest management practices. Farmers rely strongly on the effect of pesticides while important but labour-intensive activities such as sanitary pruning, frequent harvests and, above all, the sanitation of pod husks are only rarely practiced (Taher 1996, Lass 1985a).

The soils of the investigated cocoa plots have high stocks of soluble minerals (Ca, Mg and K; cf. Wood 1980). This is not uncommon in the humid tropics if high geologic activity results in young soils. The average nitrogen contents are moderate compared to literature values for cocoa plots (Hartemink 2005, Wood 1980). The lack of any influence on yield indicates that these nutrients are usually not limiting. Only for wet, stagnant soil water conditions and available P, influences were found.

Available phosphorus (56 kg $ha^{-1}$ on average) was low compared to other cocoa sites (cf. Hartemink 2005), and lower than recommended for successful cocoa growing (Wood 1980). The results of the Lanfer classification scheme confirm the impression about the nutrient status, but also reveal that humus content ($C_t$) is low. Improved organic matter management would also benefit N and P contents.

Phosphorus is a key factor for sustainable agriculture in the Tropics and may limit production (IRRI 1990, Appiah 2004, Ojeniyi et al. 1982). P deficits can also reduce N uptake in cocoa (Lockard and Asomaning 1964, Smith 1992) and the fixation of $N_2$, for example by leguminous shade trees (Mappaona and Kitou 1995). We find, in fact, that high P availability positively influences cocoa yields in the investigated sample of cocoa plots. Most available P is usually stored in an organically bound fraction, i.e. in litter and/or humus (White and Ayoub 1983), and is lost easily by water or wind erosion (Brams 1973). An application of P fertiliser could be particularly useful in combination with improved humus and soil cover management.

The average annual cocoa bean yield in our sample (476.9 kg $ha^{-1}$) falls within the low end of the yield spectrum reported for the entire island of Sulawesi (400 to 800 kg $ha^{-1}$; Panlibuton and Meyer 2004). It is also far below the reported Indonesian average in 2007 (801 kg $ha^{-1}$; FAOSTAT 2009). Ten years earlier spectacular yields of 2500 kg $ha^{-1}$ on average on alluvial soils without intercropping or shade trees and around 1500 kg $ha^{-1}$ in the uplands were common on Sulawesi (Ruf et al. 1995). The interpretation of our average yield value should be interpreted with caution; however, as we did not draw a random sample but purposefully oversampled low- and high-shading plots. In a representative study in the project area, farmers reported average annual yields of 531 kg $ha^{-1}$ (data from 204 cocoa producing households with productive cocoa plots/ minimum age of 4 years; van Edig and Schwarze 2007 unpubl.) Nevertheless, our average yield is close to the average yield in West Africa (495 kg $ha^{-1}$ in 2007), and higher than average yields from South America (393 kg $ha^{-1}$; FAOSTAT 2009).

Yields in our sample depend on several structural parameters of the plots. Low CC, as well as a reduced number of forest trees and intercrops, and a higher cocoa tree planting density significantly lead to higher yields. If combined to a structural management intensity index (MI), the influence is strong. In addition to structural parameters, total working time dedicated to cocoa management influences yields positively. Total labour input is not related to intensification (MI) in our study. Moreover, average labour input in 2007 (86.2 person-days $ha^{-1}$) accounts for only about one third of the labour demand for cocoa as estimated by the Indonesian Ministry of Agriculture (235 person-days $ha^{-1}$). Thus, labour inputs appear extremely low. As compared to wet rice farming, cocoa farming is seen as a labour saving option of land-use by many farmers (personal observation, Juhrbandt 2007). Extremely low labour input was also reported for (early) mixed cocoa systems in Malaysia (Lass 1985c).

The strong positive impact of labour indicates that substantial income effects may be realised without additional intensification in terms of structural modifications or higher inputs of plant protection agents. More labour investment could also raise the quality of the produced beans, for example, by a better fermentation process (Panlibuton and Meyer 2004). Fermenting is a crucial step in cocoa bean processing, influencing bean quality substantially. Currently, there exists only a single market for almost all levels of bean quality, with little price differentiation. Thus smallholder farmers have no incentives to invest more labour into an improved quality.

Cocoa farmers of the project region receive a high share of the world market price as also reported by Panlibuton and Meyer (2004). This high share is related to the relatively competitive market situation of the Indonesian cocoa sector and is much higher than for cocoa produced in other countries or for other commodities produced in Indonesia (Akiyama and Nishio 1996). In West Africa, for example, the farm gate price is usually only about 50% to 63% of world market prices (Panlibuton and Meyer 2004).

A clear trend towards low shade tree covers can be recognized across the project region for virtually all but the already least shaded plots. The effects of light and plant nutrition on cocoa yields are interrelated: Cocoa responds well to increased light if nutrients and pest pressure are not limiting (Almeida and Valle 2007, Wessel 1985, Ahenkorah et al. 1974). Long-term experimental shade and fertilizer trials in Ghana (Ahenkorah et al. 1974, Ahenkorah et al. 1987) had indicated that sun-grown cocoa plantations may not be able to sustain high yields over long periods. The deterioration of unshaded cocoa trees was more rapid and more severe than under no-shade conditions. Faster nutrient depletion was suggested as an explanation (Ahenkorah et al. 1974). Confirming the results from Dechert et al. (2004), our data do not provide evidence for particular nutritional stress. The cultivation of cocoa in full sun may still be unsustainable, e.g., because of higher weather risks (Belsky and Siebert 2003), however, in our 1-year-study we did not find any immediate yield disadvantages of low- or no-shading cocoa farming.

A radical reduction of shade canopies in intensive cocoa agroforestry can affect biological diversity and ecological functioning (Siebert 2002, Schroth and Harvey 2007, Franzen and Borgerhoff Mulder 2007). While there is strong evidence that the current structural intensification in the project region has negative impacts on biological diversity of forest species (Steffan-Dewenter et al. 2007), the functional consequences of intensification are much more difficult to quantify. Regarding impacts on hydrology, Kleinhans (2003) found that compared to primary or older secondary forest, cocoa plots have only a small negative impact on dry season hydrology, for example, while annual cultures have a much more strongly negative effect. Yet, different cocoa systems were not considered. Regarding the impacts on the ecological function of natural pest control, our data do not allow to draw clear conclusions on the role of structural intensification, although there is some evidence of reduced yield loss towards the more intensive systems. In contrast, Bos et al. (2007) found that fruit losses due to pathogenic infections and insect attacks increase with the homogenization of the agroforests, supporting the hypothesis that agricultural homogenization increases the risk of pest outbreaks.

Yields, gross margins and returns to labour turn out to increase sharply with intensification in terms of canopy thinning and plot structure simplification, indicating a strong economic incentive to intensify cocoa production by the removal of shade trees. However, shade trees in agroforestry systems often provide secondary products such as fruits and timber contributing to household income and nutrition (Rice and Greenberg 2000, Gockowski et al. 2004, Franzen and Borgerhoff Mulder 2007). Belsky and Siebert (2003) report that an increasing share of local residents in Central Sulawesi values crop diversification. Yet, the share of intercrops sales in cocoa plot revenues was found to be usually very small in LLNP region.

## 1.5 Outlook: Current status of Cocoa agroforests in Central Sulawesi and road ahead

Compared to other cocoa producing regions in the world, Central Sulawesi is still a relatively ‘young’ production frontier. Still, our results show that pest and disease pressure have started to reduce the forest rents obtainable a few years ago, and that selected nutrient deficiencies can be observed (cf. Ruf 1995). In face of these growing agro-ecological challenges in cocoa cropping, the search for 'sustainable' land use options becomes particularly important. Complementing the natural habitat of protected areas by biologically rich buffer zones, high to medium shade agroforestry could play an important role for integrated biodiversity conservation strategies in the tropics (Schroth et al. 2004; Schroth and Harvey 2007; Steffan-Dewenter et al. 2007). However, results from our cocoa management study show that - in line with the high financial attractiveness of structural intensification - a clear trend towards simplified, low-shade cocoa agroforestry is prevalent in the project area. Without suitably gauged offers of financial incentives, for example via a price premium for certified 'biodiversity-friendly' produced cocoa (Barkmann et al. 2007) or direct compensation payments for environmental services ("PES"; Schneider et al. 2007, Mas and Dietsch 2003, Dahlquist 2007), this trend is likely to continue (see also Chapter 4).

From an agronomic point of view, our results show a potential for substantial improvement, especially with regard to pest and disease management, P fertilisation and humus management as well as cocoa bean processing. The high returns to additional labour inputs in our sample indicate that a higher labour input in the respective activities is particularly called for. This may result in a further income and welfare-improvement of smallholders without necessitating a further simplification of the cocoa agroforests or higher inputs of chemical plant protection agents. Unfortunately, the farmer field schools of SUCCESS Alliance have been discontinued in 2005, and the establishment of PES or certification programs needs to overcome high implementation costs.

From a research perspective, further integrated in-depth analyses of the patterns found in this study will contribute to a better understanding of the drivers and impacts of the 'intensification syndrome' that we observe in the LLNP region. But also for some fundamental issues in environmental economics and conservation science, the study provides essential data. Particularly, we intend to quantify the private net benefits of ecosystem conversion along the entire intensification gradient from forests to monocultures (see Chapter 3). Complementing data from the project region on major biodiversity and functional ecosystem responses of intensification will allow us to compare these financial benefits to much of the environmental benefits lost (cf. Balmford et al. 2002).

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# 2 Chapter

## Socio-economic drivers of land use change in Indonesia – The case of cocoa agroforestry expansion and intensification in Central Sulawesi

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**Summary**

In many cocoa producing regions, the traditional cultivation under the canopy of planted or natural shade trees is increasingly switched to full-sun systems without shade trees. This results in potentially detrimental effects for the agroecosystem in terms of biodiversity and ecosystem function loss. The expansion of cocoa area has dominantly taken place in areas of prior primary forests, contributing substantially to the loss of remaining rainforests.

Indonesia is currently the third largest cocoa producer worldwide with a persistent production increase. At the rainforest margins around Lore Lindu National Park (LLNP) in Central Sulawesi (Indonesia), an intensification process by removing natural shade tree cover in initially diverse agroforests is ongoing. Intensification is financially favourable, but risky in terms of agronomical and ecological sustainability. Cocoa area almost tripled during the last two decades. This expansion was identified as the main driver of regional forest conversion.

In this study, we examine both the causes of cocoa agroforestry expansion and intensification by using empirical data of cocoa producing households from 12 villages in the vicinity of LLNP. Cocoa area expansion and intensification are basically affected by the same set of driving factors. In tendency, better-off households dominate both, intensification and the extension of cocoa area. I.e., neither process is poverty driven. Both land use changes are constrained by labour availability and aging households. Most significantly, migrant households, many of which stem from South Sulawesi, are triggering intensification and expansion. In summary, expansion and intensification of cocoa agroforests is rather driven by economic factors indicating a commodity and market oriented strategy of farmers than to a subsistence based strategy (impoverishment theory). Cocoa intensification and area extension are likely to go hand in hand, making a land-sparing effect of agricultural intensification unlikely for this case of cash crop production.

However, tree-crop based systems provide considerable potentials for a sustainable agricultural development particularly at forest margins if they are suitably managed. Substantial improvements are required in terms of pest and disease management, soil amelioration and replanting. The development of alternative development pathways needs to include also measures which are capable to reduce the pressure on remain-

ing rainforests, including the diversification of farm and off-farm income as well as opportunities for market incentives promoting the conservation of forests and the development of sustainable and diverse agroforestry systems.

## 2.1 Introduction

Cocoa is a perennial cash crop which is mainly produced in Latin America (Belize, Mexico, Ecuador, Peru, Costa Rica and Brazil), West Africa (Cote d'Ivoire, Cameroon, Ghana, Nigeria, and Sao Tome), and Indonesia (Sulawesi, Central Sumatra and Borneo) (Franzen and Borgerhoff Mulder 2007). It is cultivated in agroforestry systems displaying a wide spectrum of production intensities (Rice and Greenberg 2000). Whereas the cultivation under the canopy of planted or natural shade trees is the traditional way of cocoa production, full-sun cocoa cultivation is nearly devoid of shade trees and it is becoming increasingly common in the main cocoa growing regions (Ruf 2007, Franzen and Borgerhoff Mulder 2007).

In many cocoa producing regions, particularly in West Africa and on the Indonesian islands of Sulawesi and Borneo, the expansion of cocoa area has dominantly taken place in areas of prior primary forests (Rice and Greenberg 2000). Indonesia's cocoa boom was favoured by the availability of such highly suitable land providing "forest rents" (high initial soil fertility and low levels of pests and abundance of pollinators), low production cost, a relatively good transport infrastructure, favourable macroeconomic policies, and the entrepreneurship of smallholders. Also low taxation and efficiently working local cocoa marketing channels resulting in relatively high producer prices contributed to a cocoa boom (Ruf 1995, Akiyama and Nishio 1996, Ruf et al. 1996).

At the rainforest frontiers around the Lore Lindu National Park (LLNP) in Central Sulawesi (Indonesia), cocoa area increased from zero to ~ 18,000 hectares between 1980 and 2001. From 2001 to 2007, cocoa acreage further increased to 20,600 hectares (Reetz 2008). This expansion took mainly place at the upland forest margins, partly inside LLNP (Maertens 2003, Sitorus 2004). Agricultural expansion of perennial cropping systems - mainly cocoa - was identified as the main driver of regional forest conversion (Erasmi et al. 2004, Koch et al. 2008).

The expansion of cocoa cropping area may result in ecologically unwarranted deforestation. Deforestation generally describes ‘situations of complete long-term removal of tree cover’ (Kaimowitz and Angelsen 1998). The mean annual deforestation rate in LLNP area was 0.3 percent between 1983 and 2002 (Erasmi and Priess 2007). This is much lower, however, than the Indonesian average, which globally displays the second highest deforestation rate (2% p.a. between 2000 and 2005, FAO 2006). Between 2001 and 2007, forest area further decreased by 4.8% (Reetz 2008).

The conversion of intact rainforests to agricultural land use is accompanied by major losses in biological diversity and ecosystem functioning. Tropical deforestation is globally considered the single most important source of carbon dioxide emissions (Duxbury 1995), accounting for about 25% of all anthropogenic emissions of greenhouse gases in 2005 (Houghton 2005). Deforestation is also the major proximate cause of biodiversity loss (Perrings 2001, Pagiola et al. 1997) and often results in downstream damage in form of sedimentation and changing flow peaks (Chomitz and Kumari 1996, Pagiola and Holden 2001). Degradation of agroecosystems and deforestation was frequently connected to poverty-induced pressure in order to meet basic needs in the past (e.g. Brundtland Report, WCED 1987). This was recently also documented for the LLNP area (van Edig 2010). However, deforestation is regularly driven by a complex set of regionally distinct causes, where economic opportunities in combination with institutions can play an important role (Angelsen and Kaimowitz 1999, Geist and Lambin 2002, Lambin et al. 2001, Vosti et al. 2002). Particularly cash cropping is increasingly discussed as a strong driver of land use change, as farmers in developing economies pay incremental attention to signals of market development and adapt their land use to it (Brookfield 2001). Indeed, the expansion of the cash crop cocoa seems to result from other causes than poverty in LLNP area: Among the crops grown after forest conversion, cocoa dominated in most years, particularly between 2001 and 2003 (van Edig 2010). For this period a pronounced change in agricultural livelihood strategies from subsistence production of rice towards cash crop production was documented also by Weber et al. (2007). Cocoa is a crop that is predominantly grown by the less poor in the research area, though

(Schwarze et al. 2007, van Edig 2010). This raises the question whether the agents of deforestation are really the poorest farmers when considering the case of cash crop production. In-migration for example is playing a crucial role for the increasing cash crop orientation in the project region. Especially Bugis migrants are known to be specialised in cocoa cultivation and they introduce this knowledge into the area. As they often have less direct access to new arable land, they usually acquire land by buying from autochthonous farmers (Weber et al. 2007, Barkmann et al. 2010).

Besides the expansion of cocoa plantations, another crucial aspect of land use change, which is observed in LLNP region, is the intensification of cocoa agroforests. Cocoa is grown in differing agricultural intensities that can be characterized in the first place by the amount and composition of shade tree cover. Local cocoa plots are mostly established by converting natural forest lands at the rainforest margin (Juhrbandt et al. 2010, Ruf 1995, Ruf and Schroth 2004). When established under a natural forest canopy, cocoa systems often retain much of the original biological diversity (Steffan-Dewenter et al. 2007). However, they become increasingly simplified in subsequent intensification steps as their natural shade tree cover is successively removed (Siebert 2002). This ongoing process often leads to cocoa monocultures grown under full-sun conditions (Juhrbandt et al. 2010). As cocoa responds well to increased light if nutrients and pest pressure are not limiting (Almeida and Valle 2007), the intensification process goes along with increased yields, at least in the short run. Yields in the LLNP area, for example, can nearly be doubled when canopy cover is reduced from medium (50-65%) to zero-shade conditions (Steffan-Dewenter et al. 2007). Most recent data from a more detailed dataset confirm these results (Juhrbandt et al. 2010).

Agricultural intensification is usually defined as a process of raising land productivity over time through increases in inputs on a per unit area basis (Shriar 2000, Ellis 2000, Brookfield 1993) within the context of the prevailing social and economic drivers (Lambin et al. 2000). Lambin et al. (2001) identify three major paths to intensification corresponding basically to the induced intensification theory (Turner and Ali 1996). These paths can be applied well to cash-crop production in the LLNP region:

1. Beginning land scarcity drives intensification in economies not yet fully integrated in the market. Land scarcity is usually connected to population density and population growth. It reduces land-labour ratios and shifts production towards high value crops and market commodities.
2. In the following commodification pathway, markets trigger the commercial intensification of agriculture. This can cause economic differentiation, the rise of wage labour, and other adjustments.

Market opportunities, cash crop production and government intervention often attract migrants, thus, inducing linkages among all three pathways.

Agricultural intensification leads to changes in cropping regimes, which can result in altered agroecosystems. These modified systems often display a reduction in species diversity and they may, in consequence, be more susceptible to exogenous shocks or environmental changes (Perrings 2001, Lee et al. 2001). Likewise in the LLNP region, the described intensification process causes environmental damage. Ecological analyses covering the LLNP project area indicate that the most substantial losses of the original forest species diversity occur with the initial conversion of forests to agroforestry systems and then during the final intensification step towards the very intensively managed full-sun cocoa systems (Steffan-Dewenter et al. 2007). At medium intensities, relatively high levels of biodiversity can be maintained at high cocoa yields (Clough et al. 2011). In the long-term, risks of yield losses in full-sun systems have been hypothesized to increase because of a higher susceptibility to drought, a faster decline of soil nutrient status, and increased insect and disease infestations (Belsky and Siebert 2003). In fact, many cocoa growing regions in Central Sulawesi suffer from severe infestation by pests and diseases. In cases of very high infestation rates, cocoa production is likely to break down (Ruf 2007).

From a perspective of food and livelihood security, the growing reliance of local households on high intensity-cocoa cropping is a risky strategy because income from cocoa is susceptible to unpredictable global market forces and price changes (Belsky and Siebert 2003). Furthermore, the advantages of shade trees, which provide for example fruits and timber, are getting lost during intensification (Rice and Greenberg 2000, Gockowski et al. 2004, Franzen and Borgerhoff Mulder 2007). Sustainably managed cocoa agroforests can retain a substantial portion of the original forest's environmental benefits, however (Rice and Greenberg 2000, Asare 2006, Schroth and Harvey 2007, Bisseleua and Vidal 2008, Gockowski and Sonwa 2008, Cassano et al. 2009). This was also shown in great detail for the LLNP region (Steffan-Dewenter et al. 2007, Tscharntke et al. 2011).

In contrast to the deforestation literature, studies on driving factors of intensification are comparatively rare. While in the past, research focused mainly on land-cover change, such as deforestation, meanwhile the importance of the more subtle processes of land cover modification have been recognised. One of the most significant forms of land-cover modification is agricultural land intensification (Lambin et al. 2000). However, factors determining farmer decisions to intensify production are not entirely understood (Pagiola and Holden 2001). In the economic sciences, there is a long tradition in examining agricultural intensification as a function of management, input levels and external factors such as prices, e.g. by production function analysis. However, few studies include driving factors others than economic incentives (Lambin et al. 2000). Likewise, the ongoing trend of simplifying the shade canopies of cocoa agroforestry systems in various parts of the tropics has, so far, received little attention (Siebert 2002, Schroth and Harvey 2007).

The objective of this study is to examine the socio-economic drivers of land-use change in the LLNP region by focusing on the expansion and intensification of cocoa agroforests. Using detailed cocoa production data from the household level, we assess the impact of household and farm characteristics on the likelihood and degree of past cocoa area extension. We compare the drivers of cash crop expansion to driving factors of the intensification of cocoa agroforestry.

## 2.2 Methodology

### 2.2.1 Analytical Framework

Cocoa producing households of the LLNP region make decisions about forest clearance, land-use and farm resource allocation, leading to activities that directly change land use. Agents of land-use change form the core of the analytical framework; consequently the analysis is carried out on farm household level (cf. Wunder 2005). Farmer decisions are based on household characteristics concerning resource endowments (factor use constraints) and exogenous decision parameters (prices, environmental factors etc.), which together form the set of immediate causes of land use change (Kaimowitz and Angelsen 1998). Broader contextual changes in economic, political, cultural demographic and technological forces determine agents' characteristics and decision parameters. These factors belong to the *underlying* causes of land use change (Geist and Lambin 2002). In contrast to *underlying* causes, which will not be considered in this study, the immediate causes of land use change are directly relevant to decision makers. Immediate causes are mostly better to handle, preferably in micro-level models. It is important to separate these two levels in order to keep the cause-effect relationship consistent (Kaimowitz and Angelsen 1998, Geist and Lambin 2002).

The immediate causes of land-use change related to cocoa production include the characteristics of cocoa producing households and refer to physical capital (farm structure and land resources), personal capital (education, household demographics), social capital (membership in organisations, ethnicity), financial capital (credit and off-farm income) and poverty.

### 2.2.2 Study region and sample selection

Empirical data on cocoa agroforestry management were gathered in 12 villages in the vicinity of LLNP in Central Sulawesi, Indonesia. The villages are located in four valleys covering altitudes from 75 to 1275 m a.s.l.: Palu, Palolo, Napu, and Kulawi valley. The region provides favourable agro-climatic conditions for cocoa farming (Wood 1985). In each of the 12 villages, a sample of one cocoa plot of each of 12 cocoa producing households was selected, resulting in a total sample size of 144 plots. The cocoa agroforestry plots were systematically chosen to represent the entire intensification gradient of high to low canopy closure (CC) values. Canopy closure is the proportion of the sky hemisphere obscured by vegetation when viewed from a single point (Jennings et al. 1999). Site selection was conducted based on farmer assessments of plot canopy closure and on-site verification by hemispherical convex densiometer measurements (Model-C, Robert E. Lemmon). Per village, three plots were identified for each of 4 *a priori* defined shading categories: (near) natural forest cover (>85% CC; category "1"), dense shade cover (>65% CC; "2"); medium shade cover (>35% CC; "3"); low to zero shade (0-35% CC; "4"). Plots were characterised in terms of plot history and structure including cocoa tree density, intercrops and shade trees. Shade tree cover, i.e. CC, was monitored three times from 2006 to 2008. We measured CC as the average of 8-16 randomly selected points in cocoa tree gaps per plot using a hemispherical convex densiometer.

Farmers were contracted to prepare weekly records on yields and several yield determining factors from January to December 2007. Surveyed parameters include capital and labour used for management activities and input (e.g., fertilizer, pesticides) as well as output in terms of dry cocoa bean yield.

Cross sectional data from cocoa agroforestry are complemented by socio-economic farm and household data from panel surveys conducted in 2001, 2004 and 2006 (van Edig and Schwarze). These panel data stem from a 13 village random sample (Zeller et al. 2002), which overlapped with the cocoa agroforestry sample (n=144) in 80 cocoa farming households. However, basic socio-economic characteristics were surveyed for the complete cocoa agroforestry sample.

### 2.2.3 Measuring rainforest conversion led by cocoa area extension

In this study, we explicitly consider only land conversion as triggered by cocoa area extension because direct indicators of deforestation are difficult to quantify. The total area deforested in the region can not be decomposed into distinct subsequent land uses, because cocoa is often not planted directly after clear-cutting, but rather subsequent to several years of annual crops, such as maize and beans (Juhrbandt et al. 2010). To circumvent the mentioned difficulties, we apply the increase in cocoa agroforestry area from 2001 to 2006 as a proxy for cocoa led land conversion, assuming most of the new cocoa area was derived more or less directly from natural rain forests. Since cocoa is the main driving force of deforestation in the area, we consider this simplification as justified. Cocoa area extension in this time frame is derived from the socioeconomic panel dataset. For this purpose, total cocoa area per household was extracted from panel data of 2001 and 2006 (13 village random sample, see 2.2.2). Per household cocoa area of 2001 was subtracted from cocoa area of 2006 in order to obtain the increase in cocoa area.

### 2.2.4 Measuring agricultural intensification

The concept of intensification is poorly defined in the literature and adequate measuring techniques are lacking (Shriar 2000). In the past, intensification was "usually measured in terms of output per unit of land or, as a surrogate, input variables against constant land" (Turner and Doolittle 1978). Nowadays this approach is considered unsuitable for comprehensive intensification studies because of their impreciseness or even incorrectness, particularly in regions with a high diversity in production strategies (Shriar 2000, Lambin et al. 2001). Shriar (2000, 2005) developed an Agricultural Intensity Index (AI Index) for evaluating the intensity of different farm units based on farmer technologies and practices. In contrast to earlier approaches, he considers indications of scale and uses local knowledge to assess the degree to which each strategy contributes to higher yields. However, the applied specification of intensity ranks appears rather coarse and the index lacks information on plot structure parameters that would make it a suitable tool for measuring intensification in agroforests.

This was attempted by Mas and Dietsch (2003), who developed a Management Index (MI) for coffee agroforests based on five plot structure parameters. We adopt this approach for cocoa agroforests, and define a MI based on three plot structure parameters (canopy openness, planting density and number of native forest trees on the cocoa plot), as intensification in cocoa agroforests of our study region consists in the first place of removal, thinning and simplification of shade canopy cover. For the calculation of MI, all three plot structure parameters are converted into factors from 0 to 1, where 1 indicates the most intensive value of a variable. For planting density, the overall lowest value of the sample was set to 0 because a low planting density also indicates low management intensity. The factors of the other point values are derived by [point value - lowest value] / [highest value – lowest value]. The same calculation method applies for canopy openness, since high openness values are related to high management intensities. In the case of the number of forest tree species on the cocoa plot, high values indicate low management intensities; hence, a value of 0 for forest tree species is set to intensity factor 1. The according factors are then calculated by (1- [point value - lowest value] / [highest value – lowest value]). Finally these factors are summed-up for each cocoa plot, resulting in a potential MI range from 0 (least intensive) to 3 (most intensive). For modelling purposes, the MI is normalized to a range of 0 to 1 (see section 2.2.6). For the model we consider only households, for which the investigated cocoa plot (cocoa agroforestry study) captures more than 75% of total cocoa area. Hence, we obtain a study sub-sample of 78 households (71 households after data cleaning). This reduction in sample size is justified by the fact that, by doing so, we avoid that the investigated cocoa plot, which is defined in terms of management intensity, takes only a minor proportion of the overall cocoa area of the respective farm, whereas the majority in turn could be managed otherwise.

### 2.2.5 Determinants of land use change

The focus of analysis is set on the characteristics of cocoa farming households referring to physical, private, social and financial capital. Macro-level variables (e.g. demography, government policies, and world market prices) are excluded from analysis because their influence on intensification and expansion decisions is rather indirect, difficult to measure and because variation in these parameters is expected to be rather small within the project region.

Explanatory variables used for explaining agroforestry intensification and cocoa area expansion cover the following categories:

1.) Land endowments and farm structure (physical capital): *Farm area* and the *share of cocoa in total farm area.* The share of cocoa in total farm area is a parameter for farm land allocation and a proxy for farming strategy (commodity vs. subsistence orientation).

2.) Household parameters referring to personal capital: *Household size* (number of household members) is a proxy for relative labour availability in farming households. On the other hand, household size can also indicate the consumption demand of a household. The *average age of adult household members* is an indicator for the current stage within the live cycle of a household. It can reflect current household preferences with respect to innovativeness and financial and labour investments, e.g., in land clearing, crop production, education of children. *Household head completed SD* is included as an education dummy (SD=Primary School) and refers to personal capital in terms of formal education.

3.) Household parameters referring to social capital: The *average number of local organisations in which the household members are organised* is an indicator of social capital endowed by rural households. A dummy variable '*Non-indigenous households'* is included in order to capture possible differences between locals and migrants (c.f. Weber et al. 2007).

4.) Household parameters referring to financial capital include *Total off-farm income* and the *Maximum credit* a household can obtain per year by formal and informal sources as measured in IDR per year.

5.) An *index for relative poverty* is calculated applying an approach developed by Zeller et al. (2003) (see also Henry et al. 2003), based on principle component analysis (PCA). Abu Shaban (2001) developed a relative poverty index for the LLNP region derived from one expenditure-, two food-, three asset-, and four dwelling-related parameters.

6.) Variables for location include four location dummies for the four different valleys (Palu, Napu, Palolo, and Kulawi).

### 2.2.6 Regression models

Land use and land cover change research is oftentimes based on modelling approaches, because models allow for understanding key processes and for their quantification. We employ empirical-statistical models using multiple linear regression techniques to analyse the driving factors of cocoa area extension and intensification.

#### Modelling the effects on cocoa area extension

In order to identify determinants of cocoa expansion, we attempt to identify determinants not only for the probability of households to extend their cocoa area, but also of the extent of area expansion conditional to expansion. For this purpose, we apply a Tobit model which is appropriate when the same explanatory variables influence both the probability of adoption and its extent, because conventional regression methods fail to take into account the qualitative difference between zero and continuous observations (Wooldridge 2003). Input data are derived from 166 cocoa producing households of the socioeconomic panel survey. The dependant variable is the extension of cocoa cropping area between 2001 and 2006, which includes a substantial share of zero values as many households did not expand cocoa area at all. For explanatory factors lag-variables from 2001 were used to adhere to a proper cause-effect relationship.

The Tobit model is an extension of the Probit model, and it was originally developed by James Tobin (Tobin 1958). Tobit models are explicitly developed for censored dependant variables (with upper and/or lower limits), that comprise a substantial amount of zero values (Godoy et al. 1997, Godoy et al. 1998, Dolisca et al. 2007). The error term is assumed to follow a truncated normal distribution. When determining both, the probability and the intensity of adoption, elasticities measured at the means can be decomposed into an elasticity of adoption and an elasticity of effort when adoption occurs. Tobit models have been rarely applied in agroforestry studies so far (Mercer 2004).

We apply a model of the type Tobit 1 for dependant variables censored at zero:

$$y_i{*} = x_i\beta + \varepsilon_i \quad with \quad \varepsilon_i \sim N(0,\sigma^2) \tag{1}$$

$y_i{*}$ *is* a latent variable which linearly depends on $x_i$. The error term $\varepsilon_i$ is normally distributed with mean at zero and variance $\sigma^2$ (Wooldridge 2003).

The observed value $y_i$ is censored at zero:

$$y_i = \begin{cases} y_i{*} & if \quad y_i{*} > 0 \\ 0 & if \quad y_i{*} \le 0 \end{cases} \tag{2}$$

$y_i$ is the observed censored variable, which is equal to the unobserved latent variable $y_i$*, when $y_i$* is bigger than zero. In all other cases $y_i$ is equal to zero.

The coefficients are calculated by maximum likelihood estimators (MLE), whereas the likelihood consists of the product of expressions for the probability of obtaining each observation. For each observation greater than zero this expression is just the height of the appropriate density function representing the probability of getting that particular observation.

Hence, the log likelihood function can be defined by

$$\log L = \sum_{\{i|y_i>0\}} \ln\left[\sigma^{-1}\varphi\left(\frac{y_i - x_i\beta}{\sigma}\right)\right] + \sum_{\{i|y_i=0\}} \ln\left[1-\varphi\left(\frac{x_i\beta}{\sigma}\right)\right] \qquad (3)$$

$\beta$ and $\sigma$ are estimated in an iterative numerical procedure. The ML estimator requires homoscedasticity and the normal distribution of the error term (Schmidheiny 2007). In order to avoid heteroscedasticity, robust standard errors as proposed by White (1980) were applied in the analysis (Gujarati 2004). Standard errors of fitted values are tested for normality, using kernel density plots and Shapiro-Wilk tests.

The direct interpretation of $\beta$ coefficients would reveal information only on the latent variable $y_i$*, which mostly is of minor interest. In order to interpret the effects on the expected value of the observed (censored) value, marginal effects should be analysed (cf. Wooldridge 2003, Cong 2000, McDonald and Moffitt 1980).

Two distinct effects are of major interest in our study:

1.) The changes in the probability of being uncensored, hence the probability of cocoa area extension:

$$\partial P \frac{(y_i * > 0)}{\partial x_i} \qquad (4)$$

and 2.) The changes in the conditional expected value of the dependant variable, hence the effects on the extent of area expansion, conditional on expansion:

$$\partial E \frac{\left(y_i * \middle| y_i * > 0\right)}{\partial x_i} \tag{5}$$

The probability of cocoa area extension (equation (4)) is, in addition, calculated with a Probit model in order to test the consistency of Tobit regression results. Tobit and Probit regressions are calculated in Stata 9.2.

**Modelling the effects on intensification**

For the analysis of intensification determinants, we have to consider that the MI is bound between 0 and 3. For variables with a lower and upper bound, the beta distribution can be a suitable model. Particularly, when the boundaries are fixed (i.e., there are no out-of-domain scores) and when boundary scores are qualitatively equal to interior scores, a beta regression should be preferred to a Tobit regression (Smithson and Verkuilen 2006). In contrast, Tobit models treat boundary cases as qualitatively distinct from cases in the interior (see previous paragraph).

Ferrari and Cribari-Neto (2004) propose a regression model that is tailored for situations where the dependent variable ($y$) is measured continuously on the standard unit interval, i.e. $0 < y < 1$. Fitting a bounded dependant variable which exceeds this range can be realized by just rescaling this variable (cf. Smithson and Verkuilen 2006). This type of regression model is based on the assumption that the response is beta distributed. The beta distribution is very flexible for modelling proportions since its density can have quite different shapes depending on the values of the two parameters that index the distribution (Paolino 2001). The model of Ferrari and Cribari-Neto (2004) is defined by only two shape parameters that do not correspond directly to either the mean or variance of the distribution. Rather, the mean and variance of a (standard) two parameter beta distribution are functions of the two shape parameters, $\alpha$ and $\beta$. It is considered to be flexible enough to handle a wide range of applications (Paolino 2001).

Instead of using the conventional parameterization approach with two shape parameters ($\alpha$ and $\beta$), Buis (2006) proposes an alternative parameterization with one location and one scale parameter ($\varphi$ and $\mu$). We here apply the alternative parameterization of the beta regression which is useful if covariates are present (Ferrari and Cribari-Neto 2004, Paolino 2001, Smithson and Verkuilen 2006) and which corresponds to the conventions of Generalized Linear Models (GLM) (Buis 2006).
The probability density for the beta distribution in the alternative parameterization is given by

$$f\left(y|\mu,\varphi\right)=\frac{\Gamma(\varphi)}{\Gamma(\mu\varphi)\Gamma\left[(1-\mu)\varphi\right]}\,y^{\mu\varphi-1}(y-1)^{(1-\mu)\,\varphi-1},\quad 0<y<1 \qquad (6)$$

where $\mu > 0$, $\varphi > 0$ and $\Gamma(.)$ is the gamma function. The mean and variance of $y$ are, respectively,

$$E(y)=\mu \qquad (7)$$

and

$$\operatorname{var}(y)=\mu(1-\mu)\frac{1}{1+\varphi} \qquad (8)$$

The likelihood function is then defined by

$$\log L(\mu,\varphi|y)=\sum_{i=1}^{N}\ln\Gamma(\varphi)-\ln\left[\Gamma(\mu\varphi)\right]-\ln\left[\Gamma((1-\mu)\varphi)\right]+\left[\mu\varphi-1\right]\ln(y)+\left[(1-\mu)\varphi-1\right]\ln(y-1) \qquad (9)$$

We use a statistical package for Stata 9.2 (‘betafit’), developed by Cox, Jenkins and Buis (2006), which fits by maximum likelihood a two-parameter beta distribution to a distribution of the dependant variable, using the alternative parameterization approach. $\mu$ is reported on the logit scale, hence it ranges from 0 to 1. $\varphi$ is reported on the logarithmic scale to ensure that it remains positive. The postestimation command ‘dbetafit’ calculates various types of marginal effects. We consider marginal effects of each continuous explanatory variable, while keeping all variables at their specified values. The marginal effect is the change in predicted dependant variable for a unit change in the explanatory variable, assuming that the effect does not change over that interval. For dummy variables, a discrete change effect will be estimated, which shows the changes in predicted dependant variable when the explanatory variable changes from its minimum value to its maximum value, while keeping all other variables at their specified values (mean values). Robust standard errors are obtained by using a Huber/White/sandwich estimator of variance. Model consistency was tested by applying post-estimation tests for OLS estimators in linear regression analysis. Influential values were detected and cleaned using Cook's distance measures (d-values >0.5 were excluded). Multicollinearity was checked with VIF and 1/VIF (=tolerance). Input data are derived from the cocoa agroforestry study as well as from the socioeconomic panel survey of 2007.

## 2.3 Results

### 2.3.1 Cocoa expansion and intensification

Tab. 6 provides an overview on the summary statistics of dependant and explanatory variables for the cocoa area expansion and the cocoa intensification model. Variables used in the cocoa area expansion model (n=166) are lag-variables of 2001.

On average, households own a total farm area of 1.5 hectares, while approximately 41% of the total farm area is used for cocoa cropping. About one half (46%) of the sampled households (n=166) has increased its cocoa plantation area between 2001 and 2006. Among these households, the average amount of cocoa area acquired was 0.25 hectares. The average share in cocoa cropping area in 2001 was already around 40%. The average total farm area in 2001 was 2.4 hectares for this sample (range 0.14 – 12.5 ha). The average household size was 4.2, and 25% of the households are non-local inhabitants. 64% of the cocoa producers obtain, to some extent, income from other sources than farming, mainly from own small business or wage labour. 90% of the farmers have access to (at least small amounts of informal) credit. Most factors display a very high variability in values, revealing substantial heterogeneity of household and farm characteristics in the project area. This is particularly true for financial capital variables such as revenues from a non-agricultural business or the maximum credit available to a household (Tab.6).

The average household size in 2007 is 4.5, and 24% of the households are of non-local ethnicity at that time. 21% of the cocoa farmers obtain to some extent income from an own small business and all farmers have access to (at least small amounts of informal) credit (Tab.6) in 2007.

Table 6. Summary statistics for dependant and explanatory variables for both models (cocoa area expansion model: N=166, note that explanatory variables are lag-variables of 2001; cocoa intensification model: N=63, see 2.3.3)

| | Mean | | Std. Dev. | | Min | | Max | |
|---|---|---|---|---|---|---|---|---|
| | N=166 | N=63 | N=166 | N=63 | N=166 | N=63 | N=166 | N=63 |
| MI Index (0-1) | | 0.54 | | 0.17 | | 0.2 | | 0.93 |
| Cocoa area expansion 2001-2006 [ha] | 0.25 | | 0.38 | | 0 | | 2 | |
| Farm area [ha] | 2.41 | 1.49 | 2.05 | 0.86 | 0.14 | 0.23 | 12.5 | 4 |
| % Cocoa area | 40.7 | 44.4 | 33.8 | 32.3 | 0 | 4.85 | 100 | 100 |
| Household size | 4.2 | 4.43 | 1.9 | 1.59 | 2 | 2 | 10 | 8 |
| Av. age of adult HH members | 33.6 | 38.7 | 7.5 | 7.99 | 19.5 | 25 | 61 | 73.5 |
| Av. no. of organisations per adult HH member | 0.6 | 0.47 | 0.6 | 0.6 | 0 | 0 | 3 | 2.67 |
| Poverty Index | 0.05 | -0.15 | 1 | 0.86 | -1.84 | -2.08 | 2.67 | 1.75 |
| Max. credit [1000 IDR] | 1,695 | 5,037 | 4,368 | 7,100 | 0 | 300 | 32,000 | 35,000 |
| Off-farm income [1000 IDR] | 1,811 | 3,371 | 2,953 | 4,462 | 0 | 0 | 16,032 | 20,000 |
| HH head completed SD (0/1) | 0.81 | 0.81 | 0.39 | 0.4 | 0 | 0 | 1 | 1 |
| Non-indigenous HH (0/1) | 0.25 | 0.24 | 0.44 | 0.43 | 0 | 0 | 1 | 1 |
| Napu valley (0/1) | 0.33 | 0.33 | 0.47 | 0.48 | 0 | 0 | 1 | 1 |
| Palolo valley (0/1) | 0.16 | 0.17 | 0.37 | 0.38 | 0 | 0 | 1 | 1 |
| Palu valley (0/1) | 0.21 | 0.44 | 0.41 | 0.5 | 0 | 0 | 1 | 1 |
| Kulawi valley (0/1) | 0.30 | 0.16 | 0.46 | 0.37 | 0 | 0 | 1 | 1 |

### 2.3.2 Determinants of cocoa area expansion

Tobit regression results display very similar results for marginal effects on the probability to expand cocoa area and marginal discrete changes in cocoa area conditional to area expansion (Tab.7). Hence, we can conclude that basically the same driving factors impact the decision to enlarge cocoa cropping land at all and the decision on the extend cocoa area expansion. Non-indigenous households and household size

increase the probability and extent of cocoa area expansion significantly, while the average age of adult household members, total farm area and the share of cocoa in total farm area is negatively influencing cocoa area extension, the same is true for the incidence that a household is located in Palolo or Palu valley.
Probit regression reveals similar results for the probability of cocoa area extension.

Table 7. Tobit regression results for Cocoa area extension between 2001 and 2006 Marginal effects after robust regression (n=166)

| | ME for probability to extend cocoa area [y=Pr(y>0)]; n=166 | | | ME for conditional extension of cocoa area [y=E(y\|y>0)]; n=166 | | |
|---|---|---|---|---|---|---|
| | dy/dx | Std. Err. | z | dy/dx | Std. Err. | z |
| Farm area [are] 2001 | -0.001 | 0.000 | -3.31*** | -0.033 | 0.010 | -3.47*** |
| % Cocoa in farm area 2001 | -0.010 | 0.001 | -6.51*** | -0.413 | 0.067 | -6.15*** |
| Household size 2001 | 0.040 | 0.024 | 1.68* | 1.739 | 1.052 | 1.65* |
| Av. age of adult HH members 2001 | -0.013 | 0.005 | -2.75*** | -0.581 | 0.197 | -2.95*** |
| Av. no. of organisations per adult HH member 2001 | -0.042 | 0.073 | -0.58 | -1.812 | 3.173 | -0.57 |
| Max. credit [1000 IDR] 2001 | 5.78E-06 | 1.00E-05 | 0.55 | 2.49E-04 | 4.60E-04 | 0.54 |
| Off-farm income [1000 IDR] 2001 | -1.18E-05 | 1.00E-05 | -0.88 | -5.11E-04 | 5.80E-04 | -0.89 |
| Poverty Index 2001 | 0.055 | 0.048 | 1.15 | 2.366 | 2.011 | 1.18 |
| HH head completed SD (0/1) | -0.072 | 0.110 | -0.66 | -3.213 | 4.971 | -0.65 |
| Non-indigenous HH (0/1) | 0.296 | 0.098 | 3.02*** | 14.590 | 5.947 | 2.45** |
| Napu valley (0/1) | -0.073 | 0.102 | -0.72 | -3.130 | 4.330 | -0.72 |
| Palolo valley (0/1) | -0.291 | 0.141 | -2.07** | -11.915 | 5.448 | -2.19** |
| Palu valley (0/1) | -0.166 | 0.096 | -1.74* | -6.902 | 3.853 | -1.79* |

(0/1) dy/dx is for discrete change of dummy variable from 0 to 1
ME= Marginal effects after Tobit robust regression (intreg): dy/dx for y=Pr(y>0)=0.437; dy/dx for y=E(y|y>0)=38.23
Dependent variable: Cocoa area extension 2001-2006 [ha]
89 left-censored observations, 77 uncensored observations, 0 right-censored observations
*** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level
Kulawi valley=0

### 2.3.3 Determinants of cocoa agroforestry intensification

In order to examine driving factors of cocoa agroforestry intensification, we conducted a beta distributed regression analysis with a proportional dependant variable (MI) (Tab.8). Displayed are marginal discrete changes in MI after robust beta regression due to one unit change in the respective explanatory variable, holding all other variables constant. Non-indigenous households, household size and average number of social organisations per adult household member and are positively influencing cocoa agroforestry intensification, while average age of adult household members, maximum available credit, off-farm income and location in Palolo valley are negatively affecting agricultural intensification in cocoa plantations. Eight influential cases were excluded by Cook's distance procedure reducing the sample size from 71 to 63 cases.

Table 8. Results of beta distributed regression analysis for Management Index (MI), Coefficients and Marginal effects after robust regression (n=63).

| | Beta robust regression | | | ME (dy/dx) at x | |
|---|---|---|---|---|---|
| | Coef. | Std. Err. | z | Coef. | Std. Err. |
| Farm area [ha] | 0.048 | 0.091 | 0.53 | 0.012 | 0.023 |
| % Cocoa area | -0.003 | 0.002 | -1.23 | -0.001 | 0.001 |
| Household size | 0.105 | 0.041 | 2.59*** | 0.026 | 0.010 |
| Av. age of adult HH members | -0.017 | 0.007 | -2.24** | -0.004 | 0.002 |
| Av. no. of organisations per adult HH member | 0.276 | 0.087 | 3.15*** | 0.068 | 0.022 |
| Poverty Index | -0.109 | 0.116 | -0.94 | -0.027 | 0.029 |
| Max. credit [1000 IDR] | -3.35E-05 | 1.18E-05 | -2.84*** | -8.3E-06 | 2.9E-06 |
| Off-farm income [1000 IDR] | -4.30E-05 | 1.61E-05 | -2.67*** | -1.1E-05 | 4.0E-06 |
| | | | | Min -->Max | |
| | | | | Coef. | Std. Err. |
| HH head completed SD (0/1) | -0.151 | 0.189 | -0.8 | -0.033 | 0.041 |
| Non-indigenous HH (0/1) | 0.306 | 0.153 | 2.01** | 0.076 | 0.038 |
| Napu valley (0/1) | -0.044 | 0.297 | -0.15 | -0.011 | 0.074 |
| Palolo valley (0/1) | -0.929 | 0.327 | -2.84*** | -0.217 | 0.066 |
| Palu valley (0/1) | 0.002 | 0.310 | 0.01 | 5E-04 | 0.076 |
| Const. | 0.804 | 0.483 | 1.66* | | |
| /ln_phi | 2.703 | 0.170 | 15.91*** | | |
| phi | 14.927 | 2.537 | | | |

ME= Marginal effects after Beta robust regression (dbetafit) at variable values
Min -->Max= discrete effect of changing from minimum to maximum for dummy variables
Dependant variable: Management Index (MI)
*** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level
Kulawi valley=0

### 2.3.4 Relationship between agricultural intensification and cocoa area expansion

Plotting the MI (note: this index is gathered in 2007) against the cocoa area extension from 2001 to 2006 reveals a positive although weak relationship (Fig. 11). The overlap of the two samples (Intensification model, n=71 and Cocoa expansion model, n=166) is only 35 households of which for 25 households the cocoa area extension is bounded to zero. Conditional to area expansion, the Pearson correlation value (r= 0.55, n=10) is significant at the 10% level. Due to the small sample overlap, we did not estimate a Tobit model for this analysis.

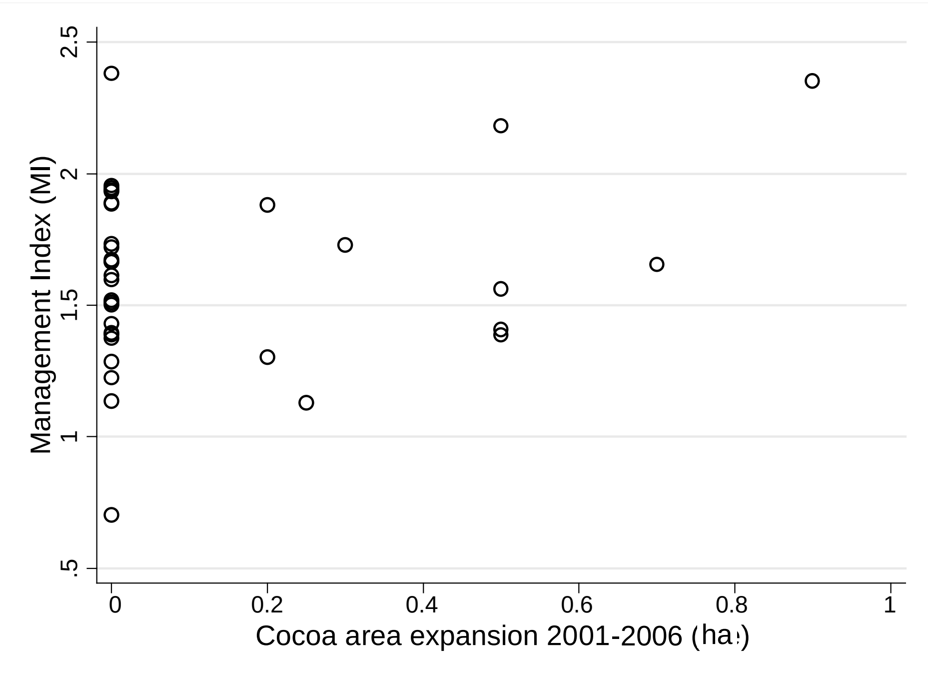


Figure 11. Management Index (MI) plotted against cocoa area expansion from 2001 to 2006 (n=35).

## 2.4 Discussion

### 2.4.1 Expansion of cocoa agroforests in LLNP region

Households with a smaller *total farm area* and a lower initial *share in cocoa plantation area* in 2001 were more likely to extend cocoa cropping area in the following years. This is not surprising since the profitability of cocoa was already well known in the project area at that time. Households with small or no cocoa acreage were particularly motivated to start cocoa cropping or to expand cocoa area when noting the success neighbouring cocoa farmers.

Larger households took significantly more newly aquired land into cocoa cultivation between 2001 and 2006, indicating the importance of labour availability for the establishment of new cocoa plots. On the other hand, this result may also indicate the higher income demand (from cocoa production) of larger households. One additional *household member* increased the expanded cocoa area by 1.7 are (=0.017 ha). Younger households obviously took more new cocoa area into production, a result which corresponds to the deforestation studies conducted by van Edig (2010) and Nuryartono (2005). Formal education (whether *household head completed primary school (SD)* or not) had no influence on the later expansion of cocoa area. In contrast, Godoy et al. (1997) for example found a forest preserving effect of higher education for rural households in Honduras, because better education may open up opportunities for non-agricultural labour.

Social capital in terms of membership in local organisations had no effect on cocoa area extension. However, it fostered deforestation in general (van Edig 2010). We presumed social capital to positively influence cocoa expansion as it is supposed to trigger and strengthen market linkages in the first place, particularly for cash crops. Non-indigenous households significantly acquired more cocoa area than indigenous households between 2001 and 2006. Keeping all other factors constant, these households have an increased probability to expand cocoa area of nearly 30%. Especially migrants from South Sulawesi (Bugis) are known as ‘cocoa experts’, triggering cocoa area extension by the purchase of new land (Weber et al. 2007, Faust et al. 2003). Likewise, in the Western Brazilian Amazon, large swift population movements into forest margin areas were found to trigger increased deforestation (Vosti et al. 2002).

We found no significant influence of off-farm income on the probability and amount of cocoa area extension. In contrast, Godoy et al. (1997) report off-farm labour to reduce the pressure on remaining (rainforest) lands in Honduras (see also Rudel et al. 2005). However, this outcome was not supported in a recent deforestation study from the project area (van Edig 2010).

Likewise, we do not observe any effect of formal and informal credit availability on the probability and extent of cocoa expansion, although credit availability was expected to trigger deforestation, as it allows for investments (cf. Lee et al. 2001). On the other hand, credit markets are highly imperfect in the project region and particularly formal credits are difficult to be obtained by local farmers (Nuryartono 2005). Cocoa area extension between 2001 and 2006 was significantly less in Palolo valley and in Palu valley then in Kulawi valley. Palolo valley is the oldest cocoa production region in the project area and the most developed in terms of management and market connections. Accordingly, most lands suitable for cocoa cropping were probably already taken into cultivation by 2001; hence, substantial expansion was not possible anymore. In contrast, Palu valley is close to the market capital Palu and due to its climatic conditions less suitable for cocoa production and has little forest land left for conversion to agroforestry plots.

Most strikingly, poverty was found to have no influence on cocoa expansion, which stands in contrast to results from several deforestation studies (van Edig 2010, Nuryartono 2005, Geist and Lambin 2002). Using the full panel dataset (all farming households, N=266; in contrast to our subsample of cocoa farming households, N=166), van Edig (2010) analysed the determinants of deforestation, i.e. the area of forest converted to other land uses between 2001 and 2006. Also measured in relative poverty terms, poorer households were more likely to convert forests and the availability of social capital to a household also fostered the probability of forest conversion (van Edig 2010). This combination of household characteristics is predominantly found in households of local ethnics (Nuryartono 2005). Contrarily, in our study, rather the ‘better-off’ and the migrant households were in tendency more likely to enlarge cocoa cropping area, while influence of social capital was not significant. Hence, our results suggest that even though in general poorer smallholders are more likely to clear forests, in the case of cash crop area extension the underlying drivers are other factors than poverty. Also several other authors argue that poverty is never the sole and often not even the major cause for tropical deforestation and land-cover change worldwide. Rather, economic opportunities are important drivers of land-cover change (Angelsen and Kaimowitz 1999, Geist and Lambin 2002, Lambin et al. 2001), which obviously is the case when focusing on land conversion in terms of following cash crop production.

### 2.4.2 Intensification of cocoa agroforests in LLNP region

In contrast to cocoa area expansion, cocoa intensification is not influenced by farm area or share of cocoa area in total farm area. Hence, intensification of cocoa agroforests is unlikely to be influenced by farm structure and specialisation. In contrast, Keil et al. (2007) found that the higher levels of cocoa specialisation were enhancing the technical efficiency of cocoa production in the project region. However, the measure of technical efficiency is not completely comparable with the measure of intensification.

In Brazil, Vosti et al. (2002) found that farms with larger household labour endowments are moving into more intensive land uses. Seasonal labour bottlenecks on the other hand can hinder the intensification process. Likewise in our study, the positive relationship between *household size* and agricultural intensification is significant. 'Older' households manage cocoa plantations less intensively. The *average age of adult household members* is, as supposed, negatively related to intensification, indicating that intensification may still have some characteristics of an innovation, which is more likely to be adopted by the younger and more innovative generation. Also, younger and larger households may have a particularly high requirement for cash income to meet investment needs (e.g. for building a house, schooling of children). The increased income needs may encourage farmers to adopt more intensive cocoa agroforestry systems. In contrast, formal education does not influence the intensity of cocoa management: Whether the *household head has completed primary school (SD)* or not, has no effect on intensification. This suggests that formal education may not be an adequate indicator for intensification-relevant knowledge or experience. Social capital as measured by the *households' memberships in local organisations* positively influences intensification. Social networks play an important role for smallholders. They can trigger and strengthen market linkages and may help to distribute intensification relevant knowledge.

*Non-indigenous households* have a significantly higher share in intensive cocoa plantations than local ethnicities. This supports previous qualitative findings on migrants immigrating into the area, bringing about a much more developed know-how on intensive cocoa management than was available before (cf. Weber et al. 2007). Holding all other parameters constant, the MI is 7.6 percent points higher for non-local households.

Income gained from *off-farm* sources is not triggering intensification. In contrast it is negatively related to the MI. Likewise, the *maximum credit* a household can obtain in one year has a negative influence on intensification. These results figure out the basic characteristic of agroforestry intensification in LLNP area: Generally the intensification process is not necessarily associated with higher cash investments because the process consists mainly in reducing shade canopy cover by the extraction of shade trees, which may only cost additional labour at best. Credit is needed for consumption and it facilitates investments (cf. Lee et al. 2001). Also off-farm labour provides additional financial capital, which may be used for more cash intensive investments.

No significant influence of *poverty* on cocoa intensification could be detected here, but in tendency the ‘better-off’ households are more likely to intensify. Poorer households tend to have a higher marginal utility of consumption (Pagiola and Holden 2001), which may result rather in food crop first then in cash crop first strategies. Hence, cash crop driven intensification is rather expected to be triggered by the relatively ‘better-off’ households.

### 2.4.3 The relationship between cocoa agroforestry intensification and its expansion

Both, the extension of cocoa agroforests as well as its intensification are basically determined by the same set of driving factors. Moreover, we detect a weak although significant positive relationship between the intensification of cocoa agroforests and cocoa area expansion from 2001-2006. Households who produce cocoa more intensively in 2007 also acquired more cocoa area between 2001 and 2006, either by converting forest and planting cocoa themselves (directly or after some seasons of annual crops) or by purchase.

An increase in income from agricultural activities (for example by intensification) would lead to less forest conversion in the view of the impoverishment ('full-belly economy') hypothesis (Wunder 2005), because farmers would have to produce less to have the same income, hence to meet a 'target revenue'. The impoverishment approach refers to a combination of poverty and demographics ('vicious cycle') as the main cause for deforestation. In the past, the assumption that agricultural intensification leads to lower pressures on common property resources, such as tropical rainforests, has been a relatively common view (Smith 1990, Brady 1996, López 1998, Shriar 2000, Wunder 2005).

Contrarily, the neoclassical hypothesis assumes deforestation agents to be optimizers reacting to economic opportunities whether they are poor or not. A higher profitability of a certain crop will lead not only to increased allocation of labour and capital but also to increased land demand in order to maximise production of and revenues from the respective crop (Wunder 2005).

Reviewing 148 economic models and empirical studies by on the relationship between tropical deforestation and higher agricultural productivity, Kaimowitz and Angelsen (1998) concluded that in general, technological advances tend to make agriculture more profitable and hence cause higher deforestation rates. This finding is particularly underpinned by seven studies from Indonesia, where neo-classical explanation approaches for forest conversion have proven to be more relevant than the impoverishment mechanism of a vicious cycle (Kaimowitz and Angelsen 1998). Also in a case study review of Barraclough and Ghimire (1995) for developing countries, the adoption of more productive technologies correlated with the expansion of market opportunities and induced an increase in all production factors, including land. Positive relationships between intensification and deforestation have also been reported by Foster and Rosenzweig (2003), Lee et al. (2001), Fearnside (1999) and Perz (2003).

Likewise, within agricultural intensification theory a subsistence-oriented and a commodity/market-oriented production strategy can be distinguished (Shriar 2005, induced intensification, Turner and Ali 1996). In a subsistence economy, risk minimization and labour saving strategies are of prior importance. As intensification usually implies labour increase, farmers will hesitate to intensify unless an urgent need (population change/ land pressure change) forces them to. In contrast, the model of an ideal market implies a 'commodity behaviour' in that small-holders increasingly move into market production (Turner and Ali 1996). However, farmers might be constrained in fully responding to market signals due to limiting factors such as poverty and geographical isolation. Moreover, farmers may also fail to respond to it because their production goals are not completely market-oriented, causing 'hybrid' farming behaviour which ranges along a continuum of the two ideal models and may prevail in a single farm. Indeed, many households in the project region are 'rice-cocoa combiners' (Binternagel et al. 2010, Schwarze 2004). They balance the risk-avoidance of food-cropping with the higher market risk implied by cash cropping (Turner and Ali 1996).

Furthermore, global forces such as world market prices have an increasing influence on land-cover change, and may replace or rearrange local drivers of land-use change (Lambin et al. 2001). Currently, cocoa prices are still rising on global markets (~18% annually during the last 3 years, ICCO 2010) and the continuing increase in global demand of 2-3% per year is likely to keep this trend in the near future (ICCO 2008). Following this outlook, it is likely that the profitability of cocoa intensification and cocoa area extension remains stable or even increases in the next few years unless disease and pest pressure as well as aging plantations interfere with the development.

The improved income opportunities can trigger an inflow of migrants who themselves accelerate deforestation (Tomich et al. 2001, Mortimore 1993, Lambin et al. 2000). A succession of local migration waves and cycles of cocoa adoption dominates Indonesia's cocoa sector development. In Central Sulawesi, after a rapid adoption of cocoa production, farmers soon faced land scarcity in the easily accessible and level valley bottoms. As a result, farmers migrated to other (upland) areas with still abundant land resources (Ruf 2007). At the moment, the LLNP region is characterised by high population growth and ongoing migration to the forest frontier area. Often only unfavourable or protected land is left for conversion. A low rural off-farm labour absorption further triggers agricultural expansion and deforestation in the uplands (Maertens et al. 2006). During the past decades an inflow of migrants from South Sulawesi triggered more intensified cocoa cropping, and induced substantial changes to land-use strategies even in many autochthonous households who switched from a food-crop to a cash crop orientation (Weber et al. 2007, Faust et al. 2003). The LLNP region, thus, follows a commodification pathway, triggered by in-migration and market opportunities.

## 2.5 Conclusion

In summary, by analysing the determinants of cocoa agroforestry expansion and intensification, we find substantial corroboration for the presumption that cocoa agroforestry and particularly its intensification in Central Sulawesi is unlikely to have a land-sparing effect under current economic and demographic conditions in the area. Contrarily, because cocoa production, and particularly its intensification, is so profitable, it triggers further conversion of new lands into cocoa agroforests.

Deforestation was often found to be pushed also by government policies on migration and settlement. The hypothesis that migrants push forward the deforestation process (Weber et al. 2007) can be supported concerning the extension of cocoa area in LLNP region. Other studies from the project region reported that new forest patches are dominantly cleared by local ethnicities, whereas they are later on often bought by migrant groups, often Bugis from South Sulawesi, who have the necessary financial capital to purchase even already established cocoa plots and who also have the knowledge for an intensive agroforestry management (Nuryartono 2005, Faust et al. 2003, Weber et al. 2007).

### 2.5.1 Removing pressure on land in forest frontiers

The establishment of new cocoa plots slightly decreases in Central Sulawesi since 2003 (Ruf 2007, Weber et al. 2007, van Edig 2010). However, there is no indication that this process is going to stop entirely. Even though the reduced cocoa extension might be a signal for increasing land scarcity in the region, we have to assume that rainforest encroachment will continue under current economic, biophysical and policy conditions. Deforestation is likely to persist as long as the strong economic incentive of cocoa production lasts, even though it might already be more difficult to access and less suitable for agriculture because it is located on slopes and even though situated inside the National Park borders.

Forest protection is in the first place a task of the public sector. Policies may enforce land-use regulations incorporating penalties as disincentives for deforestation or improve the economic benefits of activities which discourage deforestation, or combinations of both approaches. However, where land is still abundant, direct regulatory approaches are difficult to enforce and expensive. Farmers will ignore deforestation restrictions if profits remain high (cf. Vosti et al. 2002). Hence, in many cocoa producing regions, the ‘old way’ of producing cocoa, namely by clearing forests, is still apparent (Ruf 2007). Labour absorbing land use activities could have a braking effect on deforestation, if they are capable to increase both, land and labour productivity; otherwise they would not be considered profitable by farmers (Gockowski et al. 2001, Vosti et al. 2002). Enhanced labour opportunities outside the agricultural and forest sector can help reducing pressure on remaining rainforests (Schwarze and Zeller 2005, Rudel et al. 2005). Allowing for the sustainable extraction of timber and NTFP could also help to protect remaining forests, but making these products more profitable can also result in damaging extraction techniques due to absent control mechanisms (Schwarze et al. 2007). Carbon markets also offer great opportunities for slowing deforestation but substantial policy action will be needed in order to address questions of implementation, including transaction costs (Seeberg-Elverfeldt et al. 2009, Vosti et al. 2002).

### 2.5.2 Promoting sustainable intensification

Factors determining intensification decisions are complex. Policy changes should specifically promote (sustainable) intensification and at the same time discourage area expansion in order to be effective (Pagiola and Holden 2001). The sustainable intensification objective refers to an increase of agricultural production with a simultaneous maintenance or enhancement of the natural resource base. This is to be achieved by a combination of adequate technologies, policy and market incentives and institutional reforms which are suitable for bringing in line farmers’ short term welfare objectives with long-term regional sustainability criteria (Reardon and Vosti

1995, Tilman et al. 2002, Vosti et al. 2002, Ruben et al. 1998, Kuyvenhoven et al. 1998). Alternative land-uses at the forest margin differ significantly in their potential for conservation of above-ground biodiversity, but agroforests can often maintain a high level of biodiversity are mostly agronomically sustainable (Steffan-Dewenter et al. 2007, Gockowski et al. 2001, Tomich et al. 2001). Moreover, cocoa agroforests can sequester substantial amounts of carbon dioxide and should therefore be stronger considered in discussions of carbon sinks and emission trading (Seeberg-Elverfeldt et al. 2009, Newmark 1998).

However, agroforestry is usually more knowledge-intensive than other land-use options because of its complex management requirements (Mercer 2004). The adoption of more sustainable agroforestry systems is also constrained by its labour-intensity, especially due to seasonal labour bottlenecks (Vosti et al 2002). Cocoa production in LLNP region requires substantial improvements, especially with regard to pest and disease management, P fertilisation and humus management as well as cocoa bean processing (see also Ruf 2007). Higher labour input in the respective activities can increase cocoa yields noticeably and is critical for maintaining production in the long term (Juhrbandt et al., 2010, Clough et al. 2009). Moreover, when cocoa agroforests display a high diversity of shade trees dispensing moderate shading levels, they can provide important habitats also for forest-based species in an integrated buffer-zone management. Economic incentives which offset the attractiveness of full sun cocoa agroforestry could be a measure to ensure both high levels of biodiversity and stable incomes in forest frontiers (Clough et al. 2011, Juhrbandt et al. 2010). However, such instruments should be coupled with effective disincentives for further forest conversion, because, as Carpentier et al. (2000) assert: ‘agricultural intensification is necessary but not sufficient to slow deforestation.’

### 2.5.3 Research implications

For the development of a policy-driven strategy for increasing production, it is necessary to understand the process of agricultural intensification as well as its implications for environment and livelihoods. Forest margin areas provide unique ‘laboratory’ situations for examining these processes over a gradient of population-and market-driven intensification of agriculture (Gockowski et al. 2001). The set of socio-economic driving factors for cocoa area extension and intensification analysed in this study has some shortcomings. For example, it lacks an indicator variable for transport infrastructure, which was not available in our data set. However, transport infrastructure is assumed to be relatively good in the sampled villages, as they are all connected to tarmac roads. Moreover, we were not able to include an indicator for tenure security in our analysis. Van Edig (2010) reports that a lack of secure land titles enhances the probability of rural households to clear forest. Planting trees after forest conversion is a frequent strategy to claim tenure in many regions in Southeast Asia. In a study in Sumatra, for instance (Otsuka et al. 2001) found that planting trees on newly cleared forest lands (but not on purchased bush-fallow land) enhanced individual tenure rights. The variable *household size* has a weakness in that it may at the same time indicate labour availability and consumption demand. Also the variable *average membership of adult household members in social organisations* is somehow ambiguous because it is not defined, to which kind of organisations it refers. There is a huge variety in local farmer groups and other religious or social organisation with differing objectives (cf. Seeberg-Elverfeldt 2008, Kemper et al. 2008), which may have distinct impacts on cocoa intensification and area expansion. In this context, a broader data basis and further research is required.

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# 3 Chapter

## Economic valuation of forest conversion and agroforestry intensification at rainforest margins in Indonesia

Authors: Juhrbandt, J., Barkmann, J., N.N., Version for Discussion paper.

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**Summary**

Tropical rainforests provide a wide range ecosystem services benefiting not only local farmers but also regional or international communities. Most of these goods and services arising from environmental functions are not captured by the market, and hence, they are not included in economic accounting when these forests are converted into other land uses.

In the vicinity of the Lore Lindu National Park (LLNP) in Central Sulawesi (Indonesia), the expansion of cocoa agroforests is the main driver of regional forest conversion. Moreover, agroforestry systems are increasingly intensified by the extraction of shade trees, thereby causing further environmental degradation. In order to quantify potential trade-offs resulting from ongoing land use change in the LLNP area, we calculate net benefits for a gradient in land use intensity, ranging from natural forests and production forest to four cocoa agroforestry systems of differing management intensity. Economic consequences of land use change are expressed as marginal net benefits which accrue when switching from one land use type to a more intensive option. Marginal net benefits are calculated by applying cost-benefit analysis within an impact pathway framework. We focus on several important provisioning, supporting and regulating ecosystem services, including the provision of timber, rattan, cocoa income and biodiversity, the supporting services from pollination and soil fertility and the regulation of atmospheric carbon dioxide.

Marginal changes in private net benefits from cocoa production, timber and rattan harvest are always positive when converting natural forests or production forest into agroforestry systems. In contrast, public goods and services, including carbon sequestration and avoided emissions, pollination services and biodiversity show net losses when switching to a more intensive land use in all cases. However, converting one hectare of natural forest to cocoa agroforest of the most intensive system results in total net benefits of 12,500 USD over 25 years. Public goods and services do not provide sufficient net benefits to offset returns from conversion to cocoa agroforests. Concerning the intensification of cocoa systems, a carbon sequestration project at current carbon prices is not sufficient to offset returns from intensively managed cocoa agroforests.

The high private returns resulting from forest conversion to cocoa agroforests and the increasing profitability of cocoa agroforests along the intensification gradient raises trade-offs in the provision of ecosystem services provided by forests and extensive agroforestry systems. In order to make potential values from indirect ecosystem benefits tangible and effective, they have to be internalized in economic accounting and in policy making for future land-use planning.

## 3.1 Introduction

The pressure on tropical forests remains high: During the last 30 years, 288 million hectares (21%) of tropical forest areas have been deforested, mainly driven by rapid economic growth in several tropical areas (Bawa et al. 2004). Indonesia globally displays the second highest annual net loss in forest area (2% annual forest loss between 2000 and 2005, FAO 2006).

Tropical rainforests provide a wide range of goods and services for local farmers but also for the global community. Besides direct economic benefits derived from goods such as timber and non-timber forest products (NTFP) and services such as the provision of genetic material and the potential for tourism, also indirect benefits are generated by ecosystem functions that forests provide, such as carbon storage, watershed protection, nutrient cycling, and microclimatic functions (Pearce 2001). These goods and services can be captured by the concept of Ecosystem Services (ES) (Millennium Ecosystem Assessment 2005). ES are utilized aspects of ecosystems (used actively or passively) to "produce" human well-being. They include ecosystem organization (structure), operation (process) and outflows and they can be consumed directly or indirectly (Fisher et al. 2008, Boyd and Banzhaf 2007). In the Millennium Ecosystem Assessment (2005), ES are categorized as supporting, regulating, provisioning and cultural services. Many of these services can be characterized as public goods, because their positive effects are not exclusive and do not create rivalry among those who benefit (Heal 2000). As a consequence, the value of most ES is not reflected by market prices. This may cause the illusion that the economic value of these benefits is zero. For this reason, it is important to quantify potential trade-offs resulting from ongoing land use change. This requires the calculation of net benefits arising from various ES for different land use alternatives.

In an early attempt to aggregate more than 100 studies which aim at valuing ecosystem goods and services, Costanza et al. (1997) calculate a total annual value of global "nature's services". This approach was later heavily criticised mainly because the included macroeconomic extrapolations contradict microeconomic theory. For example, marginal values depend on the shape of the demand curve and can therefore not be summed up directly. Moreover, the flow of goods and services resulting from converted habitats can differ substantially depending on the type and intensity of the subsequent land-use. Hence, upscaling their value is not straight forward. Finally, most policies are more adequately informed when provided with marginal changes in economic values (Balmford et al. 2002, Toman 1998, Turner et al. 1998, Nunes and van den Bergh 2001, Bockstael et al. 2000).

In order to achieve a comprehensive synthesis of the value of nature conservation, Balmford et al. (2002) reviewed more than 300 case studies on ES evaluation, selecting only those which consider the most important marketed goods as well as at least one non-marketed service, and those which apply marginal values. Only five studies were found which correspond to these criteria. Two of the five studies examine the economic impact of tropical forest conversion (Yaron 2002, Kumari 1996 and 1994). Yaron (2002) investigated the economic value of land use alternatives to a natural forest cover in the Mount Cameroon region. The study is comprehensively comparing forest conversion to small scale farms or to industrial plantation crops (oil palm plantation). However, economic impacts of the intensity of land-use are not considered here. Kumari (1996, 1994) analyses the economic value of benefits arising from peat swamp forests under alternative logging management schemes in Northern Selangor, Malaysia. Yet, the study does not include the conversion of forest to agricultural land use as an option, as peat swamps are of limited productivity for agriculture. Timber harvesting is the main extractive activity within the production forests of that area.

Van Beukering et al. (2003) determine the total economic value of the Leuser Ecosystem in Northern Sumatra, subject to the consequences of deforestation. In a dynamic simulation model, they examine three scenarios: a conservation scenario (strict protection of rainforest), a deforestation scenario (following the current trend, with subsequent rice, vegetable and cash crop cultivation), and a selective use scenario (reduced logging and reforestation). The study does not include any non-forest land use options though. Although capturing a reasonably wide range of direct and indirect use values, the analysis is based on many assumptions and literature information due to missing data in the project region. Non-use values such as option (captures potential future use only) and existence values (e.g. of biodiversity) are not included in the calculations.

In conclusion, we have to notice a substantial lack of high quality studies on the economic valuation of environmental goods and services particularly for tropical forest margin zones.

The area in and around Lore Lindu National Park (LLNP) in Central Sulawesi is covered to nearly 70% by tropical rainforests, providing a wide range of ecosystem goods and services. Forests are characterized by a high degree of endemism in flora and fauna, and are part of the *Wallacea* biodiversity 'hotspot' (Myers et al. 2000). The main driver of regional forest conversion is the expansion of cocoa agroforests (Erasmi et al. 2004, Koch et al. 2008). Cocoa is the dominant cash crop in that region, whereas wet rice is the main staple crop. Between 1980 and 2001, the cocoa cropping area increased from zero to ~18.000 ha (Maertens 2003). From 2001 to 2007, cocoa acreage further increased to 20,600 hectares (Reetz 2008). Additionally, a shift takes place from multilayer agroforestry systems (AFS) with diverse shade canopies to rather simply structured cocoa plantations with only one or two planted shade tree species (Siebert 2002, Steffan-Dewenter et al. 2007, Juhrbandt et al. 2010). This intensification process of cocoa AFS appears as a financially favoured strategy to local farmers, since yields can nearly be doubled when decreasing canopy cover from medium (50-65%) to zero-shade conditions. However, cocoa cultivation in intensive zero-shade systems potentially threatens the provision of ES (Steffan-Dewenter et al. 2007, Schneider et al. 2007, Juhrbandt et al. 2010). Moreover, from a perspective of food and livelihood security, the growing reliance of local households on high intensity-cocoa cropping is a risky strategy because income from cocoa is susceptible to unpredictable global market forces and price changes (Belsky and Siebert 2003).

First attempts were made in the LLNP region by The Nature Conservancy (TNC) to estimate the economic value of agricultural and forest products, as well as environmental impacts especially on the watershed protection function (Deschamps 2001). TNC carried out an 'Agricultural Producer and Resource User Survey', using a representative sample of 305 households in 11 villages around LLNP. Surveyed factors included agricultural production, livestock inventories, forest products, the frequency of environmental events (conflicts with wildlife, diarrhoea, drought, erosion, floods, forest fires and malaria) and their impacts on rural households, the effects of forest conversion on sedimentation and on water quality, flow rates and stability for agricultural systems (Deschamps 2001, Deschamps and Hartman 2005). The study captures a range of benefits from agricultural and forest products in terms of gross income without considering any production or harvest costs. Although some environmental offsite–costs (e.g. cleaning of irrigation channels), and the amount of water used for domestic and agricultural purposes were calculated, many cause-impact relations remain unclear. Especially, no knowledge exists to what extent the watershed protection function changes with conversion to different land use systems.

The development of economically sound conservation strategies in the project region and elsewhere is hampered by a lack of knowledge on the economic value of non-market benefits produced by forest ecosystems and the different agricultural land use systems that replace those (Barkmann et al. 2007). The study at hand aims at carrying out a more comprehensive and careful approach to the economic valuation of forest conversion and is at the same time a first attempt to also include a gradient in agroforestry intensification. Economic consequences of land use change are expressed as marginal net benefits resulting from switching from one land use type to a more intensive option.

We capture marketable private benefits directly affecting local farmers as well as public goods and services, whose values are not represented in market prices and which mostly affect a larger community on regional or even on global level. Estimated values include provisioning, supporting and regulating ES. We focus on the provision of timber and rattan, on cocoa income and biodiversity, on supporting services from pollination and on soil fertility, and on the regulation of atmospheric carbon dioxide. While timber, rattan, cocoa and soil fertility on cocoa plots provide private benefits for rural households, carbon sequestration and avoided emission as well as pollination and biodiversity can be considered as public goods and services (cf. Olschewski et al. 2010).

## 3.2 Methodology

### 3.2.1 Cost-benefit Analysis (CBA)

Sound development and conservation strategies have to be provided with information on the costs and benefits of alternative land-use options. Including the economic value of ecosystem services in a CBA framework for assessing changes in natural resources is a concept of high importance and legal standing (Bockstael et al. 2000). CBA is the most common method of economic project and policy appraisal and the most suitable in welfare economic analyses. A comprehensive CBA includes the economic valuation of a wide range of environmental goods and services, and is a suitable method for comparing alternative land use options according to their net economic benefits (Bann 1998). Benefit-cost rules imply that a decision to convert a tropical forest into an alternative land use needs justification in terms of benefits of forest conversion exceeding the benefits of forest conservation (Brown et al. 1993).

When linking ecosystem services to human welfare in economic valuation studies, it is crucial to assess marginal values: Because the value of ES always depends on the type of current use and on the type of alternative (forgone) use of the corresponding resource, it is mandatory to ask for the benefits and costs of a one unit change in the resource (e.g. the conversion of one additional hectare of rainforest) (Balmford et al. 2002, Turner et al. 1998).

In order to comprehensively capture land use change and its impacts on ecological functions and economic costs and benefits, the structure of the analysis follows the so called ‘impact pathway approach’. Developed within the EU funded External Costs of Energy Project (ExternE) (European Commission 1995), it attempts to quantify the "actual" effects of ecosystem change resulting from the exposure to a "burden" at a specific place and time, rather than estimating a "potential" impact of ecosystem change (Krewitt et al. 1998).

### 3.2.2 General procedure in CBA

According to Daily et al. (2000) the following fundamental steps are required in economic valuation analysis within a CBA framework: First, study boundaries (temporal and geographical) are defined. Second, possible land-use alternatives have to be selected. Subsequently, impacts have to be identified for all land-use alternatives. Adapting an impact pathway framework developed by van Beukering et al. (2003), we describe the impacts of land-use change (a 'burden') on primary and secondary biophysical functions and how these biophysical functions translate into economic impacts, expressed as costs and benefits (see Fig. 12 and 13). Value categories and ecological impacts have to be reviewed, whereby irrelevant categories should be sorted out. Finally, the economic valuation translates the impacts of choosing any of the alternatives in comparison to the status quo into comparable units of human well-being.

Economic impacts in a CBA framework are typically measured in monetary terms (cf. Brown et al. 1993, Bann 1998 and Gregersen et al. 1995). We quantify socioeconomic impacts by calculating monetary values for all value categories and for each land use alternative. Finally, a sensitivity analysis has to be conducted in order to identify factors which most influence the results, e.g. differing discount rates (van Beukering et al. 2003). When comparing net benefits from different land use alternatives, it may not be necessary to estimate all values associated with the respective alternative (and in most cases data availability may not be sufficient to do so), but the ones which contribute most substantially to changes in the total economic value of a land use change (Bann 1998).

Following Bockstael et al. (2000) (cf. also Daily et al. 2000), we consider an ecosystem as a natural asset because ecosystems provide services over time. Accordingly, the total value of the asset reflects the value of the time profile of the services it provides. As for the different land use alternatives, the stream of costs and benefits may vary over time, they need to be discounted to yield net present values (NPV).

Choosing an appropriate discount rate is a disputed issue, as sufficiently high discount rates can be used to justify resource exploitation to an extend which results in catastrophically high environmental costs in the future (Daily et al. 2000). Different discount rates should therefore be tested in a sensitivity analysis in order to estimate their influence on resulting NPVs.

Double counting of an environmental benefit may arise from the simultaneous use of different valuation techniques, as the same ecosystem service can generate multiple benefits. Therefore, it is critical to distinguish intermediate and final services from benefits. Pollination, for instance, can be considered an intermediate service, whereas a corresponding final service provided could be food production and a resulting benefit may be income from fruit harvest. To avoid double counting, only benefits should be valued and aggregated (Fisher et al. 2008).

### 3.2.3 Scenarios: Land use alternatives

The calculation of the economic value of ES requires the identification of use alternatives referring to well-defined changes in ecosystems (Bockstael et al. 2000). With respect to the most relevant land use change pathway from forests to intensive cocoa plantations in the LLNP area, we define two different forest scenarios and four different AFS as land use alternatives in CBA analysis. For forests, we differentiate between:

1) Near natural (primary) forest with low human disturbance (NF). NF is assumed to provide habitat for local biodiversity, to store carbon and to ensure watershed protection and pollination services.

2) Production forest subject to sustainable selective logging and NTFP use (PF). Actual timber and NTFP extraction rates may currently not be sustainable in the project region. However, we need to apply a sustainable PF scenario, using provision rates based on biomass growth, since actual harvest data of timber and NTFP are not available (see 3.2.6 timber and NTFP extraction). Furthermore, PF also provides carbon storage, watershed protection and pollination service.

For agricultural land use scenarios, cocoa AFS were selected, as these are known to be the main driver of deforestation in the project region (Erasmi et al. 2004, Koch et al. 2008). New plots can be opened up by clear cutting primary or secondary forests, and planting cocoa and legume shade trees after some seasons of annual crops (maize, beans). Alternatively, they are established by maintaining a certain amount of the natural forest cover and planting cocoa in the understorey. As cocoa trees become productive, shade tree cover is typically reduced, thereby simplifying plot structure and reducing species diversity (Juhrbandt et al. 2010). Within the resulting intensification gradient, we will analyse four AFS with different management intensities. Management intensity of AFS is calculated by an Agricultural Intensification (AI) index (see 3.2.6, cocoa production). We distinguish:

A) An extensive, forest-like AFS with many natural shade tree species and dense shade tree cover (AIQ1),

B) A mixed AFS with planted and natural shade trees with a slightly opened shade tree cover and many intercrops (AIQ2),

C) A simple mixed AFS with intercrops but no or few natural shade trees and an open shade canopy (AIQ3),

D) An intensive AFS with no or only planted shade, mostly from legume trees (AIQ4).

Marginal changes of net benefits will be calculated for the whole gradient of land use from NF and PF to AIQ4.

Wet rice farming is not considered as a land use option in our study, as forest conversion to paddy rice fields is currently negligible when compared to cocoa cultivation (Reetz 2008). Nevertheless, forest conversion and land use change has off-site impacts on wet rice farming down-stream, which will also be quantified.

### 3.2.4 Impact pathway: Changes in direct and indirect benefits

Impacts from forest conversion to agricultural land-use (agroforestry) are depicted in Fig. 12. Direct private benefits which are threatened by forest conversion include timber and NTFP availability, which can be calculated by attaching local market prices to the annual amount of sustainably harvestable timber and NTFP. Reductions in indirect public benefits occur, for example, through the reduction in watershed protection resulting in high discharge peaks or very low discharge during drought, thereby affecting wet rice irrigation in off-site areas. Declining soil fertility and reduced pollination services are both affecting agroforestry yields over time. Both reduced wet rice yields and agroforestry yields can be calculated using production functions and market prices. Loss in forest biomass, especially forest conversion to agricultural land use, is not only resulting in decreased amounts of harvestable timber and NTFP but also in carbon dioxide emissions, which can be captured by accounted carbon credits in a REDD scheme (Reducing Emissions from Deforestation and Degradation) (cf. Santilli et al. 2005). Last not least, forest habitat loss results in biodiversity reduction, which can be accounted for by Willingness-To-Pay (WTP) studies for local and global preferences for biodiversity conservation.

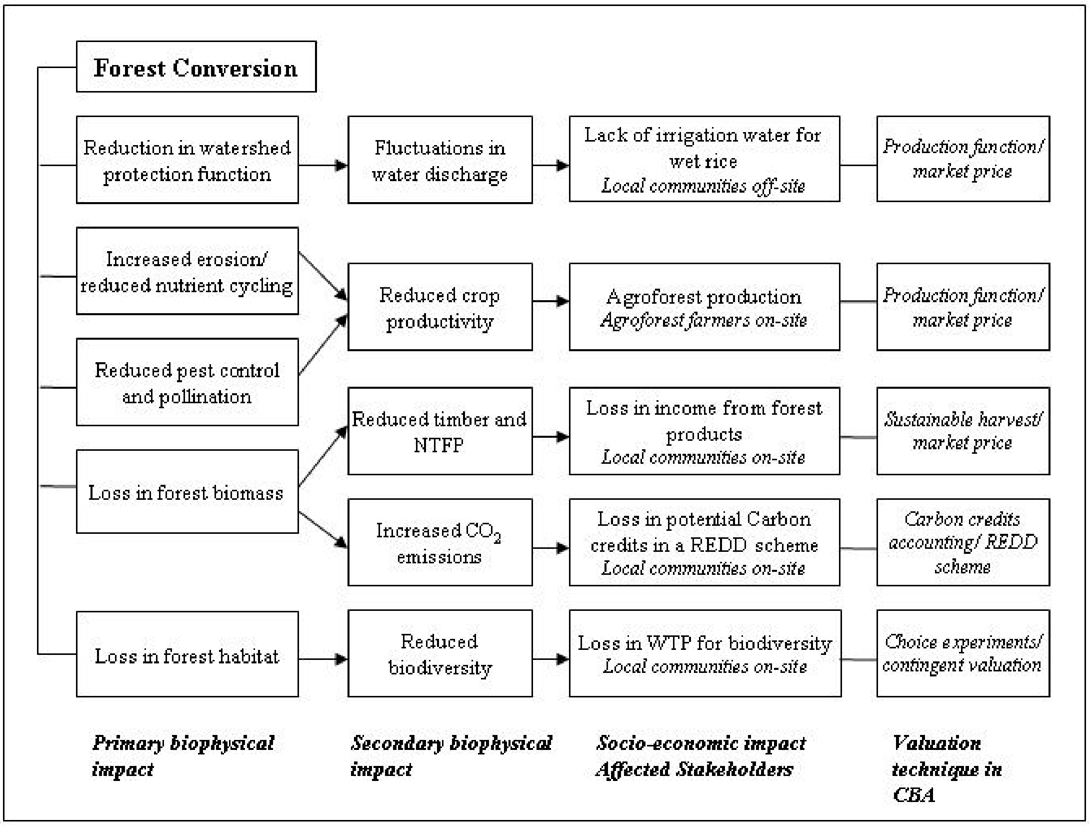


Figure 12: Impact pathway of forest conversion in LLNP region (adapted from van Beukering et al. 2003)

Fig.13 depicts the impact pathway of agroforestry intensification in LLNP region. The intensification of AFS leads to a change in microclimate, particularly in increased radiation due to a reduced shade tree cover. This affects cocoa yields positively and can be measured in a production function approach. Shade tree extraction on the other hand also leads to a reduced $CO_2$ sequestration potential of agroforestry plots over time. More intensively managed agroforests are susceptible to a faster soil fertility loss, which can likewise be captured via production function analysis.

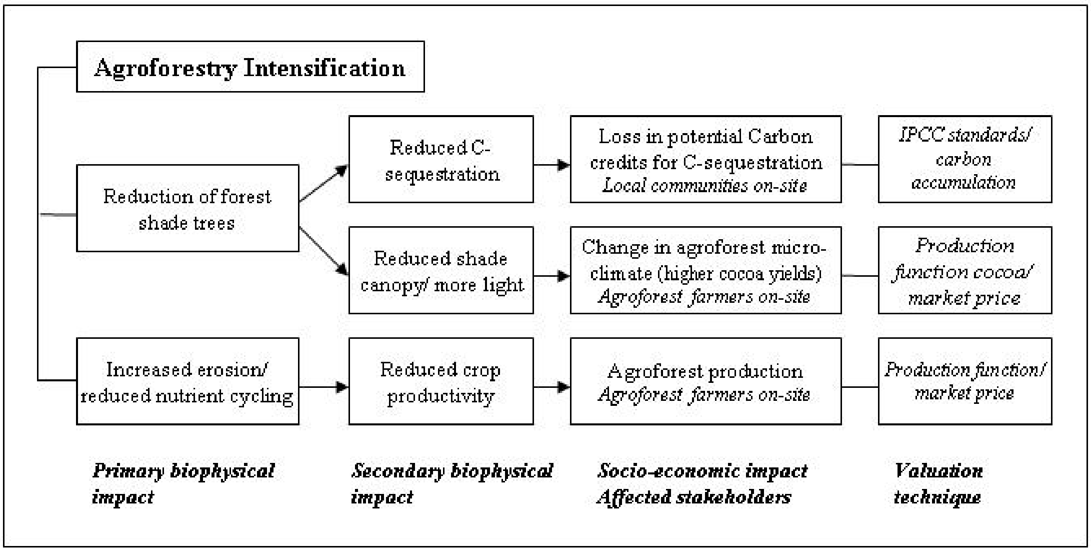


Figure 13: Impact pathway of agroforestry intensification in LLNP region (adapted from van Beukering et al. 2003)

### 3.2.5 Study boundaries

The investigated land use changes result in on-site effects (e.g. pest control, soil fertility) as well as in regional (e.g. flood control, water provision) or global off-site effects (e.g. carbon sequestration) (Daily et al. 2000). As geographic study boundary we consider the STORMA project region (Zeller et al. 2002). This area has a size of 7500km$^2$ of which 67% were covered by natural forests by 2002. The project area includes the Lore Lindu National Park (LLNP) which has a size of 2200km$^2$. The region is topographically diverse with mountains reaching up to 2600 m a.s.l. and has a humid tropical climate with a humidity of 85-95%, mean annual temperatures around 25°C at sea level and an annual precipitation of more than 2500mm, which is subject to high local variability (Whitten et al. 2002). By 2002, perennial crops like cocoa and coffee are grown in agroforestry systems on 5% of the land cover (Erasmi et al. 2004), also on sloping land up to 1400 m a.s.l.. Wet rice is mainly cultivated in the valley bottoms.

On-site land use change is the conversion of NF to PF and cocoa AFS and the intensification of AFS. This impacts soil fertility and shade tree cover. In contrast, off-site impacts of forest conversion into cocoa agroforests are captured by changes in watershed functions impacting the availability of irrigation water for wet rice production in the project area (down-stream effects) (see 3.2.6, watershed protection). But also impacts on the provision of carbon dioxide regulating and pollination supporting services as well as on local biodiversity can have effects beyond the location of forest conversion to cocoa plantations and even beyond the geographical boundaries of the study region. While the value of pollination services is assessed for coffee production on a regional scale (project area) (see 3.2.6, pollination services), the value of $CO_2$ regulating and biodiversity is captured by global carbon credit trade (see 3.2.6, carbon dioxide regulation) and the biodiversity value as WTP value on OECD level (see 3.2.6, biodiversity).

The time frame needs to be sufficiently long to allow for the detectability of environmental impacts, which usually only measurable after a certain time lag. For the scenario analysis of the Leuser ecosystem, 30 years were projected (van Beukering et al. 2003), using discount rates between 0 and 15% in sensitivity analysis. Yaron (2002) projects costs and benefits for alternative land use scenarios over 32 years with discount rates of 10% and 35%, the latter is assumed to reflect more realistically the decision making of individual farmers in the Mount Cameroon region. Kumari (1996) projects different forest management options in Malaysia over a period of 100 years, applying discount rates of 8% and 2%. As cocoa plantations are usually productive for 25-30 years (Ryan et al. 2009), we apply a time frame of 25 years for all flows of benefits and costs arising from different land use options. Following Seeberg-Elverfeldt et al. (2009), we start out at a discount rate of 10%, which is close to the Indonesian interest rate in 2007 (year of data collection) (Reuters 2007). The discount rate as well as other important input factors is varied in sensitivity analysis by 25%.

### 3.2.6 Ecosystem services and data sources

**Timber production**

In Central Sulawesi, local use of wood is mainly for construction and firewood. Wood for local use is mostly collected in forest gardens rather than in primary forests, which are generally further away (Schwarze et al. 2007). Hence, construction wood and firewood are not relevant for the scenarios investigated here and are therefore excluded from this analysis.

However, valuable timber species harvested in primary forests are also sold on local markets (Pitopang, pers. communication March 2010). Because exact data on timber harvest rates do not exist, we do not estimate actual local harvest but the yearly potential provision of sustainably harvestable timber (cf. Bann 1998, Naidoo and Ricketts 2006, van Beukering et al. 2003). We assume that timber is harvested in production forests (PF) and to certain extent also in agroforestry systems (ASF). For PF, available data from the project region include annual biomass production of the most important timber species in the region. Since we assume sustainable harvest, we expect the production rates to remain stable over time. Ten locally important timber species were selected on the basis of forest surveys (Pitopang, unpublished, Hertel et al. 2009) and the Plant Resources of South-East Asia Compendium ('major commercial timbers' in PROSEA 5(1), Soerianegara and Lemmens 1993). We apply wood biomass production data estimated by Hertel et al. (2009). These estimates are based on taxonomic family level only, but can nevertheless be considered appropriate because wood density is a taxonomically conservative trait (Baker et al. 2004 and Slik 2006 cited in Culmsee et al. 2010). Wood densities were taken from Soerianegara and Lemmens (1993) and the ICRAF Wood Density Database for the conversion of kilogram into cubic meters, and adjusted for water content at measurement (usually 12 or 15%). We assume branches to be excluded from timber marketing and apply a stem: total wood biomass ratio of 0.72 (Higuchi et al. 1994). Furthermore, following Thang (1987), we assume that 70% of logged stems can be converted into marketable timber. Sawn timber prices for the 10 species were collected from local markets in Palu (Pitopang 2010, pers. communication, March 2010). Following van Beukering et al. (2003), we apply a sawn timber: round wood ratio of 2:1, as suggested by Monk et al. (1997, in van Beukering et al. 2003). Market prices are then attached to the potential quantity of sustainably harvestable timber (cf. Bann 1998). For the deduction of harvesting and transport cost, a value proposed by Brown (1999) for tropical forests (17 USD $m^{-3}$) is adopted which was already applied for forests in Sumatra (van Beukering et al. 2003) and adjusted for inflation (21.68 UDS $m^{-3}$, annual *Statistical Abstracts of the United States*, http://www.census.gov/compendia/statab/*)*.

Also AFS can comprise timber trees for shading purpose and also for household use; particularly less intensive and more shaded AFS can retain a certain share of natural forest trees (cf. Juhrbandt et al. 2010). We calculate the timber value for AFS systems as shares of PF timber values on basis of basal area relations (see 3.2.6, carbon dioxide regulation).

When forest is converted into AFS, one-time revenues from timber harvest (by clear-cutting) can be expected. We calculate this value on basis of total above-ground biomass (AGB) values taken from Culmsee et al. (2010) and applying a wood biomass: AGB ratio of 0.92 (see Hertel et al. 2009).

**Non-timber forest products (NTFP) - Rattan**

Non-timber forest products (NTFP) play an important role as an income source for rural households, particularly for poor households (Schwarze et al. 2007). In the LLNP area, 76% of the households collect forest products. Rattan is the most important marketed NTFP and it is mainly collected for selling. Almost three-quarters of the income from forest products originate from the sale of rattan. Moreover, rattan is the only important NTFP which is exclusively collected in primary forests (Schwarze et al. 2007). These characteristics make rattan a sufficiently representative NTPF for valuation in this case study.

To be harvestable, a rattan cane should have a diameter of at least 2.8 cm and a length of 10 m (Siebert 1993). Rattan canes of these large diameters can be harvested after 15-25 years (Silitonga 2002). Siebert (2004, 2005) identified *Calamus zollingeri* as one of the most important rattan species in the LLNP region. Sustainable harvest rates in the LLNP region have been calculated to 56-101 m cane length $ha^{-1}$ $yr^{-1}$.

The most common marketed diameter class is 3- 3.5 cm (Siebert 2004). For the same reasons as explained for timber extraction, we assume for this study rattan harvest under sustainable conditions, hence production rates are assumed to remain stable over time.

Stiegel (2010) calculated the annually harvestable cane length per hectare forest for the three most important commercial species in the project region, which are *C. zollingeri* (local name: Bantang; 899 m $ha^{-1}$ $yr^{-1}$), *C. ornatus var. celebicus* (local name: Lambang; 994 m $ha^{-1}$ $yr^{-1}$) and *Daemonorops macroptera* (local name: Noko; 30 m $ha^{-1}$ $yr^{-1}$). Cane length estimates are based on rattan growth rates provided by Siebert (2004), Dransfield and Manokran (1994) and Silitonga (2002). All three species grow in clusters below 1300 m a.s.l., thereby providing opportunities for sustainable harvest, as rattan cane extraction does not necessarily destroy plant individuals. In order to attach prices based on weight unit to harvestable rattan quantities, we convert harvestable cane lengths into harvestable weights via volume calculation. Harvestable canes of these species have diameters between 2 and 4 cm (Stiegel 2010), we assume an average diameter of 3 cm for *C. zollingeri* and *C. ornatus var. celebicus and* 3.5 cm for *D. macroptera* (Stiegel, pers. communication, April 2010) for calculating harvestable volumes and weights. Assuming a constant cane diameter, a cylinder form of rattan cane and the weight to be a linear function of cane volume, the harvestable rattan weight can be calculated as

$$W = k\,(\pi/4)\,D^2\,L \qquad (1)$$

With k= constant (specific gravity), W= weight, D= diameter and L= cane length.

Specific gravities are not available for the three species; therefore we apply literature values. Sulaiman and Lim (1990) calculated specific gravities for 11-years-old *C. manan* in Malaysia (diameter 2.2-3.7 cm) for the bottom (0.48) and middle part (0.32) of the cane. In contrast, in India, Bhat et al. (1991) found higher values for the two large diameter (>1.8 cm) species *C. nagbettai* (0.666) and *C. thwaitesii* (0.48). We thus choose an average value of 0.49 for specific gravity.

Rattan prices per kilogram for the three species are taken from a socioeconomic rattan survey, conducted in 2008 in the study region (V. Gonzalez, unpublished data).

Also the costs of rattan harvesting were taken from the same data source, using the relation of kilogram harvested to the number of days needed for the harvest in order to calculate labour costs per kg for the three species which could then be converted to costs per hectare and year, assuming a wage rate of 15,000 IDR (= 1.64 USD) per day, referring to the lower end of empirical local wage rates.

**Cocoa production**

Data on cocoa production stem from a detailed AFS management study conducted in the project area in 2007 (cf. Juhrbandt et al. 2010). In total 144 cocoa plots from different households were selected in 12 villages around LLNP. The plots were selected as to uniformly cover a gradient from densely shaded and biologically diverse systems to intensive and simple structured systems with little or no shading trees. A socioeconomic land use survey was administered to all households, and structural parameters of the cacao plots were recorded. Farmers were contracted to prepare weekly monitoring data on inputs, outputs, labour activities and market prices. From these data, we calculated cocoa income as well as intercrop income. Family labour is valued at the lower end of local wage rates (15,000 IDR per day). The value of purchased inputs is low, and the cacao sector is free from substantial market distortions (subsidies, taxes) in Indonesia. Thus, input and output prices need not be adjusted (cf. Yaron 2002). Average farm gate prices for cocoa beans were closely correlated to the world market price for the duration of the study ($R^2$: 0.83; Juhrbandt et al. 2010).

In order to define a measure for agricultural intensity, we develop an advanced version of an agricultural intensification index, based on previous approaches by (Mas and Dietsch 2003) and (Shriar 2000, 2005). We define an Agricultural Intensification (AI) index based on 3 plot structure parameters (canopy openness, planting density and number of native forest trees on the cocoa plot), as intensification in cocoa agroforests of our study region consists in the first place of removal, thinning and simplification of shade canopy cover. Because households are more likely to intensify the higher the efficiency of the intensification technology (Pagiola and Holden 2001), we additionally account for the relative importance of these factors for increasing productivity, by applying weights as multipliers for the intensity scores (cf. Shriar 2000, 2005). But unlike in previous studies, we here the define weights based on statistical coefficients as calculated in a Cobb-Douglas production function (CDPF) of cocoa yields ($R^2$=0.22):

$$Yc_{ha} = e^{0.869} * PD^{0.414} * OP^{0.6} * e^{(FT*-0.351)} \quad (2)$$

With $Yc_{ha}$= cocoa yield per hectare, PD= planting density of cocoa trees, OP= Openness of canopy cover (%) and FT (0/1) = incidence of forest trees on plot. This procedure assures a reasonable weighting of intensity scores by applying empirical data from the AFS study. Products of weights and scores are finally summed up. All 144 cocoa plots are grouped into quartiles by using the AI Index.

Tab. 9 displays descriptive statistics for the important characteristics of these four AFS quartiles. AI Index Quartile (AIQ) 1 is the least intensified AFS, displaying the densest canopy cover and the lowest yields and net revenues. AIQ 2 and 3 are intermediate intensive AFS, displaying substantially higher yields and revenues and AIQ 4 is most intensively managed AFS, although revenues from intercrops play only a minor role here.

Table 9. Descriptive statistics of cocoa agroforest characteristics for different intensities (AIQ1-4)

| **AI Index Quartile (AIQ)** | **AIQ 1 (N=36)** | | **AIQ 2 (N=35)** | | **AIQ 3 (N=36)** | | **AIQ 4 (N=36)** | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Canopy openness [%] | 26.9 | 12.8 | 48.7 | 16.3 | 67.6 | 15.6 | 87.6 | 9.2 |
| Planting density [cocoa trees $ha^{-1}$] | 879.1 | 190.2 | 889.7 | 197.4 | 988.8 | 197.0 | 1225.3 | 239.0 |
| Forest trees on cocoa plot (0/1) | 0.69 | 0.47 | 0.75 | 0.44 | 0.61 | 0.49 | 0.57 | 0.5 |
| Cocoa variable costs [USD $ha^{-1}$] | 22.6 | 44.3 | 22.7 | 32.0 | 26.0 | 32.7 | 29.5 | 39.2 |
| Cocoa labour input [USD $ha^{-1}$] | 330.0 | 296.5 | 353.5 | 262.3 | 307.2 | 242.4 | 293.6 | 217.6 |
| Gross margin intercrops [USD $ha^{-1}$] | 40.2 | 106.5 | 67.3 | 135.8 | 13.1 | 80.8 | 11.2 | 34.1 |

Following Obiri et al. (2007) and Ryan et al. (2009) we fitted a yield curve from a regression of cocoa tree age using empirical data from the 144 cocoa plots.

The nested term for the yield-age curve ($R^2$=0.07) is

$$Age = e^{(3.82 - 0.086*TA + 1.33*\ln TA)} \quad (3)$$

With TA= average cocoa tree age.

The yield curve was then integrated in the overall production function analysis, using a CDPF form with total dry cocoa yield per year as dependant variable (adj. $R^2$= 0.70)

$$Yc = e^{-9.77} * TW^{0.16} * SPc^{0.735} * IP^{0.202} * Age^{0.933} * nTr^{1.391} * nTr_2^{-0.12} * OP^{0.333} * Site^{0.554} * e^{(CPB*-0.321)} * e^{(FT*-0.481)} * e^{(dIP*0.891)} \quad (4)$$

With TW= Total labour input [$ha^{-1}$], SPc= size of cocoa plot [ha], IP= Total fertilizer and pesticide input [1000 IDR], Age= nested term for the yield-age curve, nTr= total number of cocoa trees on plot, nTr2= squared number of cocoa trees, OP= canopy openness [%], Site= nested term of site-specific variables, CPB= dummy for the incidence of heavy yield loss due to the Cocoa Pod Borer [0/1], FT= incidence of forest trees on the plot [0/1] and dIP= dummy if fertilizer and pesticides are not used [0/1].

The site specific vector *Site* was fitted as cocoa yield per hectare following Stoorvogel et al. (2004) ($R^2$= 0.60).

$$Site = -727.1 + RF * 507.2 + Ptot * 95.1 + DF * 80.87 + WL * -195.96 \quad (5)$$

With RF= Yearly rainfall [1000 mm $a^{-1}$], Ptot= Total soil phosphorus content [kg $ha^{-1}$], DF= Distance to forest edge [km] and WL= dummy for waterlogging conditions [0/1]. For further details on production function analysis, please see also the Appendix I.

The life cycle of a cocoa tree is estimated to last 25-30 years (Ryan et al. 2009). Using the production function approach, we estimate cocoa bean yields for AIQ 1-4 from plot establishment until the age of 25. Plot establishment costs are likewise taken from empirical data of the AFS study (201.5 USD $ha^{-1}$, 337.0 USD $ha^{-1}$, 401.8 USD $ha^{-1}$ and 478.9 USD $ha^{-1}$ for AIQ1, 2, 3, 4 respectively).

Gross margins from cocoa cultivation are calculated by applying an average producer price of 2007 for each of the four AIQ. Variable costs, including input, wage labour costs, transport and material are deducted from gross income as well as shadow prices for family labour to obtain gross margins (GM) for cocoa production. Gross margins for intercrops grown on the cocoa plot are calculated in the same way for each of the four AIQ. Total gross margins (GM cocoa + GM intercrops) are calculated and discounted for year 1 to year 25, assuming yields, variable costs and labour as well as GM from intercrops to be zero for the first two years. For the rest of the time span, these parameters except cocoa yields are assumed to remain stable. In year one instead, establishment costs (averages for each AIQ, derived from own data) are included in GM, which already include labour costs of family and wage labour.

**Nutrient cycling and soil fertility**

Soils are generally fertile in the project region (Dechert et al. 2004, Duwe 2009) but some indicators of soil fertility can decrease after forest conversion. Dechert et al. (2004) found lower carbon and nitrogen stocks in agroforests and maize plots when compared to natural forests. Annual net nutrient losses (by harvest and leaching) are higher in agroforestry plots (N -0.7%; P -0.4% of total stocks) when compared to natural forest (N -0.02%; P 0%) (Dechert et al. 2005). However, cocoa agroforestry systems are generally able to stabilize soil nutrient status (Dechert et al. 2004); and soil N cycling is not significantly different between natural forests and agroforests in the project region (Corre et al. 2006).

Soil parameters limiting cocoa yields in the LLNP region are basically the total amount of phosphor and water logging conditions (Duwe 2009, Juhrbandt et al. 2010). P was considered the most limiting nutrient in cocoa agroforests also by Smiley and Kroschel (2010). Low P concentrations may also decrease nitrogen uptake (Lockard and Asomaning 1964 and Smith 1992, cited in Duwe 2009). This is because nitrogen fixation as promoted by leguminous trees in agroforests is dependant on P availability.

Unshaded cocoa trees are expected to require more fertilizer than shaded ones, and a lack of fertilizer, especially P results in declining yields in less than 10 years (Ahenkorah et al. 1974). In 20 years of experimental cocoa cultivation in Ghana, available P in unfertilized and zero shade plots fell by 38%, hence 1.9% per year (Ahenkorah et al. 1987). Total P-losses in Malaysian cocoa systems under fertilized conditions were 5 kg per ha and year by harvest, whereas under unfertilized conditions, yearly P-losses are two to three times higher (Hartemink and Donald 2005a). Annual total P losses in the project region are 0.4% of the total stock in unfertilized agroforestry systems compared to 0% in natural forests (Dechert et al. 2005). Only 27.3% of the AFS study cocoa plots were fertilized in 2007. In general, cocoa fertilization in the LLNP area can be considered irregularly and suboptimal (cf. Juhrbandt et al. 2010). The factor IP in the CDPF consists mainly of expenses for pesticides and herbicides (74% of IP on average). This sufficiently allows us to assume no fertilizer use during the projected 25 years, and consider more intensively managed plots to be more susceptible to P-loss, than shaded AFS. On this basis, we apply a rather conservative estimate of an annual P-loss of 0.2% for AIQ 1, 0.4% for AIQ 2 and 3 and 0.6% for AIQ 4. Reduced P-contents over time are inserted in the CDPF to estimate resulting yields over time. Resulting yield estimates are compared to ‘normal’ CDPF yields (without P-loss) in order to receive the resulting loss in cocoa GM.

**Microclimatic functions**

Microclimatic functions are important for cocoa production in terms of light intensity on the cocoa plot. Higher light intensities promote higher cocoa yields at least on the short run (Juhrbandt et al. 2010). Canopy openness is the reciprocal value of canopy cover and it was included in the estimation of the AI Index. Hence, the marginal changes in yields and net benefits between the four agroforestry systems represent to a large extent the difference in light intensity. In addition, higher humidity under dense shade canopies can favour pathogens such as the Black Pod Disease (*Phytophtora* sp.), which causes yield losses (Clough et al. 2009). Its effects on cocoa yields are not quantifiable for our data set, though, and were therefore not included in our study.

**Pollination services**

Pollination is an ecosystem service of high importance for farmers worldwide as 35% of global crop production depends on pollinators (Klein et al. 2007). Bees are the predominant and economically most important group of pollinators in most geographical regions (Kremen et al. 2007). In coffee production, bee pollination is known to increase fruit set and berry weight (Klein et al. 2003). Estimating the value of bee pollination requires the analysis of the local crop management in the context of the surrounding landscape matrix (Kremen et al. 2004, Kremen 2005, Daily et al. 1997).

Olschewksi et al. (2006) conducted an economic valuation of coffee pollination by bees in the LLNP area in Indonesia as well as in Ecuador. Fruitset and berry weight as well as coffee yields were connected to forest distance. Thereby they calculated the marginal net revenue decrease from coffee production when forest distance from coffee plot increased in 100-m steps. The average pollination value amounts to 35 USD $ha^{-1}$ forest in Indonesia and 36 USD $ha^{-1}$ in Ecuador for a forest loss scenario of the first 100m forest margin (32 ha). The complete deforestation scenario (100 ha) reveals values of 47 USD $ha^{-1}$ for Indonesia and 49 USD $ha^{-1}$ forest in Ecuador. We apply the complete deforestation scenario for Indonesia and use the estimated value of 47 USD $ha^{-1}$ for pollination services. We assume pollination services to be available also in production forest subject to a sustainable use of timber and rattan, since bee diversity and crop variation is often highest when multiple, forested and open habitats are available (Klein et al. 2002, Klein 2009, Winfree et al. 2007).

**Watershed protection**

Deforestation often leads to increased variability in discharge patterns, thereby causing high fluctuations in water supply and water quality (Keil et al. 2003). Leemhuis et al. (2007) integrate remote sensing and hydrological modelling to analyse the impact of land cover changes on water resources in the mesoscale Gumbasa river catchment, which covers large parts of the northern LLNP area. Elevation dependant land use change scenarios were applied in order to investigate the impact of land use change on the water budget. The total area of the Gumbasa catchment amounts to 1275 $km^2$, and it is to 86% covered by natural forests. The forested area below

1200m a.s.l. accounts for 688.5 $km^2$. If all forest in the Gumbasa catchment below 1200 m a.s.l. is converted to perennial crop land, i.e. to cacao, ("perennial crop scenario"), 37.1% of the regional forest cover is lost. As a result, the total annual discharge increases by 5.8%. This figure increases to 11.4% in an annual crops scenario. Using the hydrological model WASIM-ETH, Leemhuis (2005) simulated the daily amount of discharge for the outlet of the Gumbasa catchment under different scenarios in comparison with a baseline model for the year 2003. The main irrigation scheme in Palu valley extracts water from this outlet.

Monthly total discharge for the baseline scenario (E0L0) is taken from Leemhuis (unpublished data). For the perennial crop scenario (E0LA2), only the annual change in total discharge compared to the baseline is available (Leemhuis 2005).

A minimum discharge level of the Gumbasa river is required at the outlet in order to allow for water extraction for irrigation (259,200 $m^3$ per day). This amount is subtracted from the total discharge. Also a maximum level of discharge is defined in order to account for high sedimentation rates during flood event, which require the closing of the outlet to prevent damage of irrigation channels (4,320,000 $m^3$ per day) (Leemhuis 2005).

The water discharge is then converted into available irrigation water for the technically irrigated wet rice area in Palu valley by using a distribution algorithm developed by Gessert (2008). The distribution algorithm consists of a ranking of rice fields according to their location within an irrigation unit with wet rice. In the Palu valley, Gessert (2008) studied a rice growing unit of 23.6 ha, which was partitioned into 6 ranks. We assume the studied area of 23.6 ha to be a representative case for the irrigated wet rice area in Palu valley and apply the relative partitions referring the ranks to the total irrigated wet rice area in Palu valley which is supplied with irrigation water from Gumbasa catchment. This area amounts to 6,500 ha of technical irrigated wet rice are cultivated. The total harvested rice area is given as 14,627 ha in 2002. The difference between these figures is supposed to be irrigated rice land with a simple irrigation system based on unreliable water supply (Leemhuis 2005, Keil et al. 2007). Following these authors we apply both figures as minimum and maximum irrigated rice area fed by irrigation water from Gumbasa catchment. For water supply by precipitation, we apply data from the climate station in Sigimpu, Palu valley for 2003 (STORMA-B1, Kreilein, H.).

Two rice harvests per year are usual in Palu valley, each season requires from seedling to harvest stage 120 days. Total water demand for one wet rice season is estimated at approximately 1500 mm (Bouman et al. 2007). Based on his survey results, Gessert (2008) splits this amount into four main periods within one season, namely the seedling stage (1. month, 250 mm), growth stage A and B (2. and 3. month, each requires 500 mm) and harvest stage (4. month, 250 mm). In Maranatha (Palu river area), most rice fields follow a temporal pattern, in which the first season lasts from December to March and the second season from April to July. Following Gessert (2008), we assume that harvests will be zero in case of zero water availability (from precipitation and irrigation) for one month within one season. Moreover, all growth stages are assumed to be equally affected by water availability (Krupp et al. (1971) in De Datta et al. 1973:22). Based on these assumptions, a water dependant production function for wet rice as developed by (Bouman and Tuong 2001) can be applied to calculate per hectare rice yields in our project region.

The water related wet rice production function (Bouman and Tuong 2001) is expressed as:

$$Yr_w = Yr_p * (1 - e^{(b*(C-WI))}) \qquad (6)$$

With $Yr_w$= Water dependant rice yield [t $ha^{-1}$], $Yr_p$= potential rice yield [t $ha^{-1}$] (average value for Maranatha= 4.17 t $ha^{-1}$, Gessert 2008), b= Initial factor-use efficiency (0.0035 for this area, Gessert 2008), C= Minimum water input and WI= Total water input [mm] (from precipitation and irrigation). The minimum water input (C) is set at 300 mm, a value referring to the cumulative evapotranspiration in the vegetative growth phase (Bouman and Tuong 2001). For calculating the value of rice production, an average producer price of 3720 IDR per kg rice is applied (Gessert 2008).

**Atmospheric Carbon dioxide regulation**

The global carbon market is growing rapidly, it doubled during 2008 alone (Reuters 2009). The compliance market is regulated by mandatory regional, national or international carbon reduction regimes and consists of companies and governments that by law must surrender emission allowances or credits. It is very big in size, both in value and volume, and exceeds the voluntary (non-compliance) market by far (Capoor and Ambrosi 2007). However, for forestry related carbon credits the voluntary markets have become the primary source of supply and demand, hence in Indonesia for example, all forest carbon projects are placed in the voluntary sector.

The active carbon absorption in vegetation usually involves the planting of new trees within reforestation, afforestation and agroforestry schemes. As only the net amount of sequestered carbon is relevant from a climate change mitigation perspective, carbon projects need a baseline and a fixed project cycle period. The carbon offsets originating from registered or approved Clean Development Mechanism (CDM) projects are called Certified Emission Reductions (CER). The CDM allows countries with an emission-limitation commitment (Annex I Parties under the Kyoto Protocol) to implement emission-reduction projects in developing countries (non-Annex I Parties), by which saleable CER can be obtained (UNFCCC 2008).

Avoiding emissions by conserving existing vegetation requires the prevention or reduction of deforestation and forest degradation by land-use change (referred to as ‘Avoided deforestation’ or ‘Reduced Emissions from Deforestation and Degradation (REDD)’. In the case of deforestation avoidance, farmers are compensated for not clearing forests for agricultural use and timber extraction. This is in line with the “compensated reduction proposal”, which states that countries electing to reduce their national emissions from deforestation would be authorized to issue carbon certificates, similar to the CERs of the CDM (Santilli et al. 2005).

***Carbon sequestration in agroforests***

*Biomass and carbon accumulation*

The methodology for estimating biomass and carbon accumulation in agroforestry systems can be largely adapted from Seeberg-Elverfeldt (2008) (cf. Seeberg-

Elverfeldt et al. 2009). She investigated the impact of payments for carbon sequestration on the households and their land-use systems in the LLNP region. In detail these land-use systems comprise four cocoa agroforestry systems (AFS D-G). AFS D exhibits a high degree of shading and low management intensity (Canopy cover [CC]~86%), AFS E is shaded by planted and naturally grown trees (CC ~66-85%), while AFS F has a lower density of the shade tree layer, which is dominated by leguminous trees (CC ~33-65%) and AFS G involves intensive management and fully sun grown cacao with few or no shade trees (CC ~5-35%). The applied AFS categories are similar to the AI Index quartiles (AIQ1-4) used in this study and are therefore adapted here (Tab. 10).

Table 10. Overview on data sources used for carbon accounting in this study (in bold letters) and in Seeberg-Elverfeldt (2008)

| | | | | | **Data source** |
|---|---|---|---|---|---|
| **Agroforest categories (own study)** | **AIQ 1** | **AIQ 2** | **AIQ 3** | **AIQ 4** | own data |
| Agroforest categories (Seeberg-Elverfeldt 2008) | AFS D | AFS E | AFS F | AFS G | Seeberg-Elverfeldt (2008) |
| **Average canopy openness AIQ [%] 2008** | **35.7** | **50** | **61.7** | **83** | own data |
| Canopy openness [%] | 14 | 15-34 | 35-64 | 65-95 | Seeberg-Elverfeldt (2008) |
| **Average planting densities for AIQ** | **879.1** | **889.7** | **988.8** | **1225.3** | own data |
| Assumed planting densities | 1111 | 1111 | 1111 | 1333 | Seeberg-Elverfeldt (2008) and Nicklas (2006) |
| **Basal area of shade trees assumed for AIQ [$m^2$ $ha^{-1}$]** | **21 (100%)** | **15 (71%)** | **12 (57%)** | **3 (28.5%)** | Kessler, pers. communication in Seeberg-Elverfeldt (2008), and own assumptions |
| Basal area of shade trees assumed [$m^2$ $ha^{-1}$] | 21 (100%) | 15 (71%) | 12 (57%) | 0 | Kessler, pers. communication in Seeberg-Elverfeldt (2008) |
| **Carbon fixation rate of shade trees in AIQ [tC $ha^{-1}$ $yr^{-1}$]** | **2.8** | **2** | **1.6** | **0.8** | Kessler, pers. communication in Seeberg-Elverfeldt (2008), Brown et al. (1996) and own assumption |
| Carbon fixation rate of shade trees in AFS [tC $ha^{-1}$ $yr^{-1}$] | 2.8 | 2 | 1.6 | 0 | Kessler, pers. communication in Seeberg-Elverfeldt (2008) and Brown et al. (1996) |

For carbon pool calculation, we consider above- and belowground living biomass. We adopt a logarithmic cocoa biomass growth model which was developed by Seeberg-Elverfeldt (2008) on basis of allometric equations elaborated by Ortiz and Riascos (2006), and Smiley (2006) (both cited in Seeberg-Elverfeldt 2008) and using data of Nicklas (2006). The logarithmic growth model (LGM) for total cocoa tree biomass ($TB_c$) in kilogram ($R^2$= 0.76), with cocoa tree age (TA) as explanatory factor is defined as:

$$TB_c=-4.2874+(9.6312*\ln(TA)) \tag{7}$$

Total biomass per hectare can be calculated by multiplying this amount by the planting density (cocoa trees per ha). For converting total per hectare cocoa tree biomass into per hectare carbon stocks, we apply a conversion factor of 0.45 (cf. Smiley and Kroschel 2008). In Tab. 11 we compare per hectare carbon accumulation calculated by equation (7) (LGM, Seeberg-Elverfeldt 2008) with several values found in the literature.

Table 11. Amount of carbon in cocoa tree biomass accumulated per hectare at different tree ages, planting densities and locations.

| Source | Location | tC $ha^{-1}$ | Cocoa tree age | Cocoa trees $ha^{-1}$ | Biomass partition |
|---|---|---|---|---|---|
| Seeberg-Elverfeldt (2008) LGM | LLNP | 5.6 | 5 | 1111 | total |
| Seeberg-Elverfeldt (2008) LGM | LLNP | 8.9 | 10 | 1111 | total |
| Seeberg-Elverfeldt (2008) LGM | LLNP | 10.9 | 15 | 1111 | total |
| Seeberg-Elverfeldt (2008) LGM | LLNP | 12.3 | 20 | 1111 | total |
| Seeberg-Elverfeldt (2008) LGM | LLNP | 13.4 | 25 | 1111 | total |
| Smiley and Kroschel (2008) | LLNP (Napu) | 12.2 | 8 | 1111 | above-ground |
| Smiley and Kroschel (2008) | LLNP (Palolo) | 21 | 9 | 1111 | above-ground |
| Leuschner et al. (subm.) | LLNP | 3.8 | per year | 1111 | total |
| Beer et al. (1990) | Venezuela | 10.98 | 30 | 950 | total |
| Isaac et al. (2005) | Ghana | 2.4 | 2 | 3125 | above-ground |
| Isaac et al. (2005) | Ghana | 16.8 | 15 | 1362 | above-ground |
| Isaac et al. (2005) | Ghana | 15.9 | 30 | 900 | above-ground |

LGM= Logarithmic growth model developed by Seeberg-Elverfeldt (2008). LLNP= Lore Lindu National Park area.

To make data from Tab. 11 more comparable, we interpolate all values to carbon accumulation in total biomass, using a root: shoot ratio of 0.28 (Smiley 2006, cited in Seeberg-Elverfeldt 2008) and at a planting density of 1000 cocoa trees $ha^{-1}$ (Fig.14).

LGM-calculated carbon accumulation is substantially lower than most values found in literature.

Therefore, we modify the LGM as follows:

$$TBc=-4.2874+ (14*\ln(TA)). \quad (8)$$

By using equation (8), we achieve carbon accumulation values which comply more with literature values (Fig.14).

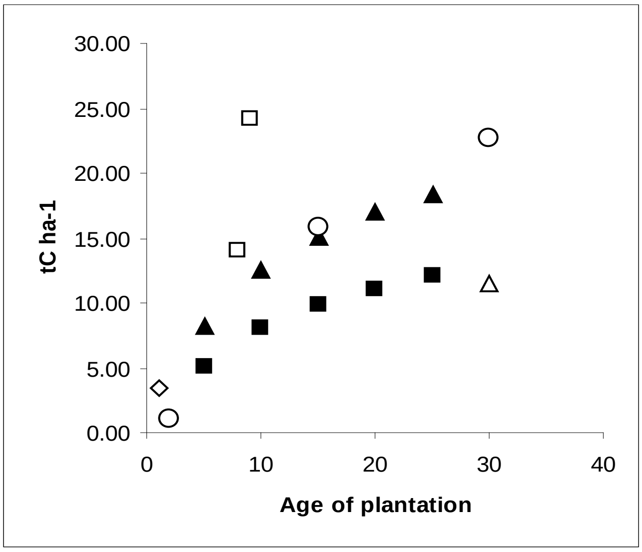


Figure 14: Per hectare carbon stock in total cocoa biomass at 1000 cocoa trees ha$^{-1}$ and different ages.

-■- LGM calculated values (Seeberg-Elverfeldt 2008, equation (1)), -▲- LGM calculated values (adapted, equation (2)), -□- Smiley and Kroschel (2008), -◊- Leuschner et al. (subm), -Δ- Beer et. al. (1990), -○-Isaac et al. (2005).

Soil organic carbon (SOC) remained fairly stable in cocoa agroforests of the LLNP region during 8 to 15 years (Smiley and Kroschel 2008). Hence, we exclude SOC from the analysis of carbon sequestration in cocoa agroforests.

Specific carbon accumulation rates of shade trees are not available for the study region; hence we approximate values by using data from natural forest stands. Total above-and belowground net primary production in six natural forest stands was estimated to be 15.3 t ha$^{-1}$ yr$^{-1}$ (6.7 tC ha$^{-1}$yr$^{-1}$), at a mean basal area of 40.3 m$^{2}$ ha$^{-1}$ (Hertel et al. 2009). As the basal area is a good predictor of total biomass

(MacDicken 1997), we apply basal area proportions for the four AIQ, following Seeberg-Elverfeldt (2008). Basal area of shade trees ($m^2$ $ha^{-1}$) is 21 in AFS D (100%), 15 in AFS E (71%) and 12 in AFS F (57%) (pers. comm. Kessler 2008 in Seeberg-Elverfeldt 2008). At least for AFS D Kessler's' estimate can be supported by forest structure inventories conducted by Dietz et al. (2006), who calculated an average basal area of forest trees of 19.4 $m^2$ $ha^{-1}$ (median 23.4 $m^2$ $ha^{-1}$) in three cocoa agroforests with natural forest tree shade cover. Seeberg-Elverfeldt (2008) did not account for any shade tree biomass for in the most intensive system G. However, concerning the most intensive system AIQ 4 of our study, we consider the estimate of zero for shade tree biomass to be underestimated as the canopy cover is on average still 17% (openness 83%). Hence we apply a hypothetical value of 3 $m^2$ $ha^{-1}$ (28.6%) as basal area of shade trees for AIQ 4. Consequently, carbon accumulation rates of shade trees are estimated to be 2 tC $ha^{-1}$ $yr^{-1}$ in AIQ 2, 1.6 tC $ha^{-1}$ $yr^{-1}$ for AIQ 3 and 0.4 tC $ha^{-1}$ $yr^{-1}$ for AIQ 4.

*Accounting Certified Emission Reductions (CER)*

The carbon project baseline has to correspond to the carbon stock in a without-project scenario (UNFCCC 2003). Following Olschewski and Benitez (2005) and Seeberg-Elverfeldt (2008) we assume year 0 as the baseline year, where the AFS is not yet in place and the carbon stock is zero. However, in contrast to the authors listed above, we also take the previous land use into account. This is necessary when considering marginal changes in NPV of land use change. Afforestation projects can not be legitimated when prior deforestation is less than 10 years ago (VCS 2008). Hence, for the conversion of NF or PF to one of the four ASF, no CER can be generated and the resulting carbon value has to be accounted at zero.

When assuming that a cocoa plantation of the type AIQ1 for example is cleared after a first project period of 25 years and then replanted as type AIQ4 for a second project period, the prior $CO_2$ emissions resulting from clearing the first plantation have to be accounted as carbon loss at year 0 of the second project phase.

We calculate carbon accumulation in cocoa agroforests for a period of 25 years, assuming cocoa planting density to remain stable throughout this time period.

For converting tC ha$^{-1}$ into carbon dioxide equivalents ($CO_2$e) as the tradable form of carbon, we use the UNFCCC conversion factor of 3.667 (UNFCCC 1997).

Certified Emissions Reductions (CER) are certificates for the reduction of greenhouse gas emissions. One CER is equivalent to one tonne of $CO_2$e. CERs are used for permanent reductions through emission reduction and avoidance and non-permanent reductions by forestry projects. In 2003, at the Ninth Conference of the Parties (COP9) it was decided to assign non-permanent credits for afforestation projects under the CDM because carbon is not stored indefinitely and can be suddenly released to the atmosphere. Non-permanent CER can be temporary (tCER) or long-term (lCER). Following Seeberg-Elverfeldt (2008) and Olschewski and Benitez (2005), we apply an accounting methodology for tCER, which are limited to five years and have to be recertified afterwards.

We account temporary CER (tCER) for a period of 25 years, whereby it is assumed that credits are synchronous with commitment periods. Hence, they are issued at the end of the first commitment period and expire 5 years later (Dutschke and Schlamadinger 2003, Olschewski and Benítez 2005).

The net carbon accumulation is calculated by using an equation elaborated by Olschewski and Benitez (2005):

$$\sum tCER*(1+d)^{-t} = \frac{(netCO_2storage)_5}{(1+d)^5} + \frac{(netCO_2storage)_{10}}{(1+d)^{10}} + ... + \frac{(netCO_2storage)_{25}}{(1+d)^{25}} \qquad (9)$$

With d= discount rate.

In order to calculate the Net Present Value (NPV) of tCER resulting from agroforestry carbon sequestration, the tCER have to be converted into permanent CER. Assuming a discount rate of 3% according to low interest rates in Annex I countries (Deutsche Bundesbank 2007, cited in Seeberg-Elverfeldt 2008), a tCER with duration of 5 years has a value of 14% of that of a permanent credit (Olschewski and Benitez 2005, Seeberg-Elverfeldt 2008). Carbon prices around 5 € (6.75 USD) per t$CO_2$e can be considered the lower end of medium-risk CER prices in 2007, whereas 25 € (33.75 USD) represents the higher end (Capoor and Ambrosi 2007). Using a price of 12 € (16.2 USD) seems most reasonable according to current market prices (PointCarbon 2010).

***REDD schemes for forest conservation***

REDD is currently not part of the Kyoto Protocol, but as the political climate change negotiations are heavily focused on REDD and it is likely to be included in a post-Kyoto agreement. Hence we assume here, that it is a valid means of avoiding $CO_2$ emissions. REDD schemes are compatible with sustainable forest management in terms of timber and NTFP use (VCS 2008).

Following Seeberg-Elverfeldt (2008), we apply a simplified approach of accounting permanent CER gained from preventing forest loss based on a previous method developed by Soares-Filho et al. (2006). Thereby the present deforestation trends are hypothesized to continue in a 'business-as-usual' (BAU) scenario, whereas in a 'project scenario', this rate could be reduced or deforestation even prevented entirely. A similar approach to account for avoided carbon emissions is used by Naidoo and Ricketts (2006).

Satellite image analysis revealed an average annual forest loss of 0.3% for the study region between 1983 and 2002 (Erasmi and Priess 2007). The rate between 1972 and 2002 is slightly higher (0.6%, Erasmi et al. 2004). However, this is a rather small rate compared to other estimates within comparable time periods for Sulawesi (-1.7%/year 1985-1997, FWI/GFW 2002) and the whole Indonesian Archipelago (-1.2%/year, 1990-2000, FAO 2003).

Deforestation activities differ significantly in their intensity throughout the region. The Dongi-Dongi region in the North-East of the LLNP for example faced a tremendous amount of forest loss of around 2,200 ha only in the year 2001 (Erasmi et al. 2004). We therefore we apply the deforestation rate for Sulawesi (-1.7 % annually).

**Biodiversity (Existence value)**

Sulawesi is part of the Wallacean biogeographic region, which is one of 25 global biodiversity hotspots, occupying an area of 212.3 million hectares in the year 2000 (Myers et al. 2000). Its flora and fauna is characterised by a high degree of endemicity (Whitten et al. 2002). Prominent endemic species include the mammals anoa (*Bubalus sp*.) and babirussa (*Babyrousa babirussa*). Also several endemic bird species can be found in the LLNP area (Waltert et al. 2004).

Local preferences for biodiversity conservation were examined in a study conducted by Glenk et al. (2006a), who included different population sizes of the endemic dwarf buffalo Anoa (*Bupalus depressicornis*, *B. quarlesi*) as an attribute in a choice experiment. The anoa is the most widely known forest species in the region (Glenk et al. 2006a); and LLNP area represents a core area for potential conservation efforts for the anoa. However, its current population size is estimated at roughly 350 individuals with a decreasing tendency (Glenk et. al. 2006b, Burton et al. 2005).

Willingness-to-pay (WTP) statements were collected for anoa populations of different sizes (10, 180, 350, 520 animals in LLNP area). The marginal annual WTP per household for an additional individual was a rather small amount of 52 IDR (=0.0057 USD) (Barkmann et al. 2007). Scaling this amount up to the LLNP area and the 33,000 households living in this region (Maertens et al. 2006), the loss of the current population size of 320 anoa individuals would cost 60,178 USD or 0.14 USD per hectare of natural forest.

In an attempt to estimate the WTP of OECD countries citizen for conserving biological diversity, Hillmann and Barkmann (2009) extrapolated values from 2 WTP studies covering 3 OECD countries. Menzel (2004) calculated the WTP of German citizens for avoiding the projected loss of half of 50,000 endangered species in developing countries for a period of 10 years (2003-2013, double dichotomous choice method). Horton et al. (2003) calculated the WTP of UK and Italy households for the implementation of two projected conservation area program, covering 5% or 20% of the Brazilian Amazon area (payment ladder approach). Reviewed WTP values were converted to USD, adjusted for inflation and weighted for population size and Gross Domestic Product (GDP) of OECD member countries. The total WTP for OECD households is estimated at roughly 43 billion USD annually (Hillmann and Barkmann 2009). Relating this amount to the remaining area of biodiversity hotspots (212.3 million ha, Myers et al. 2000), results in a per hectare WTP of 204.3 USD $ha^{-1}$ $yr^{-1}$ (Hillmann, unpublished data). We apply the WTP estimate for OECD countries citizens only as the local WTP is neglectable.

**Tourism**

Tourism is currently very limited in the LLNP region and therefore its economic value may be rather neglectable. Especially since the conflicts in Poso region (2000/2001) and the Bali bomb in 2002, the number of visitors has decreased. Moreover, reliable data on tourism development is not available for the project region (Mehring, personal communication). Hence, we exclude this component from the analysis.

## 3.3 Results

### 3.3.1 Revenues from Timber and NTFP (Rattan)

Ten locally important timber species from the LLNP area were identified, among which the plant families of the *Sapotaceae* and the *Burseraceae* are dominant (Tab. 12). Particularly *Sapotaceae* species provide timber of high value on the local markets and have reasonable high wood production rates. But also *Fagaceae* can play an important role due to their high wood production rates. Harvest costs amount to 16.6% of harvestable timber value. The total gross margin (GM) of timber harvest in production forest is 278.5 USD $ha^{-1}$ $yr^{-1}$, resulting in a Net Present Value of 2,807 USD $ha^{-1}$ over 25 years at 10% discount rate.

When forest is completely cleared, a one-time net revenue from harvested timber of 14,722 USD $ha^{-1}$ can be expected (Tab. 13).

Table 12. Production and economic value of selected commercial timber species from LLNP area under sustainable harvest conditions, as calculated from wood biomass production data given by Hertel et al. (2009).

| Scientific name | Family | (1) Wood mass production [t ha$^{-1}$ yr$^{-1}$] | (2) Wood density at dry weight [kg m$^{-3}$] | (3) Harvestable timber volume [m3 ha$^{-1}$ yr$^{-1}$] | (4) Sawn timber price at local market [Mio. IDR m$^{-3}$] | (5) Value of harvestable roundwood [USD ha$^{-1}$ yr$^{-1}$] | (6) Harvest costs [USD ha$^{-1}$] | GM of timber harvest [USD ha$^{-1}$ yr$^{-1}$] |
|---|---|---|---|---|---|---|---|---|
| *Anthocephalus chinensis* | Rubiaceae | 0.06 | 317.1 | 0.10 | 1.4 | 7.75 | 2.18 | 5.57 |
| *Canarium asperum Benth*<br>*Canarium hirsutum Wildd*<br>*Canarium maluense Lauterb. subsp. celebicum Leenh.* | Burseraceae | 0.24 | 497.0 | 0.25 | 2.4 | 32.70 | 5.37 | 27.33 |
| *Lithocarpus indutus Blume* | Fagaceae | 1.72 | 701.4 | 1.24 | 2.2 | 149.58 | 26.80 | 122.78 |
| *Magnolia candolii (Blume) H. Keng Var* | Magnoliaceae | 0.01 | 529.2 | 0.01 | 2.2 | 1.20 | 0.21 | 0.98 |
| *Palaquium luzoniensis (Fern-Vill) Vidal*<br>*Palaquium maluense*<br>*Palaquium obovatum (Griff) Engl. var orientale H.J. Lam*<br>*Pouteria firma (miq) behmi* | Sapotaceae | 0.99 | 519.2 | 0.96 | 2.7 | 142.67 | 20.83 | 121.84 |
| **Sum** | | **3.03** | | **2.56** | | **333.90** | **55.40** | **278.50** |

Data sources: (1) Hertel et al. 2009, (2) Soerianegara and Lemmens 1993, ICRAF Wood density database, (3) attaching a stem:wood biomass ratio of 0.72 (Higuchi et al. 1994) and a harvest rate of 70% (Thang 1987), (4) pers. comm. Pitopang, March 2010, (5) attaching a sawn timber:roundwood price ratio of 2:1 (Monk et al. 1997), (6) Brown 1999. 1 USD = 9091 IDR (2007).

Table 13. Production and economic value of selected commercial timber species from LLNP area at complete forest clearing conditions as calculated from above ground biomass data given by Culmsee et al. 2010.

| **Scientific name** | **Family** | **(1) Above ground biomass [t ha$^{-1}$]** | **(2) Wood density at dry weight [kg m$^{-3}$] family level** | **(3) Timber volume [m$^3$ ha$^{-1}$]** | **(4) Sawn timber price at local market [Mio. IDR m$^{-3}$]** | **(5) Value of roundwood [USD ha$^{-1}$]** | **(6) Harvest costs [USD ha$^{-1}$]** | **Net revenue timber harvest [USD ha$^{-1}$]** |
|---|---|---|---|---|---|---|---|---|
| *Anthocephalus chinensis* | Rubiaceae | 2.15 | 317.1 | 3.14 | 1.4 | 242.8 | 68.1 | 174.0 |
| *Canarium asperum Benth*<br>*Canarium hirsutum Wildd*<br>*Canarium maluense Lauterb. subsp. celebicum Leenh.* | Burseraceae | 18.30 | 497.0 | 17.70 | 2.4 | 2336.4 | 383.7 | 1953.0 |
| *Lithocarpus indutus Blume* | Fagaceae | 118.60 | 701.4 | 78.40 | 2.2 | 9486.3 | 1699.7 | 7787.0 |
| *Magnolia candolii (Blume) H. Keng Var* | Magnoliaceae | 2.55 | 529.2 | 2.23 | 2.2 | 269.8 | 48.3 | 221.0 |
| *Palaquium luzoniensis (Fern-Vill) Vidal*<br>*Palaquium maluense*<br>*Palaquium obovatum (Griff) Engl. var orientale H.J. Lam*<br>*Pouteria firma (miq) behmi* | Sapotaceae | 40.50 | 519.2 | 36.17 | 2.7 | 5371.2 | 784.2 | 4587.0 |
| **SUM** | | **182.1** | | **137.6** | | **17706.5** | **2984.0** | **14722.0** |

Data sources: (1) Culmsee et al. 2010, (2) Soerianegara and Lemmens 1993, ICRAF Wood density database (3) attaching a wood biomass:AGB ratio of 0.92 (Hertel et al. 2009), a wood a stem:wood biomass ratio of 0.72 (Higuchi et al. 1994) and a harvest rate of 70% (Thang 1987), (4) pers. comm. Pitopang, March 2010, (5) attaching a sawn timber: roundwood price ratio of 2:1 (Monk et al. 1997), (6) Brown 1999. 1 USD=9091 IDR (2007).

In order to derive the value of sustainable timber harvest from shade trees in AFS we apply basal area relations, taking basal area of forest as the baseline (100%) (40.3 $m^2$ $ha^{-1}$, Hertel et al. 2009). Thereby we receive gross margins and net present values for AIQ1 (52.1% of forest basal area), AIQ2 (37.2%), AIQ3 (29.7%) and AIQ4 (7.4%) (Tab.14).

When NF or PF is converted into an AFS, revenues of one-time timber harvest of total forest clearing (see Tab.13) has to be related to basal areas to derive one-time revenues for partially forest conversion, since depending on AFS, a certain amount of shade trees remains in the system. Taking forest as baseline (100%), conversion to AIQ1 results in 47.9% of timber harvest by forest clearing, in 62.8% for AIQ2, in 70.3% for AIQ3 and in 92.6% for AIQ4. The resulting revenues are displayed in Tab.14.

Table 14. Gross margins (GM) and net present values (NPV) of sustainable timber harvest and one-time timber harvest by forest clearing for the four AFS. NPV over 25 years at 10% discount rate.

| | **AIQ 1** | **AIQ 2** | **AIQ 3** | **AIQ 4** |
|---|---|---|---|---|
| GM [USD $ha^{-1}$ $yr^{-1}$] | 145.1 | 103.6 | 82.7 | 20.6 |
| NPV [USD $ha^{-1}$ $yr^{-1}$] | 1462.2 | 1044 | 833.4 | 207.6 |
| One-time revenue from forest conversion [USD $ha^{-1}$] | 7051.8 | 9245.4 | 10349.6 | 13632.6 |

Among the three commercially important rattan species, *C. zollingeri* and *C. ornatus var. celebicus* have the highest potential for NTFP income, both displaying high production rates (Tab. 15). The labour cost share for rattan extraction is with 39% only slightly higher compared to Yaron (2002), who estimated the share of labour cost share for NTFP as 10% of the NTFP-value, and transport and marketing cost as 20%. Hence, on a per hectare basis, sustainable timber extraction is potentially by far more profitable than rattan extraction, which displays a gross margin of 42.4 USD $ha^{-1}$ $yr^{-1}$ and a net present value of 429.3 USD $ha^{-1}$ over 25 years at 10% discount rate.

Table 15. Production and value of selected commercial rattan species from LLNP area.

| Scientific name | (1) Cane growth [m $ha^{-1}$ $yr^{-1}$] | (2) Volume [$m^3$ $ha^{-1}$ $yr^{-1}$] | (3) Weight [kg $ha^{-1}$ $yr^{-1}$] | (4) Rattan price [IDR $kg^{-1}$] | (5) Value [USD $ha^{-1}$ $yr^{-1}$] | (6) Labour cost [USD $ha^{-1}$ $yr^{-1}$] | GM [USD $ha^{-1}$ $yr^{-1}$] |
|---|---|---|---|---|---|---|---|
| *C. zollingeri* | 899 | 0.64 | 311.4 | 1000 | 32.6 | 12.1 | 20.4 |
| *C. ornatus var. celebicus* | 994 | 0.70 | 344.3 | 1000 | 36.0 | 14.7 | 21.4 |
| *D. macroptera* | 30 | 0.02 | 10.4 | 900 | 1.3 | 0.5 | 0.8 |
| Sum | 1923 | 1.36 | 666.1 | | 69.9 | 27.3 | 42.6 |

Data Source: (1) Stiegel (2010), (2) Diameter, Stiegel (2010), (3) Specific weight, Sulaiman and Lim (1990), Bhat et al. (1990), (4) Gonzales, unpublished (local market prices), (5) exchange rate USD 1- IDR 9091 (2007), (6) Gonzales, unpublished.

### 3.3.2 Cocoa yields and Soil fertility

Cocoa trees are expected to yield harvest at the age of three. Projected average cocoa yields rise most sharply for AIQ 4, the most intensively managed plots, until the age of 15, and afterwards yields are declining (Fig. 15). Peak average yields are highest for AIQ 4 (547.1 kg $ha^{-1}$) and lowest for AIQ 1 (232.4 kg $ha^{-1}$). Intermediate values can be observed for AIQ 3 (452.4 kg $ha^{-1}$) and AIQ 2 (322.8 kg $ha^{-1}$). Yield losses due to decreasing soil phosphor are highest for the most intensive system AIQ 4, ranging between 0.6% in year 3 and 4.4% in year 25. Average P-loss-induced yield declines lie between 1.5% (AIQ 1) and 2.8% (AIQ 4).

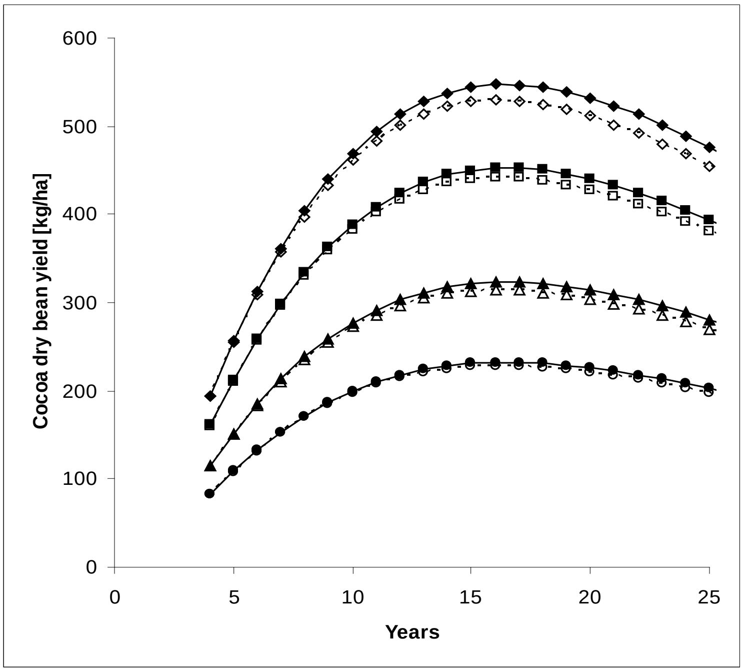


Figure 15: Estimated cocoa dry bean yields for year 1 to 25.
Hollow signs depict yields at P-loss. -♦- AIQ4 normal, -◊- AIQ1 P-loss 0.2% ha$^{-1}$ yr$^{-1}$; -■- AIQ3 normal, -□- AIQ3 P-loss 0.4% ha$^{-1}$ yr$^{-1}$; -▲- AIQ2 normal, -Δ- AIQ2 P-loss 0.4% ha$^{-1}$ yr$^{-1}$; -●- AIQ1 normal, -○- AIQ4 P-loss 0.6% ha$^{-1}$ yr$^{-1}$

Tab. 16 depicts the Net Present Values discounted at 10% interest rates for cocoa production in the four AFS intensity groups (AIQ1 to 4). Net benefits increase from the system of lowest management intensity (AIQ1) to the most intensive system AIQ4. At the same time, soil phosphor losses become more significant.

Table 16. Net Present Values (NPV) in USD ha$^{-1}$ for cocoa production under normal and P-loss conditions

| **Quartile AI Index** | **AIQ 1** | | **AIQ 2** | | **AIQ 3** | | **AIQ 4** | |
|---|---|---|---|---|---|---|---|---|
| | normal | P-loss (0.2% ha$^{-1}$ yr$^{-1}$) | normal | P-loss (0.4% ha$^{-1}$ yr$^{-1}$) | normal | P-loss (0.4% ha$^{-1}$ yr$^{-1}$) | normal | P-loss (0.6% ha$^{-1}$ yr$^{-1}$) |
| NPV at 10% | 210.9 | 189.6 | 879.1 | 830.4 | 1696.3 | 1634.6 | 2436.4 | 2334.8 |

**Watershed protection**

We calculated expected wet rice yields for a minimum wet rice area of 6,500 hectare technical irrigation area and a maximum value of 14,627 hectare total wet rice area in Palu valley (Tab. 17). Six rice field ranks in irrigation water distribution were identified by Gessert (2008). Irrigation water is sufficient for all ranks in all months of the baseline scenario at 6,500 ha wet rice area. In a total forest conversion scenario (all forest land in Gumbasa catchment is converted to cocoa agroforests), the total annual discharge would increase by 5.8% (Leemhuis et al. 2007). If this increase in irrigation water would be equally distributed on twelve months, there is no change in rice production observable because irrigation water was already sufficient in the baseline scenario.

When considering a maximum of 14,627 ha wet rice area, irrigation water supply is not sufficient for rank three to six, even in the baseline scenario. The zero value for total rice production results from the assumption that one month of insufficient water supply (from rainfall and irrigation) in a rice season (harvest) will cause a total failure of that harvest. Hence, a total rice production of zero indicates that in both rice seasons there had been at least one month of insufficient water supply. This picture does not change much in the forest conversion scenario as the small increase in total annual discharge, distributed on twelve months, is not sufficient to balance total harvest failures for the ranks three to six. In rank one and two, total rice production increases slightly due to increased irrigation water availability.

However, we consider the current state of watershed value analysis as not sufficient for including it in total net present value calculation, because it is not realistic to assume that the average increase in discharge caused by forest conversion is equally distributed over twelve months. In contrast we expect that in such a scenario, the peaks in low water and high water supply (peak flows) are more important to assess impacts on the availability of irrigation water (cf. Kleinhans 2003, Leemhuis et al. 2007). However, disaggregated discharge data on monthly basis for the forest conversion scenario were not available at the time of analysis.

Table 17. Wet rice irrigation area and total wet rice production for baseline and forest conversion scenario at 6,500 ha and 14,627 ha irrigation area.

| **Rice field rank** | **1** | **2** | **3** | **4** | **5** | **6** | **Sum** |
|---|---|---|---|---|---|---|---|
| % in irrigation area (Gessert 2008) | 47.8 | 29.9 | 15.2 | 5.1 | 1.5 | 0.5 | |
| **Baseline scenario at 6,500 ha irrigation area** | | | | | | | |
| Total irrigation area [ha] | 3,110 | 1,941 | 990 | 331 | 98 | 31 | 6,500 |
| Total rice production [t] | 25,935 | 16,186 | 8,253 | 2,763 | 819 | 255 | 54,210 |
| Value of rice production [USD] | 10,612 | 6,623 | 3,377 | 1,131 | 335 | 104 | **22,182** |
| **Forest conversion scenario at 6,500 ha irrigation area** | | | | | | | |
| Total rice production [t] | 25,935 | 16,186 | 8,253 | 2,763 | 819 | 255 | 54,210 |
| Value of rice production [USD] | 10,612 | 6,623 | 3,377 | 1,131 | 335 | 104 | **22,182** |
| **Baseline scenario at 14,627 ha irrigation area** | | | | | | | |
| Total irrigation area [ha] | 6,998 | 4,367 | 2,227 | 746 | 221 | 69 | 14,627 |
| Total rice production [t] | 58,349 | 36,368 | 0 | 0 | 0 | 0 | 9,4717 |
| Value of rice production [USD] | 23,876 | 14,882 | 0 | 0 | 0 | 0 | **38,758** |
| **Forest conversion scenario at 14,627 ha irrigation area** | | | | | | | |
| Total rice production [t] | 58,354 | 36,400 | 0 | 0 | 0 | 0 | 94,753 |
| Value of rice production [USD] | 23,878 | 14,895 | 0 | 0 | 0 | 0 | **38,773** |

### 3.3.3 Carbon dioxide regulation

#### CER values for carbon-sequestration in Agroforestry Systems

Carbon accumulation of cocoa and shade trees over 25 years together is highest for AIQ 1, comprising the highest density of shade trees, although cocoa planting densities are slightly lower than in the more intensive systems (Fig.16).

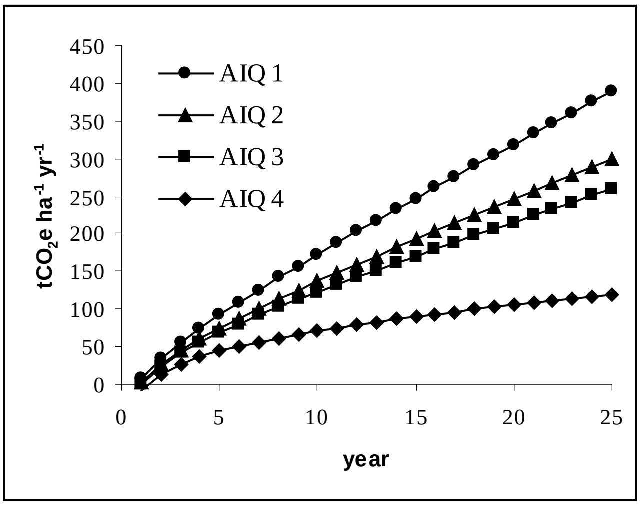


Figure 16. Carbon accumulation in $tCO_2e$ $ha^{-1}$ $yr^{-1}$ in the four AI quartiles for cocoa and shade trees

Net present values (NPV) of carbon sequestration in the four AFS are displayed in Tab. 18 for different carbon prices at 10% discount rate. However, for marginal values, the prior land use before start of the afforestation project has to taken into account (see 3.3.5).

Table 18. NPV in USD ha$^{-1}$ from carbon sequestration in the four AI quartiles at different carbon prices (at 10% discount Rate).

| | **AIQ 1** | **AIQ 2** | **AIQ 3** | **AIQ 4** |
|---|---|---|---|---|
| NPV [USD] (5€ $CO^2e^{-1}$) | 834.1 | 647.0 | 569.8 | 289.8 |
| NPV [USD] (12€ $CO^2e^{-1}$) | 2001.9 | 1552.7 | 1367.5 | 695.5 |
| NPV [USD] (25€ $CO^2e^{-1}$) | 4170.6 | 3234.8 | 2848.9 | 1448.9 |

**REDD**

We calculate annual forest loss for the project area with a size of 750,000 ha, 67% of which are covered by natural forests. Assuming a continuous deforestation rate of 1.7% per year means an annual forest area loss of 7,562 ha. Hertel et al. (2009) calculated a mean total biomass of 290 t ha$^{-1}$ for six natural forest stands at pre-montane elevation (1,050m a.s.l.) in the project area. Culmsee et al. (2010) have calculated above-ground biomass for four sites from submontane to upper montane forest. As we assume deforestation to take place mainly below 1,400 m a.s.l. we calculate a mean value (306.7 t ha$^{-1}$) from submontane (308.7 t ha$^{-1}$, 1,050 m) and lower montane forest (304.6 t ha$^{-1}$, 1,400m), hence the mean carbon stock is 138 tC ha$^{-1}$ with the data from Culmsee et al. (2010) . 85% of carbon content is assumed to be released during forest conversion (Soares-Filho et al. 2006), resulting in a projected carbon loss of 887,020 tC yr$^{-1}$ for the whole area. Hence the projected amount of avoided $CO_2$e emission in a REDD scheme would be 7.3 t$CO_2$e ha$^{-1}$ yr$^{-1}$. This is equivalent to an economic value of 49 to 247 USD ha$^{-1}$ yr$^{-1}$ according to the lowest and highest CER price. We calculate total net benefits on basis of a current price of 12 € (16.2 USD) (PointCarbon 2010).

### 3.3.4 Total Net Benefits of Ecosystem Services

Net Present Values for each land-use type sum up to Total Net Benefits, which are displayed for each value category in Tab. 19. Cocoa yield values are estimated for AFS without P-loss. Values for P-losses are differences in NPV between cocoa cultivation under normal and under P-loss conditions.

ES are distinguished into private goods and services, including income from timber, rattan and cocoa and public goods such as carbon sequestration or avoided emission, pollination services and biodiversity. Net losses due to decreasing soil phosphor content is included in the private benefit section as it is directly decreasing income from cocoa production.

Natural forests provide public goods and services only, comprising avoided carbon emissions within a REDD scheme, pollination services and habitat function for local species. Biodiversity was calculated by WTP values for OECD country citizens, and it is the most important contributor to Total Net Benefits for natural forests.

Production forests under the assumption of sustainable timber and rattan harvest potentially provide substantial private revenues. REDD projects are in line with sustainable forest management and pollination services are assumed not to be disturbed by forest use, hence, their potential values apply also in the production forest scenario. The biodiversity value is not included in the production forest scenario as it applies only to strictly protected areas, not subject to human use.

The four agroforestry systems AIQ1 to AIQ4 differ in their management intensity in terms of plot structure and in consequence also in their private and public profitability. When forest (NF or PF) is converted to AFS, one-time revenues from timber harvest can be high, particularly when the following AFS is an intensive one (AIQ4). Potential revenues from a carbon sequestration program are the only public value category for agroforestry systems. While private net revenues from cocoa cultivation increase from the least intensive system AIQ1 to the most intensive system AIQ4 by nearly 90%, the losses due to P exhaustion are relatively low but also increasing (~77%). Potential income from carbon sequestration projects exceeds cocoa income by far the low intensity systems AIQ1 and 2 but are remains significantly lower in comparison to cocoa revenues for the more intensive systems AIQ3 and 4.

Table 19. Total Net Benefits [USD $ha^{-1}$] at 10% discount rate per value category and land use type.

| | Total net benefits (NPV) at 10% DR | | | | | |
|---|---|---|---|---|---|---|
| ***Value category*** | Natural forest | Production forest | AIQ1 | AIQ2 | AIQ3 | AIQ4 |
| Timber (sust. harvest) | 0.0 | 2806.5 | 1462.2 | 1044.0 | 833.4 | 207.6 |
| Timber from forest conversion* | 0.0 | 0.0 | 7051.8 | 9245.4 | 10349.6 | 13632.6 |
| Rattan | 0.0 | 429.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cocoa | 0.0 | 0.0 | 210.0 | 879.1 | 1696.3 | 2436.4 |
| P-loss | 0.0 | 0.0 | -20.4 | -48.7 | -61.7 | -101.6 |
| C-sequestration* | 0.0 | 0.0 | 2001.9 | 1552.7 | 1367.5 | 695.5 |
| REDD | 1193.7 | 1193.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Pollination | 423.2 | 423.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Biodiversity | 2058.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

*dependant on prior land use.

### 3.3.5 Marginal Net Benefits of land use change

Of by far higher interest than Total Net Benefits is the analysis of Marginal Net Benefits for policy information as it clearly depicts trade-offs between potential land use alternatives. Marginal Net Benefits are calculated as changes in Net Present Values (NPV) occurring when changing from one land use type to the next intensive one in terms of canopy management (Tab. 20).

Converting natural forest into production forest results in a significant increase of net benefits in the first place by the potential profitability of timber harvest, even when harvest is regulated to sustainable rates. The planting of AFS after natural forest conversion increases net benefits even more, especially for the more intensive AFS.

Similar increases in marginal net benefits can be observed when switching from production forest to agroforestry, although the values are slightly lower. Moving from the low intensity AIQ1 to the next intensive AIQ2 or the most intensive AIQ4 results in a loss of net benefits, whereas switching to the moderate intensive AIQ3 leads to an increase in net benefits. Moving from AIQ2 to AIQ3 leads to an increase in net benefits, whereas switching to AIQ4 results in net losses. Also the last intensification step from AIQ3 to AIQ4 leads to a loss in net benefits.

Table 20. Marginal Net Benefits [USD ha$^{-1}$] at 10% discount rate (over all ES).

| | **Marginal changes in Net benefits [USD] at 10 % DR** | | | | | |
|---|---|---|---|---|---|---|
| **change** | **from** | | | | | |
| **to** | Natural forest | Production forest | AIQ 1 | AIQ 2 | AIQ 3 | AIQ 4 |
| Natural forest | 0,0 | | | | | |
| Production forest | 1177,1 | 0,0 | | | | |
| AIQ 1 | 5027,9 | 3850,8 | 0,0 | | | |
| AIQ 2 | 7444,1 | 6267,0 | 1967,0 | 0,0 | | |
| AIQ 3 | 9141,9 | 7964,8 | 3479,6 | 1512,6 | 0,0 | |
| AIQ 4 | 12499,3 | 11322,2 | 6165,0 | 4198,0 | 2685,4 | 0,0 |

When considering public goods and service only (Tab. 21), it becomes obvious that switching to a more intensive land use in all cases entails net losses in public benefits. It clearly comes out that converting natural forest into other land use alternatives results in most important net losses.

Table 21. Marginal Net Benefits [USD ha$^{-1}$] at 10% discount rate (public goods and services).

| | **Marginal changes in Net benefits [USD ha-1] at 10 % DR** | | | | | |
|---|---|---|---|---|---|---|
| | **Public goods and services (carbon sequestration, REDD, pollination, biodiversity)** | | | | | |
| **change** | **from** | | | | | |
| **to** | Natural forest | Production forest | AIQ 1 | AIQ 2 | AIQ 3 | AIQ 4 |
| Natural forest | 0.0 | | | | | |
| Production forest | -2058.7 | 0.0 | | | | |
| AIQ 1 | -3675.7 | -2387.5 | 0.0 | | | |
| AIQ 2 | -3675.7 | -2387.5 | -449.2 | 0.0 | | |
| AIQ 3 | -3675.7 | -2387.5 | -634.4 | -185.2 | 0.0 | |
| AIQ 4 | -3675.7 | -2387.5 | -1306.4 | -857.2 | -672.0 | 0.0 |

In contrast, marginal changes in private net benefits (Tab.22) are always positive when converting natural forests (NF) into other land uses. The same holds true for the conversion of PF to any of the four AFS. The intensification of cocoa agroforests results in positive marginal benefits as long as only private goods and services are concerned.

Table 22. Marginal Net Benefits [USD ha$^{-1}$] at 10% discount rate (private goods and services).

| | Marginal changes in Net benefits [USD] at 10 % DR | | | | | |
|---|---|---|---|---|---|---|
| | **Direct private benefits (timber, rattan, cocoa)** | | | | | |
| **change** | **from** | | | | | |
| **to** | Natural forest | Production forest | AIQ 1 | AIQ 2 | AIQ 3 | AIQ 4 |
| Natural forest | 0,0 | | | | | |
| Production forest | 3235,8 | 0,0 | | | | |
| AIQ 1 | 8703,6 | 5467,8 | 0,0 | | | |
| AIQ 2 | 11119,8 | 7884,0 | 2416,2 | 0,0 | | |
| AIQ 3 | 12817,6 | 9581,8 | 4114,0 | 1697,8 | 0,0 | |
| AIQ 4 | 16175,0 | 12939,2 | 7471,4 | 5055,2 | 3357,4 | 0,0 |

### 3.3.6 Trade-off analysis

The high private returns resulting from forest conversion to cocoa agroforests and the increasing profitability of cocoa agroforests along the intensification gradient provokes trade-offs in the provision of ecosystem services provided by forests and extensive agroforestry systems. Tab. 23 summarizes trade-offs occurring between public benefits and private returns from forest conversion to agroforests and subsequent intensification of agroforests. All analysed public goods and services do not provide sufficient public net benefits to offset private returns from forest conversion to cocoa AFS, even when applied in combination. The same is true with respect to the intensification of cocoa systems. It should be considered, however, that watershed protection values could not be included here.

Table 23. Trade-off analysis (Net present values in USD ha$^{-1}$).

| | AIQ1 | AIQ2 | AIQ3 | AIQ4 |
|---|---|---|---|---|
| | Forest conversion (NF) to agroforests | | | |
| REDD | -7509,9 | -9926,1 | -11623,9 | -14981,3 |
| Biodiversity | -6644,9 | -9061,1 | -10758,9 | -14116,3 |
| REDD + Biodiversity + Pollination | -5027,9 | -7444,1 | -9141,9 | -12499,3 |
| REDD + Biodiversity + Pollination + C-sequestration | -3026,0 | -5891,4 | -7774,4 | -13862,6 |
| | Agroforestry Intensification | | | |
| C-sequestration | -6701,70 | -9567,10 | -11450,14 | -15479,52 |

### 3.3.7 Sensitivity analysis

In order to test the sensitivity of our results with respect to changes in decisive input variables, we conduct a sensitivity analysis (Tab 24). Changes in discount rates have significant influence on NPVs in natural forest and production forest, as well as in intensive agroforestry systems. Decreasing discount rates (DR) result in higher NPV of all land use types, particularly in AIQ4; the profit-raising effect of decreased DR is higher than the profit-lowering effect of increasing DR.

Most sensitive to changing carbon prices are afforestation projects for extensive agroforestry systems. For high intensity cocoa plantations as well as for REDD schemes in production forest, the effect is relatively low.

Cocoa price changes affect NPV most severely in intensively managed cocoa plantations. A price increase benefits in particular AIQ3 and AIQ4 whereas a price decrease affects especially AIQ2 and AIQ4. Changing timber prices lead to substantial changes in NPV of PF, but also of AIQ1 and AIQ2. A change in rattan price affects PF only, and merely to a small amount.

Table 24. Sensitivity Analysis (% change in NPV for each land use alternative)

| | | **Natural forest** | **Production forest** | **AIQ1** | **AIQ2** | **AIQ3** | **AIQ4** |
|---|---|---|---|---|---|---|---|
| Reference situation (NPV in USD $ha^{-1}$ at 10% DR) | | 3675.6 | 4854.2 | 3653.7 | 3427.1 | 3835.5 | 3237.9 |
| Discount rate | 25% | -14.9 | -14.9 | -10.4 | -13.8 | -16.6 | -21.5 |
| | -25% | 20.5 | 20.5 | 14.2 | 19.2 | 23.2 | 30.5 |
| Carbon price | 25% | 8.1 | 6.1 | 13.7 | 11.3 | 8.9 | 5.4 |
| | -25% | -8.1 | -6.1 | -13.7 | -11.3 | -8.9 | -5.4 |
| Cocoa price | 25% | 0 | 0 | 11.6 | 11.5 | 27.8 | 39.2 |
| | -25% | 0 | 0 | -11.6 | -23.1 | -17.4 | -26.0 |
| Timber price | 25% | 0 | 17.3 | 12.0 | 9.1 | 6.5 | 1.9 |
| | -25% | 0 | -17.3 | -12.0 | -9.1 | -6.5 | -1.9 |
| Rattan price | 25% | 0 | 3.6 | 0 | 0 | 0 | 0 |
| | -25% | 0 | -3.7 | 0 | 0 | 0 | 0 |

## 3.4 Discussion

In this study, we quantify potential trade-offs resulting from ongoing land use change in the LLNP area by calculating net benefits arising from various ecosystem services for a gradient in land use intensity, ranging from natural forests and production forest to four cocoa AFS of differing management intensity. The valuation approach was simplified by assuming linear relationships between land use change and ecological impacts, while thresholds, discontinuities or irreversibilities in respond functions are not considered here. We assume that the changes in forest and agroforests considered in this study result in marginal values apart from the threshold zone of the safe minimum standard level (SMS), below which a system changes abruptly (or even collapses) (Fisher et al. 2008), since for agroforests, we do not exceed the period of productivity (25 years) and for production forest, we assume timber and NTFP to be extracted at sustainable rates.

### 3.4.1 Timber and Rattan provision

NPV from timber harvest form a substantial part of total NPV for production forests but also for extensive AFS that comprise high shares in shade trees on the plot. Timber values play an important role also in selective use scenario in Sumatra calculated by van Beukering et al. (2003), which is comparable to the PF scenario is our study. Harvestable timber volumes in our study (0.01 to 1.24 $m^3$ $ha^{-1}$ $yr^{-1}$ depending on tree family, in sum 2.56 $m^3$ $ha^{-1}$ $yr^{-1}$) are similar to values in van Beukering et al. (2003), ranging from 0.5 $m^3$ $ha^{-1}$ $yr^{-1}$ for meranti to 5 $m^3$ $ha^{-1}$ $yr^{-1}$ for hardwood (other timber: 2 $m^3$ $ha^{-1}$ $yr^{-1}$). Also, our timber prices derived from local markets (77 USD $m^{-3}$ to 148.5 USD $m^{-3}$ for roundwood) are comparable to values listed in van Beukering et al. (2003) (114 USD $m^{-3}$ for red meranti) and Brown (1999) (142.8 USD $m^{-3}$ for mixed hardwoods), both values were corrected for inflation. Timber harvest leads to a substantial provision value of production forests in LLNP area, although we consider a sustainable harvest scenario only (annual wood production). Moreover, only ten (although dominant) timber species are considered and timber species of very high value are not included, such as Ebony (*Diospyros macrophylla*) which has a low abundance when compared to other species. However, figures are estimated on basis of intact rainforest stands, which are not disturbed by human use yet. The abundance of the selected species may hence differ according to altitude, general forest condition and prior uses.

Throughout Indonesia, timber harvest rates are considered largely unsustainable (Palmer 2001, Resosudarmo 2002), but respective data is lacking for the LLNP area. However, Deschamps and Hartman (2005) argue that the commercial timber market in Central Sulawesi is smaller than in many other forested areas in Indonesia, because commercially valuable timber species (such as Dipterocarps) are not abundant.
Also rattan extraction was, contrary to the assumptions made for this study, reported to be realized at exploitative rates in many locations of the LLNP area (Siebert 2004). Although the presumably unsustainable income from rattan is substantial, particularly for the poorer rural households of the project region (Schwarze et al. 2007), the contribution of sustainable rattan harvest to Total Net Present Values of production forests is rather low when compared to potential income from timber harvest. Rattan production conducted at unsustainable rates in Leuser National Park were reported to account to 7226 kg $ha^{-1}$ $yr^{-1}$ (van Beukering et al. 2003), which is more than ten times higher than sustainable rattan harvest rates calculated in this study.

### 3.4.2 Income from cocoa production and its reduction by P-losses

Cocoa production turns out to be commercially most profitable when conducted in intensive, low-shade agroforestry systems. However, also yield losses due to declining soil fertility over time are projected to be higher in these systems. In a shade and manurial experiment in Bunso, Ghana, Vernon (1967) found over a time of 6 years (starting year was 1958, cocoa trees were 9 years old at that time) higher rates of yield decrease in unshaded cocoa plantations than in shaded ones (whether fertilized or not). Also Ruf and Zadi (1998) provide evidence that cocoa with less than optimum shade has a shorter life cycle. In contrast, long-term studies on cocoa agroforestry in West Africa revealed decreasing cocoa yields over time in basically all types of plantations (fertilized or not fertilized, shaded or unshaded) (Vernon 1967, Ahenkorah et al. 1987). Hence, long-term yield risks may be there in high intensity AFS, but there is no strong evidence that they will necessarily manifest.
Potentially high cocoa bean yields due to favourable soil and climate conditions as well an efficient value chain with limited state intervention result in high cocoa pro-

ducer prices (Panlibuton and Meyer 2004). This makes cocoa agroforestry a very profitable land use option in LLNP area, particularly in intensively managed systems.

### 3.4.3 Carbon sequestration and avoided emissions

Monetarized potential benefits from afforestation and REDD projects form a large share of the overall ecosystem service benefits in forests, but also in agroforests. This finding is also supported by van Beukering et al. (2003), Pearce (2001) and Yaron (2002).

Estimates for average carbon stocks are 283 tC $ha^{-1}$ for tropical primary forests in general (Pearce and Moran 1994) and 150 tC $ha^{-1}$ for Indonesian forests (Whiteman and Fraser 1997 cited in Yaron 2002). Our estimates (138 tC $ha^{-1}$) are lower than these figures, which may be due to the particular forest structure.

The calculation of benefits arising from carbon projects always involves insecurities as current carbon prices are subject to high volatility (PointCarbon 2010). Moreover, estimates for carbon credits within a REDD scheme are somehow rough approximations because carbon release differs with the type of forest conversion (Brown et al. 1993).

Including the economic value of carbon stocks could contribute substantially to the total economic value of forest conservation. Still, our study has shown that revenues a REDD project at current prices are not sufficient to offset private benefits from the conversion of NF and PF, even when values for biodiversity and pollination are added in a hypothetical combined PES scheme.

Likewise, a carbon sequestration project for agroforests does not provide sufficient revenues to offset incentives for farmers to switch to high-intensity agroforests.

### 3.4.4 Biodiversity and pollination

Tropical forest regions can in many cases be identified as win-win ecoregions in terms of biodiversity and ecosystem services indicating spatial congruence of both (Naidoo et al. 2008). The applied WTP value for biodiversity conservation is relatively high in this study compared to previous findings. Usually, biodiversity values are expected to take a relatively small range of the TEV of natural forests (cf. van

Beukering et al. 2003, Pearce 2001, Yaron 2002). In the study of Yaron (2002) (Mount Cameroon region), non-use values comprise less than 2% of the total economic value, whereas in our study, biodiversity conservation accounts for more than a half of total net benefits in natural forests (56%).

Kramer et al. (1994, cited in Pearce et al. 1999) estimates the WTP of US citizens for tropical forest conservation, which Pearce et al. (1999) extrapolated to all OECD citizens to a non-use value of 13-27 USD $ha^{-1}$. Likewise, estimates used in this study are based on calculations for OECD citizens. However, they are about 10 times higher. This may be due to the difference in calculation methods as Pearce et al. (1999) calculated WTP for the protection of additional 5% tropical forests.

Pollination services provide a comparatively low share in Total Net Benefits of natural and production forest, when compared to the biodiversity conservation value and the CER value provided in a potential REDD scheme. The importance of this value could have further decreased because since the time of data collection for the study (2000/2001), the share of coffee in cultivated land in LLNP has significantly decreased (by 27.8 % between 2001 and 2007) as many farmers have switched from coffee to cocoa agroforests (Reetz 2008).

Reduced revenues from carbon sequestration and timber harvest in *Cordia alliodora* plantations (West-Ecuador) with reduced tree densities was compensated by pollination services only in part, but it was also not sufficient to provide enough incentives for local farmers to switch to lower-density and more bee-friendly timber plantations (Olschewski et al. 2010).

### 3.4.5 Stakeholders

Especially non-market benefits often belong to different spatial dimensions, thereby affecting different stakeholders (Naidoo and Ricketts 2006, Naidoo et al. 2008). While direct benefits of forest use and conversion to agricultural lands are mostly connected to local communities realizing the conversion, environmental benefits arising from intact forests are typically enjoyed by communities located in a downstream area of the watershed (in case of watershed protection functions), or even by the global community (in case of carbon sequestration for instance). These biases in the distribution of benefits and costs arising from land use decisions have to be prevented by internalizing non-market benefits into the land use choice mechanism (Brown et al. 1993).

### 3.4.6 Trade-offs

Balmford et al. (2002) estimate as a synthesis of 5 empirical studies that on a global scale the benefit of conserving remaining habitats of all relevant biomes exceeds the opportunity costs of conversion by the factor 100.

In contrast, in our study benefits created by conserving natural forests or production forests do not exceed the opportunity costs of conversion to cocoa agroforests, no matter to which system. This difference in results is probably not only due to the very high profitability of cocoa production in Indonesia, but also due to the fact that the value of timber accruing when forest is cleared has to be included in CBA. However, other potential public benefits associated with the conservation of forests may exist that were not captured in this study.

Of particular importance may be the economic value of watershed protection, which we were not able to calculate in detail due to data gaps. Yaron (2002) for example estimates an NPV of forests preventing sedimentation of 115.7 USD $ha^{-1}$ (corrected for inflation) in the Mount Cameroon area, based on the cost of switching to groundwater supplies, as realized by a certain proportion of villages. Forest conversion generally results in a reduced evapotranspiration and consequently in higher water yields (Hibbert 1967 in Keil et al. 2003) which oftentimes leads to increased peak flows and flood rates, causing high sedimentation rates (Keil et al. 2003). Seasonal water quality changes due to increased sedimentation were measured in the LLNP area (Nopu village) by turbidity data from a weir in a slash-and-burn zone and in a in the natural forest zone. These changes were also perceived by local people. Moreover, farmers also recognized water shortages for domestic use during pronounced dry periods (Keil et al. 2003).

## 3.5 Conclusion

With this study, we aim at giving a comprehensive overview over the public and private benefits arising from ecosystem services provided along a gradient in land use in Central Sulawesi and at the same highlight potential trade-offs occurring through changes in marginal net benefits when switching from one land use alternative to a more intensive land use. Although the list of selected ES provided by forests and agroforests makes no claim to be complete, we already captured a reasonable range of direct and indirect value categories.

The described gradient in land use change (forest conversion and agroforestry intensification) is symptomatic for the LLNP region. However, we have to take into account that a farmer has always more possibilities of land use than described in our analysis, which could be even more adverse to environmental goods and services than cocoa agroforests.

The high private returns resulting from forest conversion to cocoa agroforests and the increasing profitability of cocoa agroforests along the intensification gradient raises trade-offs in the provision of ecosystem services provided by forests and extensive agroforestry systems. In order to make potential values from indirect ecosystem benefits tangible and effective, they have to be internalized in economic accounting and in policy making for future land-use planning. Still our study has demonstrated that at current market conditions (especially for carbon credits), the internalization of ES for example in payment for environmental service schemes could be substantially hampered due the high profitability of current unsustainable land use. In this case, a combination with another PES schemes such as a market-based price premium for shade-grown cocoa within a certification scheme could be a solution.

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# 4 Chapter

## Impacts of PES schemes on forest conversion and agroforestry intensification – A dynamic ex-ante modelling approach in Central Sulawesi (Indonesia)

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**Summary**

In this study, a dynamic and disaggregated farming household model is developed in order to investigate the impacts of PES schemes on agroforestry intensification and forest conversion as well as on farm structure and resource allocation over time. We conduct an ex-ante analysis of agricultural production and resource use patterns of smallholder cocoa farmers in Indonesia subject to the introduction of different PES schemes. Applying a mathematical programming approach for five time periods, impacts of two different PES scenarios are assessed across a regional intensification gradient in cocoa agroforestry: The introduction of a price premium for shade-grown cocoa, including a main shade premium and a pre-premium component, and the introduction of a carbon project, including an afforestation (agroforestry) and a REDD (Reducing emissions from deforestation and degradation) component.

The model basically optimizes cocoa productivity by allocating additional family labour to cocoa cropping, whereas wet rice and maize production and area decrease in the model. The shade premium is directly related to the productivity of the cocoa system. By increasing cocoa output price, it affects overall production structure to a larger extent than payments for carbon sequestration, which are rather dedicated to the whole cocoa system as a per hectare payment. The shade premium is better suited to prevent deforestation (on average 0.27 ha farm area increase over five years, Baseline scenario: 0.4 ha) by farm area extension than a payment for avoided deforestation under the proposed REDD scheme and current carbon market conditions (also 0.4 ha on average). In terms of agroforestry intensification, payments within a carbon afforestation project and a price premium paid for shade-grown cocoa would both be able to stabilise intensification at intermediate levels (change in canopy openness within five model periods +10.1 for the carbon project and +7.7% for the shade premium scenario; baseline scenario: +18.2%). However, for both schemes it will be difficult to attract cocoa farmers with high-intensity cocoa plantations. The shade premium for instance is only adopted by about half of the households. Adoption of the shade premium is negatively correlated to initial canopy openness; hence, the premium is adequately targeted. In contrast, carbon payments in afforestation projects should be more carefully targeted in order to effectively provide an incentive to switch to more sustainable agroforestry systems. In both PES scenarios, farmers re-

ceive slightly increased total farm revenues when compared to the baseline scenario (Carbon project scenario: +6.3%, Shade premium scenario: +3.7%). The current REDD scheme is not well targeted when the aim is to benefit the relatively poor farmers.

## 4.1 Introduction

Tropical rainforests provide a wide range of goods and services resulting from ecosystem functioning which benefit not only local farmers but also regional or international communities. Likewise, many tropical agroforestry systems have the potential to provide habitat for species not found elsewhere in farmed landscapes (McNeely and Schroth 2006). Particularly shaded agroforestry systems can maintain some of the original rainforest biodiversity (Perfecto et al. 1996, Moguel and Toledo 1999, Steffan-Dewenter et al. 2007). Moreover, a significant portion of services provided by the original ecosystem can be conserved in agroforests, such as habitat conservation, watershed protection, sediment control, improvement of soil fertility and soil moisture, pollination, biological pest and disease control, especially when compared with alternative land uses (Rice and Greenberg 2000, Bentley et al. 2004, Schroth et al. 2004, Franzen and Borgerhoff Mulder 2007, Schroth and Harvey 2007, Steffan-Dewenter et al. 2007, Bhagwat et al. 2008, Bisseleua and Vidal 2008). In contrast, reduction of shade canopies in intensively managed agroforests leads to high losses of biodiversity and ecological functioning (Siebert 2002, Schroth and Harvey 2007, Franzen and Borgerhoff Mulder 2007, Steffan-Dewenter et al. 2007).

Cocoa is a cash crop grown in agroforestry systems, which plays an important economic role for small farmers in some areas of the tropics. It can provide necessary income for purchasing food (Bentley et al. 2004) and it is especially important in areas where food security has been a problem (Belsky and Siebert 2003). Cocoa is cultivated in agroforestry systems which are known to be part of small farmers' low risk and low cost strategies in the humid tropics (Deheuvels et al. 2007).

Indonesia is the third largest producer of cocoa after Ivory Coast and Ghana with over 490.000 metric tons (MT) produced 2008/2009 (14% of global production;

(ICCO 2010a). Smallholders produce the overwhelming amount of cocoa in Indonesia (Akiyama and Nishio 1996). The provinces of Central Sulawesi, Southeast Sulawesi and South Sulawesi alone account for 75 percent of the Indonesian cocoa bean output (COPAL 2008).

The area in and around the Lore Lindu National Park (LLNP) in Central Sulawesi (Indonesia) represents an important habitat for the flora and fauna of the Wallacea biodiversity 'hotspot' (Myers et al. 2000). In this region, the expansion of cocoa agroforests is the main driver of regional forest conversion (Erasmi et al. 2004). Moreover, priorly shaded cocoa agroforestry systems are increasingly intensified by the extraction of shade trees, often resulting in zero-shade plantations (Siebert 2002). This process goes along with increased yields at least in the short run. Yet intensive zero-shade plantations are also associated with high losses of biodiversity and ecological functioning, causing further environmental degradation (Steffan-Dewenter et al. 2007). Cocoa production provides highly interesting income opportunities for smallholder farmers of the LLNP region. Farmers with shaded and highly diversified cocoa plantations have a high economic incentive to intensify their plots by shade tree removal (Juhrbandt et al. 2010).

The changes in goods and services resulting from different land covers and land use changes can be explained by the concept of Ecosystem Services (ES) (Millennium Ecosystem Assessment 2005). ES are utilized aspects of ecosystems (used actively or passively) to produce human well-being. Many of these services are public goods, because their positive effects are non-exclusive and create no rivalry among those who benefit (Heal 2000). As a consequence, most ES are not captured by market prices. Hence, they are not included in economic accounting when land use change takes place, for example forest conversion to agroforestry systems or the intensification of agroforests. Non-market ecosystem services can be internalized by institutional arrangements, including legislation and regulations in form of taxes, subsidies and targeted credits (Gobbi 2000, Alger and Caldas 1994, Donald 2004, Franzen and Borgerhoff-Mulder 2007).

For the effective use of the potential benefits provided by (agro-) ecosystems, it is essential that farmers receive clear incentives to refrain from degrading ecosystems (e.g. forest clearing or removing shade trees from agroforestry systems) (Ashley et al. 2006). Incentive-based mechanisms rest on price signals which provide incentives for changes in individual behavior (Jack et al. 2007 in Seeberg-Elverfeldt 2008).

A direct approach to establish incentive-based mechanisms is Payments for environmental services (PES) (Ferraro and Kiss 2002, Scherr et al. 2004, Wunder 2007). A PES scheme is a voluntary, conditional agreement between at least one "seller" and one "buyer" over a well-defined environmental service—or a land use presumed to produce that service (Wunder 2007). The FAO (2007) distinguishes three main types of PES mechanisms, namely direct payments (public and private), offsets (both voluntary and mandatory) and agricultural product certification programmes (ecolabels). Among the offset schemes is, for instance, carbon credit trade for carbon sequestration and avoided emissions (Jack et al. 2008). Payments for carbon sequestration could also be used as an incentive to farmers for maintaining shade trees in agroforests (Seeberg-Elverfeldt 2008, Clay 2004 in Franzen and Borgerhoff-Mulder 2007). Product certification is a management procedure by which actual production is evaluated against particular management specifications by an independent certification agency (Nunes and Riyanto 2005). A certification of shade-grown agroforestry produce, such as cocoa, for instance potentially provides farmers with additional income through premium prices (Mas and Dietsch 2003, Dahlquist et al. 2007).

PES have been suggested as a promising tool for efficient nature conservation (Wunder 2006). Incipient initiatives exist in Costa Rica and some other pilot projects throughout Latin America (Landell-Mills and Porras 2002, Pagiola et al. 2002 in Wunder 2006). However, effectiveness and implications of PES schemes have rarely been tested systematically until today, particularly in the tropics (Wunder et al. 2008). By applying a game theoretical model of community-firm interactions, Engel and Palmer (2008) have assessed to which extent PES can provide an alternative for local communities besides negotiating logging agreements with timber firms in East Kalimantan, Indonesia. Results show that PES schemes have to be carefully targeted to potential recipients, in order not to create wrong incentives (e.g., by increasing a community's expected payoff from a logging agreement) or to be ineffectively deployed (e.g., in communities that would conserve forests anyway). Seeberg-Elverfeldt et al. (2009) (cf. also Seeberg-Elverfeldt 2008) assess the impact of carbon sequestration payments for forest and different agroforestry systems (AFS). Applying a static linear programming model, they determine which level of economic incentives within a PES scheme for carbon credits is necessary to convince farmers in the LLNP region to adopt more sustainable shaded agroforestry systems and to desist from further forest conversion. However, we do not know of any previous attempts to conduct ex-ante comparisons of adoption and impacts of different PES schemes on farm structure, resource allocation and management intensity in tropical farming contexts. The development of strategies which aim at solving ecological-economic trade-offs of land use change, including potential PES schemes, requires sound knowledge of their economic and ecological implications over time though. As the extent of forest conversion and agroforestry intensification is determined by the range of potential land management alternatives a farmers has, flexible land-use intensity models are required that explicitly depict the dynamic process of decision making in order to allow for the predictability of land-use changes in quantitative terms. The modelling of quantified land-use intensification is more complex compared to models which include land-cover conversion only (Lambin et al. 2000). Dynamic mathematical programming models for instance can be an appropriate tool to achieve a deeper understanding of current land-use change and a projection of future developments.

Understanding the way rural households proceed in their land use decision making is crucial in order to conduct ex-ante assessments of policy impacts, including the introduction of PES schemes. In this study, we use dynamic and disaggregated farming household models based on mathematical programming to achieve an ex-ante analysis of agricultural production and resource use patterns of smallholder cocoa farmers in Central Sulawesi, Indonesia, subject to the introduction of two PES schemes. Of particular interest are two target parameters: a) The extension of farm area over time, indicating forest clearing activities of the farming household and b) The intensification of cocoa agroforests, taking shade canopy reduction as a proxy. Impacts of two different PES-scenarios are tested across a regional intensification gradient in cocoa agroforestry:

1. The introduction of a price premium for shade-grown cocoa, including a main shade premium for maintaining a minimum shade canopy cover and a ‘pre-premium’

component, which provides an incentive to stepwise adapt intensive cocoa plots to the main shade premium requirement.

2. The introduction of a carbon project, including an afforestation (carbon sequestration in agroforestry systems) component and a REDD component (Reducing emissions from deforestation and degradation, also referred to ‘avoided deforestation’).

Particularly the following questions are to be answered by modelling land use decisions: How does the introduction of PES schemes alter farm structure and resource allocation? How does it affect the target parameters (agroforestry intensification and forest conversion)? How do these impacts change over time? How high are adoption rates and achieved incomes of the PES schemes? How are PES adoption rates and incomes related to important farm and household characteristics?

## 4.2 Methods

### 4.2.1 Theoretical framework

We apply a common theoretical model of household behaviour as driven by profit maximisation under biophysical and socioeconomic constraints (cf. Vosti et al. 2002). The underlying hypothesis is that small-scale farmers make efficient use of their resources the way that it produces the highest possible Total net Farm Revenue (TFR), although their productivity is often constrained by location-specific attributes, limited resources and low access to improved technologies (Schultz 1964 in Schreinemachers and Berger 2006, Lambin et al. 2000). In consequence, solutions may not be fully optimal, but optimal with respect to specific constraints (Parker et al. 2003). The assumption of optimal decision-making allows focusing on factors which are policy-relevant (Schreinemachers and Berger 2006) such as impacts of the introduction of PES schemes.

This framework is consistent with economic theory, which suggests that people make decisions based of the expected change in their level of ‘utility’. Farm-household decision-making is assumed to be determined by the ambition to maximise household utility. Economists assume that monetary values (e.g. TFR) can be applied as measure of utility, particularly for its changes in consequence of altering policies and market conditions (Edward-Jones 2006, Börner 2006). Within this framework, optimization models are a useful tool in explaining decision-making processes on basis of constrained optimization (Lambin et al. 2000).

### 4.2.2 Empirical Data

Empirical data on cocoa AFS management were gathered in 12 villages in the vicinity of LLNP in Central Sulawesi, Indonesia. The villages are located in four valleys covering altitudes from 75 to 1275 m a.s.l.: Palu valley, Palolo valley, Napu valley and Kulawi valley. In each of the 12 villages, a sample of one cocoa plot of each of 12 cocoa producing households was selected, resulting in a total sample size of 144 plots. The cocoa agroforestry plots were systematically chosen to represent the entire intensification gradient of high to low canopy closure (CC) values. Canopy closure (the reciprocal of canopy openness) is the proportion of the sky hemisphere obscured by vegetation when viewed from a single point (Jennings et al. 1999).

Per village, three plots were identified for each of 4 *a priori* defined shading categories: (near) natural forest cover (>85% CC; category "1"), dense shade cover (>65% CC; "2"); medium shade cover (>35% CC; "3"); low to zero shade (0-35% CC; "4"). Plots were characterised in terms of plot history and structure including cocoa tree density, intercrops and shade trees. Shade tree cover, i.e. CC, was monitored three times from 2006 to 2008. We measured CC as the average of 8-16 randomly selected points in cocoa tree interspaces per plot using a hemispherical convex densiometer.

Farmers were contracted to prepare weekly records on yields and several yield determining factors from January to December 2007. Surveyed parameters include capital and labour used for management activities and material input (e.g. fertilizer, pesticides) as well as output in terms of dry cocoa bean yield.

One plot per shading category in each village was selected for soil analyses, resulting in a subset of 48 cocoa plots. Accessible and homogeneous plots were preferentially selected. Measured soil parameters which are essential to judge soil nutrient status in the tropics include: the total amount of carbon ($C_t$), nitrogen ($N_t$) and phosphor, the amount of available phosphor ($P_{av}$), exchangeable calcium ($Ca_{ex}$), potassium ($K_{ex}$),

magnesium ($Mg_{ex}$) and aluminium ($Al_{ex}$), and the effective *Cation Exchange Capacity* ($CEC_{eff}$). Soil analyses were conducted by Duwe (2009).
For wet rice and maize production as well as for several household characteristics, the data base is complemented by socio-economic household data for the same sample (van Edig/ Schwarze 2006). These panel data stem from a 13 village random sample (Zeller et al. 2002), which overlapped with the cocoa agroforestry sample (n=144) in 80 cocoa farming households. However, basic socio-economic characteristics were surveyed for the complete cocoa agroforestry sample.

### 4.2.3 Model type

Models are considered to be useful when they simplify reality and have a clear purpose which is to solve a particular problem (Sterman 1991). The use of mathematical programming in agriculture has its prime aim in modelling the economics of agricultural production. It is also known as process analysis or activity analysis. Models of this type can connect economic theory and data to practical problem assessment and policy analysis (Hazell and Norton 1986). Mathematical programming (MP) models are able to explicitly represent physical constraints of production and are therefore well suited for linking biophysical and economic aspects of agricultural systems (Heckelei and Britz 2005). Biophysical information can be included in the production side of the model (Altieri et al. 1993, Dalton 1996 in Ruben et al. 2001).
The advantage of MP models is the explicit consideration of resource requirements of different land-use activities and the ability to simulate policy implications (Kaimowitz and Angelsen 1998). However, results depend strongly on initial assumptions made on household preferences for allocation of time and capital, labour markets, elasticities of substitution and economies of scale, which can often not be tested by the modeller (Kaimowitz and Angelsen 1998).
One of the most prevalent optimization techniques in MP is linear programming (LP). However, even though linearity is mathematically convenient, in reality it is almost always invalid (Sterman 1991). Moreover, optimization MP models are oftentimes static in temporal terms although lags in impacts of decision-making are a crucial component of dynamic behaviour of systems (Sterman 1991). Dynamic analysis

can be realized by linking MP models for subsequent time periods. However, this rapidly increases dimensionality arising from the expansion of matrix size as temporal effects are incorporated (Pandey and Hardaker 1995). Optimization models can also be used for forecasting when it is reasonable to assume optimizing agents (Sterman 1991).

### 4.2.4 Model description

Farm household modelling procedures usually consider labour and input allocation decisions, natural resource endowments, output choice and consumption preferences under different market conditions (e.g. Singh et al 1986 in Ruben et al. 2001). Our model considers besides economic parameters also biophysical factors determining land use decisions. Moreover, it considers the competition of alternative land use activities for land, labour and capital and the profit-maximising behaviour of farmers. In the following, we describe the model structure as applied for the baseline scenario (BL). The specific modifications for the two PES scenarios are explained in 4.2.11.

We apply a non-linear programming (NLP) model on farm household level. A mathematical programming model becomes nonlinear when at least one relationship is nonlinear with respect to the variables. Our MP model is non-linear due to three incorporated Cobb-Douglas Production functions (CDPF). The internal CDPF generate crop yields flexibly from various input levels, subject to production intensity and environmental or other site specific parameters. Thereby, farm household variations in input levels of land, labour and capital as well as resulting variations in output levels of crop yields can be captured. This is a straightforward way to represent heterogeneity in farming household resource endowments and their combination as well as their environmental preconditions depending on location (Schreinemachers and Berger 2006). For details concerning production function analysis and descriptive statistics of the parameters used, regression analysis and results for CDPF for cocoa, rice and maize, see Appendix I.

Our MP model is formulated in LINGO 12.0 and it is run in five subsequent time periods (=years) in order to represent the dynamics in decision making. An objective function specifies the output parameter to be maximised, while decision variables represent the choices to be made. The model constraints restrict the choices of the decision variables to those which are possible or acceptable (Sterman 1991, Pandey and Hardaker 1995). In our study, the objective function maximises the value of Total net Farm Revenue (TFR). This is done by choosing an optimal combination of agricultural activities with an optimal allocation of farm resources.

Model development is based on empirical household data collected in the study area. Cocoa, rice and maize production takes place under near to constant returns to scale conditions (CDPF, see Appendix I). The MP is applied on a disaggregated basis. Hence, resource allocation is optimized for each single household. 110 out of 144 cocoa producing households could be modelled by this procedure (76%). Households whose decision making could not be optimized in the MP model (n=34) are not significantly different from modelled households (n=110) in most parameters of farm structure, household composition and cocoa management (t-test, p=0.05). The only significant differences (t-test, p=0.05) between the two samples were detected in (empirical) per hectare cocoa bean yields (n=34: 697.4 kg $ha^{-1}$ $yr^{-1}$, n=110: 497.7 kg $ha^{-1}$ $yr^{-1}$) and in rice cropping area (n=34: 0.44 ha, n=110: 0.23 ha). In tendency, households of n=34 are better off (poverty index) and have larger farms then n=110 households, these differences are not significant, though. In combination, however, the model constraints applied in the model are too restrictive to fit the farm resource structure of the missing 34 households. A loosening of model constraints on the other hand would be adverse to model validity. The LINGO model is linked to an Access database for importing input data of the single households and exporting solutions and output variables back to the database.

In general, NLP models are difficult to solve and require some additional precautions in programming (LINGO 1998). We apply a global solver (LINGO 1998) suitable for complex non-linear optimization problems. Concavity of models in case of maximization problems enhances the solvability of the model. Internal expressions should be continuous and smooth in order to make the model easier to solve (Howitt 2005). As the internalized Cobb-Douglas production functions are concave, solving problems can be reduced.

The use of upper and lower bounds on variables makes the solution search more efficient and avoids that the solver searches solutions in areas where optima are unlikely.

Bounding can also help keeping the solution search clear of mathematically troublesome areas such as undefined regions (LINGO 1998). The described model includes for instance boundaries for the use of labour per hectare and for per hectare yields. Boundaries are set according to empirical ranges of values. The provision of initial values for optimized model variables can affect the path the solver takes to the solution, while noticeably reducing the solution time (Howitt 2005, LINGO 1998). Our model provides initial values for all input variables which can be changed (optimized) by the model. For cocoa production these are the total labour input, the cocoa area, and the openness of the canopy cover. For rice and maize production initial values are given for acreage only. All other input variables are fixed for each household (Tab. 25). Variable units involved in the model should be of similar magnitude in order to avoid problems in solving and inaccuracy of the solution occurring due to uneven scaling (LINGO 1998). Therefore, monetary units are converted into 1000 IDR.

### 4.2.5 Model activities

The main model activities are represented by the three major crops of the study region: Cocoa as the dominant perennial crop, and wet rice and maize as the most important annual crops. For perennial crops, coffee also plays a certain role in the project area, but this crop is increasingly replaced by cocoa and currently only grown at a small scale (Reetz 2008). Other frequently grown annual crops are upland rice and peanuts, but due to their relatively small importance, they are not incorporated in the model. The same is true for livestock activities which also play only a minor role in the project region. Also crop rotations are not considered in the model since they is not relevant in this study. However, labour consuming coffee and vegetable production is considered in regard to labour inputs (45 man-days $ha^{-1}$ cf. Keil et. al 2007) but they are not considered as model activities or in terms of contribution to TFR.

The model considers off-farm activities of the respective households and includes the labour time allocated and the resulting income. Credit and labour markets are highly imperfect in the study region (Maertens et al. 2006, Nuryatono 2005, Wardhono 2007). For cocoa, the share of hired labour in total labour is only 8% on average (own data, 2007). Likewise, agricultural wage labour accounts to only 9% of total average household income in LLNP area (Schwarze and Zeller 2005). For this reason, we did not consider credit and labour markets in our model (no credit taking or labour hiring aloud).

Land use change from one crop to another is allowed within certain boundaries and is associated with costs in form of labour and capital. New land can be acquired by clearing forest and converted into all three types of land use, but also the conversion of new land is accompanied with labour and capital costs (see 4.2.8 and Tab. 25).

### 4.2.6 Model inputs

Main inputs of farming households are available land, labour, and financial capital for buying material inputs such as fertilizer or pesticides. Inputs for the production of cocoa, rice and maize enter internalized Cobb-Douglas production functions (CDPF, see Appendix I). In order to reduce dimensionality of the model, the amounts of per hectare expenses for fertilizer and pesticides (for the rice CDPF) and aggregated inputs (for the cocoa CDPF, including pesticides, herbicides and fertilizer) are fixed at empirical values. Inputs which are not included in CDPF are only considered in regard to their costs per hectare (e.g. land preparation, irrigation fees, transport costs; Tab.25).

The use of labour for rice and maize is not included in the respective production functions but treated as fixed amount per hectare and crop, since there are no detailed data on labour use available at the household level. For rice, an average of 1100 labour hours per hectare and crop is required (Gessert 2008). The average labour requirement for maize is 220 hours per hectare and crop (Keil et al. 2007). In general for rice and maize, one or two crops per year are grown; the number of harvests is kept fixed at empirical values. Labour input for cocoa is included in the CDPF, and its level is optimized in the model.

Canopy openness (the reciprocal of canopy cover or canopy closure) is an important plot structural parameter in cocoa production and a crucial yield determinant. Moreover, it can function as a proxy to management intensity of the cocoa plot (Juhrbandt and Barkmann 2008). In order to track changes of the shade canopy cover over time

under different external preconditions, canopy openness can be optimized in the model in the range of 10% increase or reduction per time step. Corresponding required labour expenditures are likewise considered (average time per year needed for eliminating shade trees when increasing canopy openness by one percentage point).
Other biophysical parameters such as rainfall, distance to forest and soil fertility, and plot structure parameters such as planting density also enter the cocoa CDPF, but are fixed, as they can hardly be changed by the farmer or are at least unlikely to be changed (see Tab. 25).

### 4.2.7 Model outputs

Model outputs depend on the production level of each of the cropping activities. Yields are generated in the production function section and then multiplied by the crop price in order to receive incomes per crop. Prices are included as one fixed village average per crop, based on empirical data. Net revenue per crop is obtained by subtracting crop variable cost from crop income. Crop variable costs consist of various input expenses, as for seeds, fertilizer and other material, transport, processing etc. For the purpose of simplification, it is assumed that harvests are sold immediately and are not stored. Moreover, risks of stochastic yield variation are not considered.

### 4.2.8 Model constraints

The extent of the activities carried out by farmers in the model is limited by constraints, in the first place by the availability of resources (land, labour and capital). The following main constraints are bounding model solutions:

- Land used for the three cropping activities can not exceed the total farm area and cropping area of the three crops can not extend area dedicated to the respective crop.

3. It is assumed that new farming area can be acquired (up to 0.25 hectare per time period) by investing labour and capital. The average working time needed for cocoa plot establishment (1047 man hours per ha; n=90 out of 144 households having own labour expenses for plot establishment) was

considered as labour input for acquiring new farm land. We assume that farmers have to pay 1/3 of total timber harvesting costs as calculated in Chapter 3 for the forest conversion scenario (2984 USD $ha^{-1}$, see Tab. 13). We do not consider revenue from timber harvest (Tab. 13, Chapter 3) for the modelled households because it is not possible to make valid statements on which stakeholders (e.g. logging companies, local population, farmers) are actually profiting to which extent from timber harvesting in forest clear-cuts in the project area.

- Likewise, up to 0.25 ha land per crop and time period can be switched to another crop, which also requires capital and labour. For establishing a cocoa plot, the same amounts of labour and capital are applied as for acquiring new land area (IDR 1.000.000, which is approximately the average sum of material and hired labour costs for plot establishment, and 1047 man hours per ha). Explicit data on the workload for rice plot establishment are not available for the project region, hence, we assume the same amount as for cocoa plot establishment. Although data on rice production costs per ha and crop are available (IDR 1.782.000, by a factor of 5.4 higher than average cocoa production costs; Gessert 2008), detailed data on rice plot establishment costs (when converted from other land uses) are lacking. However, we assume the costs to be at least 2.5 times higher than for cocoa plot establishment. Also for maize plot establishment, empirical data are lacking. We expect labour expenses to be about 1/3 lower than for cocoa and rice and the capital expenses to be half of the value for cocoa (since variable costs for maize production are about half of cocoa variable costs).
- The use of family labour is constrained by family labour capacity. The latter is based on the sum of Adult Male Equivalents (AME) per household, calculated from FAO weights for each household member older than 8 years (FAO 1997). Furthermore it is assumed that a labour day has seven hours and a month has 23 labour days. The current model considers family labour only, which is free of cost. Family labour is not only allocated to farming activities but also various other activities including leisure. As detailed data from the project region are lacking we apply an average value for South East Asia,

which accounts to 40% of family labour dedicated to farming purposes (cf. Keil et al. 2009). Leisure does not shift with income changes. Farm demographics are assumed to remain constant over the modelled time period.

- Total expenses are constrained by the available cash capital which consists of current income, remaining cash from the previous time step and off-farm income. Credit is not considered as the credit market is rather imperfect.
- Microeconomic theory states the non-separability of production and consumption decisions. As long as markets are imperfect, market commodities can not fully substitute subsistence goods (Sadoulet and de Janvry 1995 in Schreinemachers and Berger 2006). In order to account for the household requirement for rice as the basic staple food, a rice consumption constraint is included in the model (cf. also Vosti et al. 2002, Keil et al. 2009). The constraint is based on the FAO figure of 147 kg per AME and year (FAO 2003). The required amount of rice can be either produced (producer price attached) or it can be purchased (consumer price attached). The consumer price is also based on empirical data (expenditure survey, van Edig 2007) and exceeds the producer price by the factor 1.15.
- Rural farming households in the project area expend a high share of their income for buying food (74% on average, van Edig, unpublished data). This is consistent with other studies (~70%, FAO 2003; McCulloch 2008, both in Indonesia). Rice purchase was found to be around 30% of overall household expenditures (FAO 2003). Hence by using the previous constraint, we interpolate from rice purchase to total food purchase (70%), which will be included in total farm expenses.
- Per hectare yields and canopy openness are bounded into empirically observed ranges (see Tab 25).
- Net revenues from the three crops are not allowed to be negative.
- Farm and cropping area can be increased or reduced by a maximum of 0.25 hectares per time period (see above).
- Canopy openness can be increased or reduced by a maximum of 10 % per time period for a labour expense of 1.5 hours per percentage point.

Table 25. provides an overview of the main model activities, in- and outputs and constraints and the equations which interlink these components for the baseline model (BL).

Table 25. Overview of main MP model equations in BL scenario. Bold printed inputs on the right hand side are flexible inputs to be optimized by the model.

| | | | |
|---|---|---|---|
| 1 | **Objective function** | | |
| | **Total net Farm Revenue** | MAX | Net revenue from cocoa production + Net revenue from rice production + Net revenue from maize production; |
| 2 | **Revenue equations** | | |
| | Crop net revenue (cocoa, rice, maize) | = | Crop income - Crop expenses; |
| 3 | **Income equations** | | |
| | Income from cocoa, rice, maize production | = | Total crop yield * Crop price * Number of harvests (rice and maize); |
| 4 | **Expense equations** | | |
| | Cocoa expenses | = | Σ [Material, hired labour, transport, inputs (fertilizer, pesticides)]; |
| | Rice expenses | = | Σ [Fertilizer, pesticides, irrigation fees, processing, transport, seeds, land preparation]; |
| | Maize expenses | = | Σ [Fertilizer, pesticides, processing, transport, seeds, land preparation]; |
| 5 | **Production equations** | | |
| | Cocoa production | = | Total cocoa yield= *f* [**total labour input**, **cocoa area**, total input expenses, **canopy openness**, tree age factor, site specific factor, planting density, incidence of cocoa pod borer and forest trees on plot]; |
| | | | Tree age factor= *f* [cocoa tree age, logged cocoa tree age]; |
| | Cocoa yield per ha | Bound | 0<= kg $ha^{-1}$<=3000 |
| | | | Site-specific factor= *f* [rainfall, soil phosphorus content, distance to forest edge, incidence of waterlogging conditions]; |
| | Rice production | = | Total wet rice yield= *f* [**rice area**, pesticides and fertilizer expenses, use of high yielding variety, location]; |
| | Rice yield per ha | Bound | 0<= kg $ha^{-1}$ <= 4000 |
| | Maize production | = | Total maize yield= *f* [**maize area**, use of high yielding variety, location]; |
| | Maize yield per ha | Bound | 0<= kg $ha^{-1}$ <= 3000 |
| 6 | **Land equations** | | |
| | Total farm area | >= | Cropping area of cocoa, maize, rice (initial values: own data); |
| | Increase in total farm area | <= | 0.25 ha per time period; |
| | Increase/ decrease in cropping area | <= | 0.25 ha per time period per crop; |
| 7 | **Canopy openness equation (cocoa)** | | |
| | Change in canopy openness | <= | 10% per time period; |
| | Canopy openness (%) | Bound | 5<= Canopy openness <=97; |

Table 25. (contin.)

| | | | |
|---|---|---|---|
| **8** | **Labour equations** | | |
| | Family labour availability | >= | Σ [Cropping labour cocoa (own data), cropping labour rice (1100 h $ha^{-1}$ $crop^{-1}$, Gessert 2008), maize (220 h $ha^{-1}$ $crop^{-1}$, Keil et al 2007), labour for coffee and vegetable cropping (315 h $ha^{-1}$, Keil et al. 2007) off-farm labour, labour for increase in cropping area (1047 h $ha^{-1}$ for rice and cocoa, 700 h $ha^{-1}$), labour for increase in total farm area (1047 h $ha^{-1}$)]; |
| | Family labour availability | = | Adult Male Equivalent* 23 days* 12 months* 40%; |
| **9** | **Consumption equation** | | |
| | Minimum rice consumption | <= | (Total rice yield* consumer price) + Rice purchase; |
| | Minimum rice consumption | = | Adult Male Equivalent* 147 kg rice; |
| **10** | **Cash equations** | | |
| | Total cash availability | >= | Total expenses= Σ [Cropping expenses, expenses for increase in cropping area (IDR 10.000.000 for cocoa, IDR 2.500.000 for rice and IDR 5.000.000 for maize) and total farm area (IDR 10.000.000), expenses for food purchase]; |
| | Total cash availability | = | Σ [Cropping income (cocoa, rice, maize), off-farm income, rest cash from previous time period]- Total expenses; |

### 4.2.9 Time frame

Land-use decision-making is dynamic, since land and capital factors are carried over from one period to another (cf. Vosti et al 2002). Including feedbacks in an optimization model alters the conditions on which decisions were originally made. Although it increases complexity of the model it is crucial to account for changing conditions within a dynamic decision making framework. In contrast, exogenous variables influence other variables but are not calculated by the model (Sterman 1991). Especially dynamic feedbacks between social and biophysical model components (changing land use and changing environment) are rarely modelled (Veldkamp and Verburg 2004). In the study at hand, the MP model is optimized at each stage in the decision-making process (each year) for five time periods (five years), but solutions are partly carried over as new inputs from one stage to the next (from year to year), including cash capital remaining from the previous period, altered cropping and farm area as well as changed canopy openness.

### 4.2.10 Calibration and Validation

Calibration is the process of using a hypothesized function and data on input and output levels in the base year to derive model output parameter values that are close to observed base year values (Howitt 2005). Model calibration can be conducted by using information from farming system analysis (Ruben et al. 2001) and by applying appropriate constraints (Heckelei and Britz 2005). The bounding constraints used in our model are in fact calibration constraints as they limit production activity levels into empirically observed ranges (cf. Heckelei and Britz 2005).

Models should be validated in order to control for the models' adequacy with regard to their intended objective. Comparing model predictions with actual outcomes for selected important variables can help deciding when a model is 'good enough'. We compared empirical results for farm structure, crop production and canopy openness with modelled values of the first model period of the BL scenario in order to achieve the best possible congruence. This is necessary for the development of model scenarios, which simulate policy changes such as the introduction of a PES scheme. However, validation is mostly not totally reliable since because models are mainly used for the prediction of impacts under different scenarios which have not been observed in reality yet (Pandey and Hardaker 1995).

### 4.2.11 PES Scenarios

**Certification of shade-grown cocoa (SP scenario)**
Two distinct certification standards already available include a minimum shade canopy in agroforestry systems. One is the Bird Friendly® label for coffee which was developed in 1999 by the Smithsonian Migratory Bird Centre. The standard aims at protecting migratory birds and their habitats and focuses on the species composition of shade trees, canopy structure and density, secondary plant diversity and buffer zones to natural ecosystems (forests). With similar intentions, the Rainforest Alliance coordinates the development of standards for the Sustainable Agriculture Network (SAN). The label "Rainforest Alliance Certified" was established in 2003. A standard was also developed for cocoa, which likewise includes a minimum shade canopy cover of 40% (SAN 2008). Unlike the Rainforest Alliance, the Bird Friendly Standard involves organic certification as a prerequisite for certification (SMBC 2002). Under IFOAM basic standards the clearing of primary ecosystems is forbidden (IFOAM 2005).
Coffee growers certified to the Bird Friendly standard see price premiums of five to ten cents per pound in addition to the premium they already receive for being certified organic (SMBC 2008). However, a corresponding standard for cocoa does not yet exist. Hence, resulting price premiums which would be realistic to be paid to farmers are unknown. Organic cocoa growers receive usually higher prices than conventional cocoa farmers, with a premium ranging from USD 100 to USD 300 per tonne (ICCO 2010b). This premium is market-dependant however and there is no guarantied price premium or minimum price in organic agriculture. Fair trade is the only label, which assures certain price premium and a minimum price. FLO established a standard for fair-trade cocoa in 2007. Producer organizations receive at least the minimum price for fair-trade standard quality cocoa beans of USD 1,600 per metric tonne (MT) FOB. A fair-trade premium of USD 150 per metric tonne (MT) FOB

is paid for all standard cocoa qualities (FLO 2007)**.** For organic quality an additional price premium of USD 150 per MT is guaranteed.

For the study at hand, we assume a price premium of USD 150 per MT dry cocoa beans paid for cocoa which is produced under a shade tree canopy with a minimum of 40% canopy closure (or a maximum of 60% canopy openness). In order to allow the model to reach this level of canopy openness, a pre-premium is paid for those households, which still lie above the required amount of openness, but are reducing openness towards the maximum of 60%. The pre-premium is calculated as USD 150 per MT divided by 40% canopy closure which is to be reduced times the percentage canopy closure reduced. Deforestation in terms of extension of the initial farm area is not allowed when the shade premium standard is adopted (c.f. organic certification standard, IFOAM 2005). Shade premium and pre-premium are included in the model as additional activities. The cocoa price is increased by shade premium or the pre-premium, when the respective requirements (see above) are fulfilled.

**Carbon PES scheme (CA scenario)**

**Afforestation component (Carbon sequestration in agroforestry systems)**

In Chapter 3 we quantified biomass and carbon accumulation in cocoa agroforestry systems of different intensities. Following Seeberg-Elverfeldt (2008) and Olschewski and Benitez (2005), we calculated Certified Emissions Reductions (CER) which can be obtained in an afforestation project under the Clean Development Mechanism (CDM) for four cocoa systems of different management intensity in a time period of 25 years. Certified Emissions Reductions (CER) are certificates for the reduction of greenhouse gas emissions. One CER is equivalent to one tonne of $CO_2$. Potentially acquirable carbon credits and resulting net present values (NPV, in USD $ha^{-1}$) were calculated for four cocoa AFS systems differing in management intensity in context of plot structure (cf. Chapter 3). Resulting net present benefits of carbon sequestration are converted into annuities (cf. Olschewski and Benitez 2005) - annual payments which farmers could receive in case a carbon project would be established. Using quartiles of canopy openness (OP) as proxies for the four respective agroforestry systems, we obtain potential annual payments per hectare cocoa in four different canopy openness categories. Following Seeberg-Elverfeldt et al. (2009), we calculate annuity payments per hectare by multiplying the NPV of the four agroforestry systems with an annuity factor. The annuity factor is calculated according to equation (1), with i =interest rate and n =number of years. The bank interest rate of 10 percent is taken (Bank Indonesia 2006 in Seeberg-Elverfeldt et al. 2009), and the time span is 25 years.

$$AF_{n,i} = \frac{i*(1+i)^n}{(1+i)^n - 1} \tag{1}$$

Using a price of 12 € (16.2 USD) which is close to current market prices (May 2010) (PointCarbon 2010), annual per hectare payments of USD 220.5 can be received if canopy openness remains lower than 37.8%. USD 171.1 are paid for agroforestry systems with OP between 37.8% and 58%, USD 150.7 can be obtained for a OP range from 58.1% to 77.6% and only USD 72.6 are to be received for systems with a OP higher than 77.6%. Hence, each farming household receives annual payments from the afforestation component in the CA scenario. The amount of income received depends consequently on the OP value and the size of the cocoa plot.

**REDD scheme component (avoided deforestation)**

'Reduced Emissions from Deforestation and Degradation' (REDD) is a PES scheme to avoid emissions accruing through deforestation and forest degradation by land-use change. Within such schemes farmers or communities are compensated for not clearing or degrading forests for agricultural use and excessive timber extraction. REDD is currently not part of the Kyoto Protocol, but as the political climate change negotiations are heavily focused on REDD it is likely to be included in a post-Kyoto agreement. Hence we assume here, that it is a valid means of avoiding $CO_2$ emissions. REDD schemes are compatible with sustainable forest management in terms of timber and NTFP use (VCS 2008). In Chapter 3 we applied a simplified approach of accounting permanent CER gained from preventing forest loss based on a method developed by Soares-Filho et al. (2006) (cf. Seeberg-Elverfeldt 2008). Thereby the present deforestation trends are hypothesized to continue in a 'business-as-usual'

(BAU) scenario, whereas in a ‘project scenario’, this rate could be reduced or deforestation even prevented entirely. We apply a deforestation rate of 1.7%/year for the island of Sulawesi (1985-1997, FWI/GFW 2002) and biomass data from the project region (Culmsee et al. 2010). The resulting annual REDD payment according to current carbon prices (see above) per hectare of avoided forest conversion is transferred to the total area covered by natural forest in the project region and the number of households living in the project region to receive an annual per household compensation payment of USD 8.8 for not clearing any forest land. The adoption of the REDD component in the CA scenario is thus an additional model activity. Households that do not extend farm area within one time period, receive the annual REDD payment.

Total carbon income is the sum of income from the REDD component and from the afforestation component in one time period in the CA scenario. Total carbon income is included in the objective function (MAX TFR) as additional net revenue (besides net revenues from cocoa, maize and rice production). We do not apply any transaction or other costs; hence carbon income is treated as net revenue.

## 4.3 Results

### 4.3.1 Temporal changes in farm structure and revenue, resource allocation and production in the BL scenario

In the BL scenario, total net farm revenue (TFR) increases from year one to year five by around 40%. Cocoa net revenues take the dominant part in TFR (93.6 % in year 1 to 96.7% in year five). Wet rice and maize are of minor importance concerning farm income structure. Both the share of rice and maize revenues in TFR is decreasing from year one to five (4.9% to 2.2% for rice, 1.6% to 1.1%).

Concerning the temporal development of farm structure in the BL model, the share of cocoa cropping in total farm area is increasing over time, while the proportion of wet rice and other farm area is decreasing and maize cropping area remains more or less stable (Fig.17).

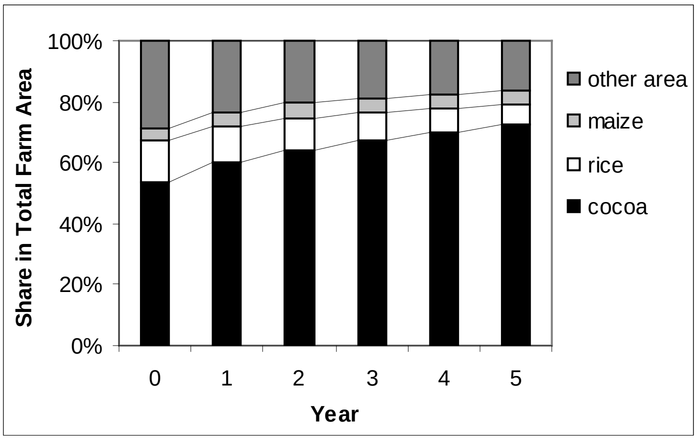


Figure 17: Change in farm structure components over modelled time period (year 1 to 5) in the BL scenario. Note: year 0 displays empirical values.

Modelled cocoa yields increase within the five years from 1,642 kg $ha^{-1}$ to 1,942 kg $ha^{-1}$ on average, which is significantly higher than empirical average yields (542 kg $ha^{-1}$ on average). Modelled rice yields decrease from an average of 830 kg $ha^{-1}$ in year one to 509 kg $ha^{-1}$ in year five. This is noticeably lower than the empirical average rice yield in the region (1,113 kg $ha^{-1}$).

Maize yields remain more or less stable over time and are with an average of 382 kg $ha^{-1}$ comparable to empirical data (364 kg $ha^{-1}$).

Family labour dedicated to farming activities accounts for ~45% for cocoa production (the share slightly increases in time: 42% in year one to 48% in year five) (Tab.26). Thus is significantly more than empirical values indicate for current labour allocation: on average only 8% of family labour is used for cocoa production.

The share in family labour allocated to rice farming decreases from 18% to 14% (mean ~16%). The percentage farm labour allocated to maize cropping is with 3% on average relatively low.

Table 26. Revenues, yields, labour and land allocation and canopy openness in the three scenarios. All values are mean values over five years model period and modelled households (n=110).

| **Scenario** | **Baseline (BL)** | | | **Carbon Project (CA)** | | | | **Shade premium (SP)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Min | Max | Mean | % change to BL | Min | Max | Mean | % change to BL | Min | Max |
| Total farm revenue [USD] | 4328 | 341 | 12761 | 4621 | 6.3 | 742 | 13109 | 4494 | 3.7 | 343 | 12922 |
| Net revenue [USD] cocoa | 4134 | 48 | 12761 | 4124 | -0.2 | 29 | 12709 | 4335 | 4.6 | 47 | 12694 |
| Net revenue [USD] rice | 138 | 0 | 1878 | 134 | -2.6 | 0 | 1840 | 108 | -27.6 | 0 | 1818 |
| Net revenue [USD] maize | 56 | 0 | 789 | 55 | -2.0 | 0 | 792 | 51 | -9.6 | 0 | 760 |
| Yield cocoa [kg $ha^{-1}$] | 1834 | 22 | 3000 | 1811 | -1 | 13 | 3000 | 1808 | -1 | 20 | 3000 |
| Yield rice [kg $ha^{-1}$] | 692 | 0 | 4000 | 699 | 1 | 0 | 4000 | 619 | -12 | 0 | 4000 |
| Yield maize [kg $ha^{-1}$] | 377 | 0 | 3000 | 634 | 41 | 0 | 3000 | 391 | 4 | 0 | 2156 |
| Labour share cocoa [%] | 44.8 | 1.8 | 99.5 | 45.8 | 2.1 | 1.8 | 99.5 | 47.8 | 6.2 | 1.8 | 99.8 |
| Labour share rice [%] | 15.6 | 0.0 | 89.3 | 15.0 | -3.9 | 0.0 | 89.3 | 12.3 | -26.4 | 0.0 | 89.3 |
| Labour share maize [%] | 3.1 | 0.0 | 39.7 | 3.0 | -3.8 | 0.0 | 39.7 | 2.8 | -10.8 | 0.0 | 37.5 |
| Land share cocoa [%] | 67.1 | 15.8 | 100.0 | 68.3 | 1.7 | 16.1 | 100.0 | 69.9 | 4.0 | 13.4 | 100.0 |
| Land share rice [%] | 9.1 | 0.0 | 66.5 | 8.3 | -9.1 | 0.0 | 52.8 | 6.8 | -34.3 | 0.0 | 67.4 |
| Land share maize [%] | 4.7 | 0.0 | 56.1 | 4.6 | -2.5 | 0.0 | 57.1 | 4.5 | -3.4 | 0.0 | 54.0 |

### 4.3.2 Changes in farm structure and revenue, resource allocation and production in PES scenarios

TFR increases in the SP and the CA scenario from year one to year five are similar to the BL scenario (~40%). The average annual TFR is slightly higher in the CA scenario (+6.3%) and in the SP scenario (+3.7%) (Tab.26). Cocoa net revenues take the dominant part in TFR also in the SP and the CA scenarios. Likewise, wet rice and maize are of minor importance concerning farm income structure. Both the share of rice and maize revenues in TFR is decreasing from year one to five in both PES scenarios. The general farm revenue structure in the SP and in the CA scenario is comparatively similar as in the BL, however in the SP model, the income share of rice and maize is further decreased when compared to the BL.

Basically the same development in farm structure as in the BL scenario can be found also within the SP and the CA scenario. While the average share of cocoa area in total farm area increases only slightly in the CA and in the SP scenario when compared to the BL model, the land share of rice decreases to a moderate amount in the CA scenario (-9.1%) and to large extent in the SP scenario (-34.3%) (Tab.26). The share of maize area decreases slightly in the two PES scenarios when compared to the BL.

While cocoa yields per hectare (five-year average) of the SP and CA scenario are comparable to the BL, the decrease in rice yield per hectare is even faster in the SP scenario than in the BL; on average yields are 12% lower than in the BL. Modelled maize yields are slightly higher in the SP scenario when compared to the BL (4%) but do significantly increase (to 40% on average) in the CA scenario (Tab.26).

The share of family labour dedicated to farming activities for cocoa production is slightly higher in the CA scenario and in the SP scenario when compared to the BL (~46% and ~48% on average respectively). Labour shares for wet rice and maize decrease slightly in the CA, while in the SP model, labour shares for rice and maize are significantly lower (-24% and -11% respectively) (Tab.26).

### 4.3.3 Adoption and income provision of PES projects

**Carbon project**

As the above described afforestation component of the carbon project is basically provided for all types of cocoa agroforests (with differing amounts of carbon credits for the different management intensities), all farmers take part in this scheme. 38% of all model farmers have moved to the second most intensive AFS (canopy openness (OP) values between 58.6% and 84.4%) after five years, 18% of this group come from the least intensive AFS (OP less than 37.1%), 10% from the second least intensive AFS (OP between 37.1% and 58.6%) and 10% from the most intensive AFS (more than 84.4% OP). 13% of all households switch to the least intensive AFS. The second least and the most intensive AFS received less admission with 8% and 5% respectively.

The average annual income a farmer obtains from the carbon project amounts to USD 269 in year one and increases until year five to USD 346 (Tab. 27). The share in TFR is relatively low, however, and also slightly decreasing during the five-year time period (7.8% to 6.1%). Total income from the carbon project consists mainly of revenues from the afforestation component (96.5%-98.4%). Only a minor and decreasing part (3.5%-1.6%) comes from a REDD scheme as described above.

Table 27. Income development and composition from a Carbon project, Adoption of REDD scheme. Averages are displayed for each model time step (n=110).

| | Total average Carbon income | | | Share of afforestation in total carbon income (%) | | | Share of REDD in total carbon income (%) | | | % of HH adopted REDD |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Mean | Min | Max | Mean | Min | Max | Mean | Min | Max | |
| 1 | 269.2 | 42.0 | 1289.2 | 96.5 | 79.2 | 100.0 | 3.5 | 0.0 | 20.8 | 67.3 |
| 2 | 290.6 | 55.0 | 1234.5 | 97.6 | 84.1 | 100.0 | 2.4 | 0.0 | 15.9 | 60.9 |
| 3 | 308.4 | 60.1 | 1179.7 | 97.8 | 85.5 | 100.0 | 2.2 | 0.0 | 14.5 | 58.2 |
| 4 | 323.3 | 70.2 | 1125.0 | 98.0 | 87.6 | 100.0 | 2.0 | 0.0 | 12.4 | 57.3 |
| 5 | 346.3 | 84.1 | 1070.3 | 98.4 | 89.6 | 100.0 | 1.6 | 0.0 | 10.4 | 51.8 |

Compensation payments for refraining from forest clearing within a REDD project are adopted by 67.3% of the households in the CA model in the first year. The participation decreases to 51.8% in year five (Tab. 27). In total, 81.8% of households take part in REDD in at least one year. 43% of the households stick to the REDD scheme over the whole period.

The amount of income from an afforestation project is positively correlated to the initial size of farm area, particularly cocoa cropping area (in year zero) and the amount of available family labour. Migrant households and households in Napu valley profit more from carbon project income, while households in Palu valley profit less (Tab. 28). Afforestation income is negatively correlated with the initial canopy openness (year zero). The adoption of the proposed REDD scheme and the amount of income (conditional to adoption) provided by it are both positively related to initial farm area and cocoa area. Both, adoption and income display a positive relationship to the poverty index, indicating that better-off households are more likely to adopt REDD and receive also higher income from it. REDD income is also positively related to the amount of off-farm income the household gains. Households in Napu valley are likely to profit more from a REDD project while Palu valley households may gain less.

Table 28. Pearson correlation coefficients between incomes from afforestation and REDD scheme, adoption of REDD scheme and household and farm characteristics (n=110).

| | Av. afforestation income over 5yr | Av. REDD income over 5yr (cond. to adoption) | Adoption of REDD within 5 yr |
|---|---|---|---|
| Initial farm area [ha] (year 0) | 0.6217* | 0.4610* | 0.2879* |
| Initial cocoa area [ha] (year 0) | 0.8431* | 0.3486* | 0.1609 |
| Initial rice area [ha] (year 0) | | | |
| Family labour availability [h $yr^{-1}$] | 0.2218* | | |
| Initial Canopy openness [%] (year 0) | -0.1923* | | |
| Poverty-Index | | 0.1789 | 0.2263* |
| Off-farm income [IDR] | | 0.1816 | |
| Non-indigenous household (0/1) | 0.2818* | | |
| Napu valley (0/1) | 0.1699 | 0.1878 | |
| Palolo valley (0/1) | | | |
| Palu valley (0/1) | -0.2211* | -0.1975 | |
| Kulawi valley (0/1) | | | |

Displayed coefficients without star are significant at the 10% level, *coefficients are significant at the 5% level.

Poverty index: Relative index based on food, expenditure, dwelling and assets parameters, E(x) = 0, positive values indicate less poverty (Abu Shaban 2001, Zeller et al. 2003). Dummy for non-indigenous household indicates migrant household.

**Shade premium**

A price premium project for shade grown cocoa provides a total average income of USD 290 in year one which increases up to USD 501 in year five (Tab. 29). The share in TFR is relatively low (5.3% in year one to 4.6% in year five). The proportion of the shade premium income in total premium income is dominant and increasing (89.6%-94.6%), while the portion of the pre-premium income is decreasing (10.4%-5.4%). In model year one, 54.5% of the households take part in the shade cocoa certification scheme, and 6.4% use the pre-premium. The adoption of the main shade premium decreases slightly until year five (49.1% of households take part), while the share of households adopting a pre-premium is almost halved (3.6%) (Tab.29). In total, over five years, 70.9% of households adopted the shade premium, while 11.8% applied the pre-premium in at least one year.

Table 29. Income development and composition from a Shade premium for cocoa, adoption of Shade Premium and Pre-premium. Averages are displayed for each model time step (n=110).

| | % Households who adopted | | Shade Premium income of adopters [USD] | | | % Share in Shade Premium income | |
|---|---|---|---|---|---|---|---|
| Year | Shade premium | Pre-Premium | Mean | Min | Max | Premium [%] | Pre-Premium [%] |
| 1 | 54.5 | 6.36 | 289.7 | 9.0 | 1294.1 | 89.6 | 10.4 |
| 2 | 54.5 | 7.27 | 313.3 | 10.0 | 1055.2 | 88.2 | 11.8 |
| 3 | 50.9 | 5.45 | 387.1 | 2.5 | 1167.0 | 90.3 | 9.7 |
| 4 | 52.7 | 2.73 | 445.5 | 2.7 | 1278.8 | 95.1 | 4.9 |
| 5 | 49.1 | 3.64 | 501.3 | 2.9 | 1390.6 | 94.6 | 5.4 |

Both the adoption of the main shade premium and the amount of income resulting from it are positively correlated with the initial area of rice cultivation (year zero) and negatively with the initial canopy openness. Furthermore, households of non-indigenous origin and those situated in Palolo valley are less likely to adopt the shade premium, while households in Napu valley tend more to adoption. The amount of income provided by a shade premium is, moreover, positively related to initial farm size and available family labour. The adoption of a pre-premium is positively related to initial canopy openness. The amount of income resulting from the pre-premium is positively correlated to initial canopy openness and location in Palolo valley (Tab. 30).

Table 30. Pearson correlation coefficients between incomes from and adoption of Shade premium and Pre-premium with household and farm characteristics (n=110).

| | Adoption of Shade premium within 5 yr | Av. Shade premium income over 5yr (cond. to adoption) | Adoption of Pre-premium within 5 yr | Av. Pre-premium income over 5yr (cond. to adoption) |
|---|---|---|---|---|
| Initial farm area [ha] (year 0) | | 0.1971* | | |
| Initial cocoa area [ha] (year 0) | | | | |
| Initial rice area [ha] (year 0) | 0.2466* | 0.3476* | | |
| Family labour availability [h $yr^{-1}$] | | 0.2730* | | |
| Initial Canopy openness [%] (year 0) | -0.6121* | -0.3219* | 0.3548* | 0.3371* |
| Poverty-Index | | | | |
| Off-farm income [IDR] | | | | |
| Non-indigenous household (0/1) | -0.1795 | | | |
| Napu valley (0/1) | 0.1778 | | | |
| Palolo valley (0/1) | -0.2690* | | | 0.2255* |
| Palu valley (0/1) | | | | |
| Kulawi valley (0/1) | | | | |

Displayed coefficients without star are significant at the 10% level, *coefficients are significant at the 5% level.
Poverty index: relative index based on food, expenditure, dwelling and assets parameters, E(x) = 0, positive values indicate less poverty (Abu Shaban 2001, Zeller et al. 2003). Dummy for non-indigenous household indicates migrant household.

### 4.3.4 Impacts of PES schemes on target parameters

**Total farm area increase (deforestation)**

The percentage of households who increase their total farm area by converting forest lands accounts to 61% in the BL scenario and remains quite stable in the SP (60%) and the CA (61%) scenario. The extent of area conversion however is substantially lower in the SP scenario (0.27 ha average increase over five years) compared to the BL (0.4 ha average increase over five years). Surprisingly, the same average amount of land is also converted in the CA scenario, indicating that the REDD payment is not hindering the total farming area expansion. The modelled development of average total farm area is depicted in Fig. 18, which demonstrates that a halt in area extension is only realized in the SP scenario.

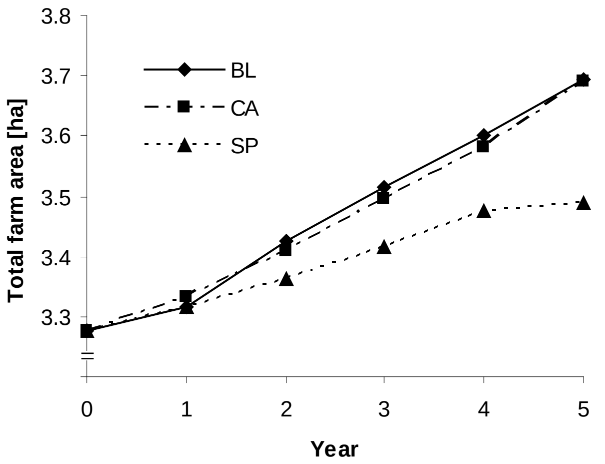


Figure 18: Increase in Total farm area [ha] over modelled time period for Baseline (BL), Carbon project (CA) and Shade premium (SP) scenarios. Note: year 0 displays empirical data.

**Increase in canopy openness (cocoa intensification)**

77% of all farmers in the BL scenario increase canopy openness (OP) over the modelled time period, whereas in the SP scenario only 69% and in the CA scenario only 66% of households increased OP. The change in OP over five years was +18.2% in the BL, but only +10.1% in the CA and an even lower value for the SP scenario of +7.7%. Fig. 19 displays the development of OP over five years for the three scenarios. Both, the CA as well as the SP scenario effectively diminish average canopy openness increase over time.

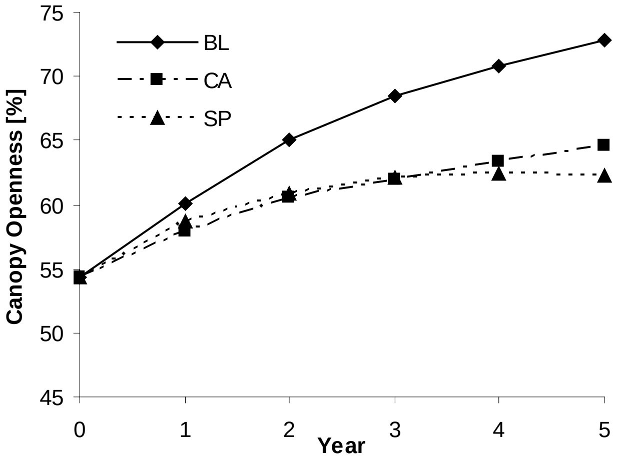


Figure 19. Increase in shade canopy openness [%] over modelled time period for Baseline (BL), Carbon project (CA) and Shade premium (SP) scenarios. Note: year 0 displays empirical data.

## 4.4 Discussion

### 4.4.1 Impacts of PES schemes on farm structure and resource allocation

In our model, a price premium paid for shade grown cocoa alters farm structure and resource allocation to larger extent than the carbon project does. This is due to the fact that the shade premium is directly related to the production of cocoa, by increasing its output price. Hence, the profitability of the payment is dependant on the productivity of the cocoa system. In contrast, payments made for carbon sequestration are rather dedicated to the whole cocoa system as a per hectare payment, hence, the overall production structure is less affected. One could also argue that in the carbon scheme, there is no incentive for the productivity of the system included.

In all three scenarios, the model basically optimizes cocoa production and farm resources are mainly allocated to this cash crop. In modelled cocoa production, the main difference to empirical values is the substantial increase in productivity. The model optimizes yields in the first place by allocating much more family labour to cocoa production than it is currently realized by local farmers (8%), although family labour availability is in the MP model already heavily constrained. Wet rice and maize cropping become less attractive in the model context and particularly farm resources allocated initially to rice are increasingly reallocated to cocoa production.

### 4.4.2 Impacts of PES schemes on target parameters: Total farm area extension and Canopy openness

The modelled extension of total farm area is, in the model context, assumed to be the amount of forest area converted to agricultural land use. In the model, this happens as soon as the initial farm area of a modelled household is completely allocated to one of the three crops: rice, maize or cocoa. Allocating initial 'unused' farm area to one of the three crops is 'cheaper' in terms of labour and capital than converting new lands. In case the conversion of new (forest) land to agricultural use is profitable to the farmer (in the model context this is more 'expensive' in terms of labour and capital), farm area extension is realized. The new land is allocated to one of the three crops. The REDD component within the proposed carbon project, offering a compensation payment of 8.8 USD per household annually for not converting forests is not able to prevent deforestation in the project area, although a substantial share of households is adopting the REDD scheme. The results indicate that households adopting REDD might be those who would not convert forests anyway because they still have sufficient farm land for establishing cocoa plots. Moreover, they profit from off-farm income sources and are generally better off. In contrast to these findings, Seeberg-Elverfeldt (2008) concludes from a linear programming model for four different AFS in the same region that REDD payments of this magnitude (5 € per hectare in her study) are only sufficient to convince cocoa farmers who manage their plots under a canopy openness lower than 37.1% (most shaded AFS). However, this group rather belongs to the poorer part of cocoa farmers. All other households would need substantially higher compensations (125€ to 700€ per hectare) to refrain from forest conversion.

The afforestation component within the carbon project is providing a good incentive for farmers to abandon the low-shade cocoa system. However, the preferred system to switch to is the one with canopy openness values between 58.6% and 84.4% (second most intensive), which does not only provide reasonably high carbon incomes but also a good productivity in terms of cocoa bean yield. The minimum shade canopy openness suggested by Bird Friendly® and Rainforest Alliance standards is 60%, which is at the lower end of this category. Hence, most cocoa plantations have canopy openness values above this minimum standard. In congruence with our results, Seeberg-Elverfeldt (2008) found that introducing carbon credits at current carbon prices could for most cocoa farmers be an incentive to switch to cocoa systems with higher shade canopies. However, farmers with very intensive cocoa plots (low-shade) could not be convinced to adopt more shaded systems. Likewise as for REDD income, the income accruing from the afforestation component is indicated to be higher for households with a good supply of land and labour, but with lower initial canopy openness values.

On average, the shade premium provides a good incentive to stabilize canopy openness at around 60%. The suggested certification scheme for shade grown cocoa is adopted by about half of the modelled households. There are indications that those who adopt the scheme as well as those who gain most income from it are like in the CA scenario farmers with cocoa plantations already displaying low canopy openness values before project start. However, parts of those households with more intensive cocoa plots apply the pre-premium, which is to help farmers to meet the target maximum canopy openness of 60%. Shade premium income is, like afforestation income, higher for those households who have a better supply with land and labour, but unlike in the CA scenario, households with larger wet rice area and local ethnicity are more likely to adopt the premium or to receive more income from it. This indicates that households with large cocoa plots and a high intensification degree may depend less on premium offers as outlined in this study.

Within our shade premium scenario, forest conversion is forbidden due to organic agriculture requirements (IFOAM 2005). In consequence, shade premium adopters do not extent total farm area within 5 years. This leads on average to a significantly lower area extension than in the BL or CA scenario.

**Model critique**

A model is by definition a simplification of reality, thus there may be many omitted factors such as unknown or not quantifiable constraints that hinder farmers in reality to optimize farm resource allocation as calculated in our scenarios. For the MP model results achieved in this study, we suggest a cautious interpretation of absolute values such as the optimized total farm revenues. The interesting point is the relative change which one scenario provokes in comparison to the baseline. Model results always depend strongly on initial assumptions which are expressed in model constraints, and which can often not be tested by the modeller (Kaimowitz and Angelsen 1998). In consequence, some results may stand in contrast to findings from other modelling studies. A major shortcoming of the described model may be that it does not include a land market. Since land markets are, like labour and credit markets, imperfect in LLNP region, they are very difficult to assess. Nevertheless, land purchase is particularly interesting in the context of cocoa production, as previous research findings indicate that dynamics in land acquirement is driven by in-migration. In-migration is playing a crucial role for the increasing cash crop orientation in the project region (cf. Chapter 2). Especially Bugis migrants are specialised in cocoa cultivation and they introduced this knowledge into the area. As they often have less direct access to new arable land, they usually acquire land by buying from autochthonous farmers, who procure new land by clearing forests since they have mostly better access to (local) authorization for doing so (Weber et al. 2007, Faust et al. 2003). To include these dynamics into an MP model approach would considerably raise its complexity though.

There is a lack in data for the harvest and use of timber in the data region. Hence, income from forest conversion can not be included in the model.

The incentive structure for the carbon sequestration project can be improved. Particularly, farm area extension needs to be further restricted, since afforestation projects can not be legitimated when prior deforestation is less than 10 years ago (VCS 2008). Experiences of carbon projects in agroforestry are limited up to now; however, new insights from practice can provide valuable inputs for achieving a more realistic parameterisation of carbon projects in a model context. For example, the targeting of the incentive could be refined by moving the focus from plot area and simple agroforestry categories to the quality of plot structure as well as on the productivity of the cocoa system.

Nevertheless, our model is able to make important statements on impacts that the introduction of different PES schemes might have on rural farming household decision making concerning land use. Most modelling procedures consider single policy instruments only. However, in reality, development projects and structural adjustment programs usually modify a whole range of production conditions (Ruben et al. 2001). We aimed at adhering to this fact by formulating each of the two PES scenarios as 'project packages' with each comprising two components. However, we did not consider non-monetary benefits of PES schemes, such as credit services, support of community management of natural resources as well as extension and training programmes. These benefits are often underrated but they can be important for producers. Certification projects, for example organic and fair-trade, often to lead to general quality improvements of agricultural produce due to capacity enhancing measures. On the other side, PES schemes can be challenged by substantial initial investment costs (Dankers and Liu 2003). These transaction costs are difficult to quantify ex-ante and were not included in this study.

## 4.5 Conclusion

Our study has shown that both, payments within a carbon afforestation project and a price premium paid for shade-grown cocoa would be able to stabilise intensification at intermediate levels on average. However, for both schemes it will be difficult to attract cocoa farmers with high-intensity cocoa plantations. Particularly carbon payments in afforestation projects should be targeted to agroforestry systems of intermediate to low intensity, in order to sharpen the incentive to switch to these more sustainable systems. Otherwise, the attractiveness of carbon payments could be mainly comprised of the size of cocoa area, which is rather an incentive for enlarging cocoa area. Contrarily, the price premium for shade-grown cocoa as suggested in this study is better tended to cocoa plantations of lower management intensity. A shade premium including organic standard requirements is also better suited to prevent deforestation by farm area extension than a payment for avoided deforestation under the proposed outline of a REDD scheme and under current carbon market conditions.

Payments for environmental services (PES) schemes provide opportunities for the effective conservation of natural resources, also in the cocoa sector (Franzen and Borgerhoff-Mulder 2007). For example, premium prices for 'high quality' shade-grown cocoa in Ecuador helped to promote shade production and to preserve traditional cocoa varieties (Bentley et al. 2004). Eco-certification in particular provides strong standards in terms of biodiversity conservation (Bennett 2008).

PES schemes should be developed in a way that they provide sufficient economic incentive for farmers to adopt and stick to environmentally friendly land use alternatives. Depending on scope and outline of the respective PES scheme, it may also include other objectives, such as providing additional and/or more reliable income. Access to premium markets through certification for example usually results in slightly increased net profits for farmers (Dankers and Liu 2003). Likewise our study depicts increased total farm revenues from both PES schemes. From a development perspective, it may be desirable for PES projects to target rather the poorer part of the local population than the better-off. Our study has shown that a price-premium for shade-grown cocoa could match this target better than a carbon project under the outlined conditions.

PES schemes often have important secondary benefits for smallholder producers such as better access to credit and extension services, more transparent weighing and grading systems, capacity building and organizational development (Rice and Greenberg 2000, Nelson et al. 2002, Neilson 2007). Farmer groups for instance can support direct marketing, facilitate product traceability, disseminate improved technology, engage in labour-sharing activities and perform an advocacy role (Neilson 2007). These non-monetary benefits are often underrated but they are important for producers. Furthermore, certification projects, for example organic and fair-trade, often seem to lead to general quality improvements, which in themselves are also valuable in conventional markets (Dankers and Liu 2003).

Barriers to the adoption of certified organic production for example include costs of the certification process, and a three-year transition period (Dahlquist et al. 2007, cf. Gobbi 2000). Furthermore, a successful certification scheme needs a comprehensive approach with adequate and sustained funding (Rice and Greenberg 2000). For mutual benefits, it must receive backing from stakeholders including producer groups, traders, manufacturers and relevant public organisations (Rice and Greenberg 2000, Duguma et al. 2001, Shapiro and Rosenquist 2004). The same is true basically for all kinds of PES schemes.

From an ex-post study on the potential of eco-certification schemes in traditional rubber agroforests in Indonesia, Bennett (2008) concludes that eco-certification can deliver sustainable conservation only if it also delivers sustainable development. Eco-certification rates in the tropics are still low, but crops already traded on global markets such as cocoa are deemed most suitable for international eco-certification (Bennett 2008).

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# Final Conclusions

The main objective of this thesis was to generate knowledge on the dynamics of land cover and land use change in the tropics in terms of rainforest conversion and agroforestry intensification. Investigating the case of the cash crop cocoa in Central Sulawesi (Indonesia), the study aimed at analysing the structure and management of agroforests along the intensification gradient, the determinants of cocoa area extension and cocoa agroforestry intensification as well as the ecological-economic trade offs resulting from both processes and the applicability of selected Payments for Environmental Services (PES) schemes to solve these trade-offs. In this section, the main findings and their implications will be summarized for each of the four study objectives, followed by some principal policy and research recommendations.

**1. Objective: To assess the structure and management of cocoa agroforestry systems in Central Sulawesi across an intensification gradient.**

Although Central Sulawesi is still a relatively 'young' production frontier compared to other cocoa producing regions in the world, local cocoa production is already facing tremendous obstacles in terms of pest and disease pressure as well as selected nutrient deficiencies. Particularly soil phosphor content and stagnant soil water conditions limit cocoa yields. Cocoa agroforestry management is in large parts suboptimal and requires substantial improvement, especially with regard to pest and disease management, P fertilisation and humus management as well as cocoa bean processing. Current labour inputs in cocoa plot management are comparatively low, indicating a deficient awareness of cocoa maintenance requirements for sustaining long-term productivity.

Cocoa plantations in LLNP region are mostly established by converting natural forest lands, and the intensification of cocoa agroforests by the removal of shade trees was ongoing in the past few years, thereby increasing short-term cocoa yields significantly. However, cocoa yields are likewise positively influenced by labour input and biophysical preconditions, thereby providing opportunities for income improvements without necessitating a further ecological degradation of cocoa agroforests by shade tree removal or higher inputs of chemical plant protection agents.

**2. Objective: To determine the socio-economic drivers of cocoa agroforestry expansion and intensification.**

Expansion and intensification of cocoa agroforests were found to be basically determined by the same set of mainly economic driving factors, indicating a substantial market orientation of local cocoa farmers. The hypothesis that migrants push forward the deforestation process was supported concerning the extension of cocoa area and the intensification of cocoa agroforests in LLNP region.

Cocoa expansion and intensification are likely to go hand in hand and they are not poverty driven. Instead, both processes are constrained by labour availability and aging households. Cocoa agroforestry and particularly its intensification in Central Sulawesi are unlikely to have a land-sparing effect under current economic and demographic conditions in the area. Since intensive cocoa cultivation is still very profitable in the region, without suitably gauged offers of financial incentives, for example via a price premium for certified 'shade-grown' produced cocoa or direct compensation payments for ecosystem services, cocoa extension and intensification is likely to continue.

**3. Objective: To conduct an economic valuation of forest conversion and agroforestry intensification.**

We assessed public and private benefits arising from various ecosystem services provided by forests and agroforests along a land use gradient in Central Sulawesi. Trade-offs were identified by changes in marginal net benefits when switching from one land use alternative to a more intensive land use. Converting natural forests or production forest into agroforestry systems always results in positive marginal changes in private net benefits from cocoa production, timber and rattan harvest. The high private returns resulting from forest conversion to cocoa agroforests and the increasing profitability of cocoa agroforests along the intensification gradient raise trade-offs in the provision of ecosystem services provided by forests and extensive agroforestry systems. Public goods and services, including carbon sequestration and avoided emission, pollination services and biodiversity show net losses when switching to a more intensive land use in all cases.

Public goods and services do not provide sufficient net benefits to offset returns from conversion to cocoa agroforests. A carbon sequestration project at current carbon prices is not sufficient to offset returns from intensively managed cocoa agroforests. Consequently, the internalization of ES in payment for environmental service schemes at current market conditions could be hindered by the high profitability of current unsustainable land use.

**4. Objective: To analyze impacts of PES schemes on forest conversion and agroforestry intensification using a dynamic ex-ante modelling approach on farm household level.**

Results from a dynamic non-linear mathematical programming model on farm household level suggest that both investigated PES schemes, payments within a carbon afforestation project and a price premium paid for shade-grown cocoa, are suitable to stabilise intensification at intermediate levels on average. However, it will be difficult to attract cocoa farmers with high-intensity cocoa plantations. Particularly carbon payments in afforestation projects should be targeted to agroforestry systems of intermediate to low intensity, in order to sharpen the incentive to switch to these more sustainable systems.

The price premium for shade-grown cocoa as suggested in this study is comparatively better targeted to cocoa plantations of lower management intensity.

The rate of farm area extension is effectively reduced only by the shade premium, which includes organic standard requirements and therefore prohibits forest clearing. This standard is better suited to prevent deforestation than the outlined REDD scheme under current carbon market conditions. Moreover, a shade premium attached to the cocoa producer price also provides additional incentive to invest in overall cocoa productivity. Carbon credits are in contrast not linked to agricultural output. The shade premium is adopted only by about half of the households, however. Although both PES schemes provide slightly increased total farm revenues, a price-premium for shade-grown cocoa is more likely to benefit poorer households, than a carbon project under the outlined conditions. Results from the MP model also indicated that increasing labour inputs in cocoa production provide an enormous potential for productivity enhancement.

**Policy and research recommendations**

In conclusion, cocoa production and particularly its intensification are likely to trigger further conversion of remaining rainforest. The described gradient in land use change (forest conversion and agroforestry intensification) is symptomatic for the LLNP region. However, tree-crop based systems in general provide considerable

potentials for a sustainable agricultural development particularly at forest margins if they are suitably managed. The development of alternative development pathways needs to include also measures which are capable to reduce the pressure on remaining rainforests, including the diversification of farm and off-farm income. Furthermore, opportunities for market incentives promoting the conservation of forests and the development of sustainable and diverse agroforestry systems should be further explored.
In particular, the following policy and research recommendations can be made:

- Cocoa production in LLNP region requires substantial agronomical improvements, particularly in terms of pest and disease management, soil amelioration, replanting and cocoa bean processing. Higher labour input in the respective activities can increase cocoa yields noticeably and is critical for maintaining production in the long term. Profound training and agricultural extension service for cocoa production is rare in the area, but it is urgently needed since sustainable agroforestry management is a complex and knowledge-intensive issue.

- Enhanced labour opportunities outside the agricultural and forest sector can help reducing pressure on remaining rainforests. The sustainable extraction of timber and NTFP also has a high potential for providing additional long-term income for rural households and could thereby also help to protect remaining forests. However, sound control mechanisms have to be established in order to guaranty non-damaging extraction rates and techniques.

- The promotion of a sustainable intensification of agroforests should be accompanied by measures to discourage agricultural area expansion in order to be effective. Agroforests generally have a high potential for conserving biodiversity and are agronomically sustainable when properly managed. Therefore they can be suitable components in integrated buffer-zone management schemes for stabilising rainforest margins.

- In order to make potential values from indirect ecosystem benefits tangible and effective, they need to be internalized in economic accounting and in policy development for future land-use planning. To capture the value of the most important benefits, high quality socioeconomic and ecological data are crucial, which need to be comprehensive and spatially adjusted.

- Economic incentives such as PES schemes which offset the attractiveness of full sun cocoa agroforestry could be a measure to ensure both, high levels of biodiversity and ecosystem services and stable incomes in forest frontiers. However, such instruments should be coupled with effective disincentives for further forest conversion. PES are voluntary schemes which require a sound underpinning of complementary regulative measures and institutions, set up by sound environmental legislation and enforcement.

- PES schemes should be developed in a way that they provide sufficient economic incentive for farmers to adopt and stick to environmentally friendly land use alternatives. But PES schemes have a potential for further gains, such as providing additional and/or more reliable income, benefiting preferentially the rural poor. These advantages should be capitalized in the development of PES schemes whenever possible.

- PES schemes should capture secondary benefits for smallholder producers such as better access to credit and extension services, more transparent weighing and grading systems, capacity building and organizational development, which can also be a measure to help enhancing overall productivity of cocoa agroforests.

- Agroforests can sequester substantial amounts of carbon dioxide and should therefore be stronger considered in emission trading. However, PES schemes in the carbon sector have to be carefully targeted in order to achieve effective incentives for afforestation in agroforests and for avoiding deforestation. Current carbon prices may be too low to completely offset the economic incentive of intensive cocoa cultivation and cocoa area extension. Project planning and implementation of carbon PES schemes is in the early stages worldwide and requires internationally concerted policy action.

- A price premium for ‘shade-grown’, biodiversity-friendly cocoa at current organic produce prices provides reasonable incentives for farmers to keep agroforestry intensification at intermediate levels. It may not be sufficient for convincing high-intensity cocoa producers to switch to more sustainable agroforestry options, though. The elegance of a price-coupled PES measure is that it provides incentives for farmers to invest in overall (long-term) productivity.

- The market situation of ‘shade-grown’ cocoa from that area still remains unclear. Potential obstacles may include the low quality of Sulawesi cocoa beans, which is likely to make them unsuitable for niche markets. Further research is required with respect to this issue. Another problem might be the largely underdeveloped structure of producer alliances, cooperatives and farmer groups in the area, which would facilitate the set-up of PES schemes and can help in reducing transaction costs. These problems also have to be addressed by increased efforts of agricultural extension service.

- More research will be required with respect to agroecological processes to help develop agroforestry systems which optimise the benefits of diverse agroforestry systems, e.g. natural pest control and yield sustainability.

- Likewise, the relationship between agricultural intensification and deforestation is largely indeterminate and complex. Therefore increasing research effort has to be dedicated to the deforestation effects of agricultural intensification particularly in terms of cash crop production.

# Appendix

# Appendix I: Production function analysis

### A. Cobb-Douglas Production function (CDPF)

The Cobb-Douglas production function (Cobb and Douglas 1928) is known to be a good approximation to a situation of heterogeneous farm technology (Mundlak 1996). Nevertheless, CDPF are restrictive in the sense that the elasticities of substitution are assumed to equal one and marginal productivity is not allowed to vary between farms (Heady and Dillon 1961). Multi-factor CDPF assume strong separability (Berndt and Christensen 1973). The more flexible Translog (Transcendental logarithmic) production function imposes no restrictions upon returns to scale or substitution possibilities and is therefore suitable for efficiency analysis using a stochastic frontier approach (Keil et al. 2007). The Translog production function is an extension of the CDPF, and has both linear and quadratic terms with an arbitrary number of inputs (Berndt and Christensen 1973). Nevertheless, Translog functions oftentimes imply problems of multicollinearity, especially for smaller samples, because of their high demand on the degrees of freedom in econometric analysis (Lyu et al. 1984). Because of its versatility and suitability for small cross-sectional samples, a CDPF is chosen.

*General form*

The CDPF in its general form (Cobb and Douglas 1928) is formulated as follows:

$$y = c\Pi x_i^{a_i};\, c,\, a_i > 0 \qquad (1)$$

With c= total factor productivity and xi= input factors, in agricultural production functions usually land, labour and capital.

*Modified form with environmental parameters*

For cocoa production, a modified form of the CDPF is developed in order to capture variability resulting from environmental preconditions and other site-specific factors. Thus, the modified function includes also plot structure parameters as well as a nested term for site specific environmental factors in addition to land, labour and material inputs (cf. Stoorvogel et al. 2004). Site specific environmental factors include soil, topography, and climate variables (Antle and Capalbo 2001). These variables of the nested term are location specific and can not be modified by farmer management. In contrast, plot structure parameters like canopy openness can be modified by the farmer, therefore, they can be directly included into the CDPF as a plot structure vector.

The general form of the CDPF assumes non-zero, positive quantities of all inputs. However, in most actual production systems we find also 'non-essential' inputs -in the sense that production can occur with zero quantities (e.g. fertilizer, hired labour, pesticides, irrigation water) (Antle 2004). One approach to solve this estimation problem has been proposed by Battese (1997): In addition to the respective continuous variable, a dummy variable with the incidence of zero observation (1= zero value) is included in the CDPF.

Modified Cobb-Douglas Production function for Cocoa production

$$Y = \beta_0 * A^{\beta A} * L^{\beta L} * M^{\beta M} * P^{\beta P} * S^{\beta S} * D \, \beta_D \qquad (2)$$

with

*Y= Total production (cocoa yield)*
*$\beta_0$= Constant (total factor productivity)*
*A= Vector for land*
*L= Vector for labour*
*M = Vector for material input*
*P = Vector for plot structure parameters*
*S = Vector for site specific parameters (nested term)*
*D= Vector for dummy variables*
*$\beta_A$, $\beta_L$, $\beta_M$, $\beta_P$, $\beta_{SP}$, $\beta_D$ =Coefficients (Output elasticities)*

The function can conveniently be linearized by converting it into a log-log form, and estimated using Ordinary Least Squares (OLS) regression.

The site specific vector S is defined as:

$$S = \beta_T T + \beta_C C + \beta_S S \qquad (3)$$

with

*T= Vector for topographic variables*
*C= Vector for climate variables*
*S= Vector for soil variables*

*Regression analysis*

Coefficients of production functions were calculated using OLS estimators. The following post-estimation tests were conducted to check for model consistency:

1. Influential values were detected and cleaned using Cook's distance measures (generally d-values >0.5 were excluded).
2. Normality of residuals was tested with Wilcoxon test for normality and optically by plotting kernel density distribution against normal curve. All model display an ample normality in the distribution of residuals.
3. Homoscedasticity of residuals was tested using White's test and Breusch-Pagan test. None of the models has problems with homoscedasticity.
4. Multicollinearity was checked with VIF and 1/VIF (=tolerance). When excluding the zero-value specified dummies, no multicollinearity exists between independent variables.
5. Linearity of model was tested by plotting standardized residuals against each of the predictor variables. Significant non-linearities were not observed.
6. Model specification was tested using Ramsey Reset test for omitted variables and linktest. Models are sufficiently specified.

Besides econometric comparison, the models will be analyzed for their specific explanatory power related to the reality in the project region. Production function analysis was conducted with statistical software STATA 9.2.

## B. Production parameters

### B.1. Dependant variables

Cocoa bean yields are calculated as total kilograms sun-dried cocoa beans sold to small traders, middlemen or collection centres in 2007. Rice and maize yields are total kilograms harvested per crop.

### B.2 Independent variables for cocoa production (Tab. 31)

A range of labour, material and environmental parameters, expected to influence yield, are included into regression analysis. Labour, inputs and outputs were aggregated at a monthly and yearly level for further analyses.

*Economic variables*

Land is represented by the size of the cocoa plot in hectare. Labour input is calculated as total working time in 2007 for all management activities on the cocoa plot except harvest, because this work is directly yield-dependant. Material input costs are aggregates of expenses for pesticides, herbicides and fertilizer used in 2007. Material inputs consist predominantly of agrochemicals in the project region, although only 25% of the households are using fertilizer, 43% and 21% are using herbicides and pesticides respectively.

*Plot structure parameters*

The number of cocoa trees on the plot gives a measure of the planting density. Higher planting densities of cocoa trees may lead to higher pod production, although a threshold can be expected from which on the cocoa stand may be too dense to allow for a proper growth of cocoa trees. Also the incidence of fungal infestations is likely to increase at very high densities (Clough et al. 2009). Therefore, we include also the squared term of number of cocoa trees.

Canopy openness (100%-measured canopy closure) is included instead of canopy closure because yield depends physiologically on light quantum flux, and not on shade. Almeida and Valle (2007) state that cocoa responds well to increased light if nutrients and pest pressure are not limiting, allowing for higher yields towards a higher degree of openness and accordingly a thinner shade tree cover.

The impact of the number of native forest trees on a cocoa plot is supposed to be of complex nature: While parts of its influence may already be captured by the variable openness, as forest trees form a substantial part of the shade tree cover, and the variable planting density, due to spatial competition on the plot, there may also exist other explanations for the adverse impact of forest trees, like for example water and nutrient competition, although a positive humidity sustaining effect of forest trees in times of drought is also possible.

Similar effects can be suggested by the number of intercrops on a plot, like fruit trees, coconut palms and bananas. Species numbers are based on estimates of the farmers.

The cocoa plots included in analysis are already within a production stage; nevertheless, the cocoa stands are usually composed of trees of different ages. Hence, the average cocoa tree age can be influential for yields. Pod production is expected to increase until the age of around 10 years, and to decrease when trees are around 20 years (or even earlier if trees are heavily affected by pests or diseases) (Wood 1980). We fitted a yield curve using tree age as independent variable (cf. Obiri et al. 2007, Ryan et al. 2009).

*Site specific parameters*

Plots in short distance to the forest edge are assumed to profit from what Ruf (1995) calls the ‘forest rent’. This rent arises from positive agroecological conditions of agricultural land recently converted from primary forests, like for instance a higher soil fertility and better soil water condition. The vicinity of the forest edge also implies a higher diversity of pollinators and natural enemies to cocoa pests and diseases. A contrary effect is also possible: As sites with best soil properties are expected to be situated within the plains, these were converted first, but meanwhile as land gets scarce, forest conversion for cocoa agroforests proceeds up hillside on less depth soils and steeper slopes, which are less suitable for cocoa production.

Total and plant available soil phosphor contents represent proxies for soil fertility. High phosphor stocks are assumed to positively influence yield.

As climatic variables the average rainfall and temperature are included in the site specific term. Rainfall is presumed to positively impact cocoa yields up to a certain threshold when too heavy rainfall causes erosion or stagnant water conditions. Hence the squared average rainfall is also included. The topographic vector is represented by altitude.

*Dummy variables*

Dummies are included for continuous variables displaying a substantial number of zero values (material input expenses, number of native forest trees and intercrops). For these variables, a dummy variable with the incidence of zero observation is included in the production function. In order to account for the impacts of pest and disease attacks, a dummy is included for the incidence of severe yield loss (>20%) due to pod damage caused by Cocoa Pod Borer (CPB; *Conopomorpha cramerella)* and the Black Pod Disease (BPD; *Phytophtora sp.).*

Additionally, a dummy for waterlogged soil conditions is included with 1= moist and waterlogged sites and 0= dry and fresh sites. Steep slopes (>=2.5 at scale from 1 to 5) are indicated by the value 1.

To account for regional differences dummy for each of the four valleys are included (Napu, Palolo, Palu, Kulawi).

Table 31. Cocoa production parameters (n=143)

| | MEAN | STD | MIN | MAX |
|---|---|---|---|---|
| **Dependant variable** | | | | |
| Yield [kg] | 291.9 | 356.3 | 4.1 | 1904.2 |
| **Economic variables** | | | | |
| Total labour [h $yr^{-1}$] without harvest | 197.2 | 189.3 | 5.2 | 847.5 |
| Plot size [ha] | 0.6 | 0.57 | 0.04 | 3 |
| Material input [1000 IDR $yr^{-1}$] | 119.4 | 206.1 | 0 | 1244.3 |
| **Plot structure variables** | | | | |
| Number cocoa trees on plot | 552.5 | 604.4 | 35 | 5000 |
| Average cocoa tree age on plot | 9.6 | 4.7 | 3 | 27 |
| Number of native forest trees species on plot | 1.67 | 2.0 | 0 | 9 |
| Number of intercrop species on plot | 1.82 | 1.1 | 0 | 5 |
| Canopy openness [%] | 57.6 | 26.2 | 1.4 | 98.4 |
| **Site specific variables** | | | | |
| Distance to forest edge [km] | 1.35 | 1.35 | 0 | 7 |
| Altitude [m a.s.l.] | 637.1 | 390.0 | 75 | 1275 |
| Temperature [°C] | 23.6 | 2.0 | 21.0 | 27.4 |
| Rainfall [1000 mm $yr^{-1}$] | 1.67 | 0.3 | 1.22 | 2.09 |
| P available [kg $ha^{-1}$] (n=43) | 16.6 | 16.0 | 1.66 | 66.23 |
| P total [1000 kg $ha^{-1}$] (n=46) | 3.67 | 1.98 | 1.07 | 11.52 |
| **Dummies** | | | | |
| No input use | 0.55 | 0.5 | 0 | 1 |
| Severe pod loss due to CPB | 0.48 | 0.5 | 0 | 1 |
| Severe pod loss due to BPD | 0.43 | 0.5 | 0 | 1 |
| No native forest trees on plot | 0.62 | 0.49 | 0 | 1 |
| No intercrops on plot | 0.09 | 0.29 | 0 | 1 |
| Native forest trees on plot | 0.38 | 0.49 | 0 | 1 |
| Intercrops on plot | 0.91 | 0.29 | 0 | 1 |
| Waterlogging soil condition (n=48) | 0.39 | 0.49 | 0 | 1 |
| Steep slope | 0.15 | 0.36 | 0 | 1 |
| Napu | 0.41 | 0.49 | 0 | 1 |
| Palolo | 0.25 | 0.44 | 0 | 1 |
| Palu | 0.25 | 0.44 | 0 | 1 |
| Kulawi | 0.17 | 0.38 | 0 | 1 |

### B.3. Independent variables for wet rice and maize production (Tab. 32 and 33)

Rice and maze input variables are basically classical economic production parameters, like fertilizer, pesticide and other expenses. As wet rice production is dependant on irrigation, its expenses are included in the analysis. For non-essential inputs, a dummy for zero observations is added in the function. Expenses are displayed in 1000 IDR. A dummy for the use of High Yielding Varieties determines the use of hybrid or improved seeds.

Table 32. Rice production parameters (n=147)

| | MEAN | STD | MIN | MAX |
|---|---|---|---|---|
| **Dependant variable** | | | | |
| Yield [kg crop$^{-1}$] | 1134 | 1.439 | 20 | 15000 |
| **Economic variables** | | | | |
| Plot size [ha] | 0.54 | 0.30 | 0.07 | 1.25 |
| Fertilizer expenses [1000 IDR crop$^{-1}$] | 20.5 | 62.6 | 0 | 5300 |
| Pesticides expenses [1000 IDR crop$^{-1}$] | 64.1 | 33.1 | 0 | 4000 |
| Irrigation expenses [1000 IDR crop$^{-1}$] | 113.6 | 41.3 | 0 | 400 |
| Seed expenses [1000 IDR crop$^{-1}$] | 108.0 | 71.3 | 7.8 | 346.5 |
| Land preparation expenses [1000 IDR crop$^{-1}$] | 243.2 | 440.2 | 0.00 | 5000 |
| **Dummies** | | | | |
| No fertilizer use | 0.31 | 0.46 | 0 | 1 |
| No pesticide use | 0.31 | 0.47 | 0 | 1 |
| No irrigation use | 0.67 | 0.47 | 0 | 1 |
| No land preparation | 0.16 | 0.37 | 0 | 1 |
| Use of High Yielding Variety (HYV) | 0.56 | 0.50 | 0 | 1 |
| Napu | 0.41 | 0.49 | 0 | 1 |
| Palolo | 0.13 | 0.34 | 0 | 1 |
| Palu | 0.32 | 0.47 | 0 | 1 |
| Kulawi | 0.14 | 0.34 | 0 | 1 |

Table 33. Maize production parameters (n=59)

| | MEAN | STD | MIN | MAX |
|---|---|---|---|---|
| **Dependant variable** | | | | |
| Yield [kg $crop^{-1}$] | 1129 | 1325 | 193.6 | 7500 |
| **Economic variables** | | | | |
| Plot size [ha] | 0.74 | 0.52 | 0.2 | 2.5 |
| Fertilizer expenses [1000 IDR $crop^{-1}$] | 14.1 | 52.1 | 0 | 262.5 |
| Pesticides expenses [1000 IDR $crop^{-1}$] | 46.0 | 66.4 | 0 | 304 |
| Seed expenses [1000 IDR $crop^{-1}$] | 22.5 | 105.3 | 0 | 800 |
| Land preparation expenses [1000 IDR $crop^{-1}$] | 54.7 | 121.4 | 0 | 600 |
| **Dummies** | | | | |
| No fertilizer use | 0.92 | 0.28 | 0 | 1 |
| No pesticide use | 0.42 | 0.50 | 0 | 1 |
| No seed expenses | 0.76 | 0.43 | 0 | 1 |
| No land preparation | 0.66 | 0.48 | 0 | 1 |
| Use of High Yielding Variety (HYV) | 0.51 | 0.50 | 0 | 1 |
| Napu | 0.71 | 0.46 | 0 | 1 |
| Palolo | 0.07 | 0.25 | 0 | 1 |
| Palu | 0.14 | 0.35 | 0 | 1 |
| Kulawi | 0.08 | 0.28 | 0 | 1 |

## C. Results

### C.1. Cocoa production

Following Obiri et al. (2007) and Ryan et al. (2009) we fitted a yield curve using average cocoa tree age (TA) as independent variable.

The nested term for the yield-age curve (n= 143, $R^2$=0.07) is

$$Age = e^{(3.82 - 0.086 * TA - 1.33 * \ln TA} \qquad (4)$$

The site specific vector (cf. Stoorvogel et al. 2004) was fitted as cocoa yield per hectare (n=40, $R^2$= 0.6).

$$Site = -727.1 + RF * 507.2 + Ptot * 95.1 + DF * 80.87 + WL * -195.96 \quad (5)$$

With RF= Yearly rainfall [1000 mm $a^{-1}$], Ptot= Total soil phosphorus content [kg $ha^{-1}$], DF= Distance to forest edge [km] and WL= dummy for waterlogging conditions [0/1].

Yield curve and site-specific factor were then integrated in the overall production function analysis, using a CDPF form with total dry cocoa yield as dependant variable (n=143, adj. $R^2$= 0.7).

$$\begin{aligned} Yc = e^{-9.77} * TW^{0.16} * SPc^{0.735} * IP^{0.202} * Age^{0.933} * nTr^{1.391} * nTr_2^{-0.12} \\ * OP^{0.333} * Site^{0.554} * e^{(CPB*-0.321)} * e^{(FT*-0.481)} * e^{(dIP*0.891)} \end{aligned} \quad (6)$$

With TW= Total labour input [h $a^{-1}$], SPc= size of cocoa plot [ha], IP= Total fertilizer and pesticide expenses [1000 IDR], Age= nested term for the yield-age curve, nTr= total number of cocoa trees on plot, nTr2= squared number of cocoa trees, OP= canopy openness [%], Site= nested term of site-specific variables, CPB= dummy for the incidence of heavy yield loss due to the Cocoa Pod Borer [0/1], FT= incidence of forest trees on the plot [0/1] and dIP= dummy for no fertilizer and pesticide use [0/1].

## C.2. Rice production

The CDPF for rice was fitted for total rice yield per crop (n=139, adj. $R^2$= 0.85).

$$Yr = 424.1 * SPr^{0.75} * Pexp^{0.15} * Fexp^{0.18} * e^{(nofert*0.46)} * e^{(nopest*0.4)} * e^{(HYV*0.14)} * e^{(Kulawi*-0.25)} \tag{7}$$

With SPr= plot size [ha], Pexp= Pesticide expenses [1000 IDR $crop^{-1}$], Fexp= Fertilizer expenses [1000 IDR $crop^{-1}$], nofert= No fertilizer use [0/1], nopest= No pesticide use [0/1] and HYV= Use of High Yielding Varieties [0/1].

## C.3. Maize production

The CDPF for maize was fitted for total maize yield per crop (n=50, adj. $R^2$=0.62).

$$Ym = 1152.9 * SPm^{0.77} * e^{(HYV*0.34)} * e^{(Palu*-0.33)} * e^{(Kulawi*-0.37)} \tag{8}$$

With SPm= Plot size [ha] and HYV= Use of High Yielding Varieties [0/1].

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## Appendix II: Curriculum Vitae

Date and place of birth: 02-12-1974 in Kiel, Germany

| **Employment** | |
|---|---|
| Since Aug 06 | Department of Agricultural Economics and Rural Development, Environmental and Resource Economics, Georg-August Universität Göttingen (GAUG).<br>Current research topic: 'Economic-ecological valuation of forest conversion and agroforestry intensification in Central Sulawesi/ Indonesia', within DFG financed project 'Stability of Rainforest Margins in Indonesia' |
| Aug 04-<br>Jul 06 | Assistant at the Department of International Agriculture at the Swiss College of Agriculture (SHL), Bern, Switzerland<br>▪ Lectures and workshops in Tropical crop cultivation, biological plant protection, GIS<br>▪ Coordination of the introduction of Problem Based Learning<br>▪ Project collaborations in Cameroon (participatory development of extension contents for improved agricultural sustainability) and in Burkina Faso (development of easy-to-use excel tool for farm analysis)<br>▪ Management of the tropical greenhouse (incl. cultural events) |

| **Education** | |
|---|---|
| Apr 03-<br>June 04 | Postgraduate study course 'International Agricultural Development' at the Humboldt University of Berlin (HU), Germany |
| Oct 97-<br>Jul 02 | Studies in Biology at the GAUG (main subjects: conservation biology, tropical plant ecology and soil sciences). Diploma Thesis: 'Water household and leaf traits in eight pioneer tree species in Central Sulawesi, Indonesia' |
| Oct 95-<br>Aug 97 | Studies in Biology at the University of Greifswald, Germany |
| June 94 | Abitur in Heikendorf/Kiel, Germany |

| **Practical experience** | |
|---|---|
| Nov 03- Jul 04 | Student Assistant at the Department of Tropical and Subtropical Crop Production, HU Berlin |
| Aug 03- Oct 03 | Internship at an Bolivian Partner-NGO of the German Development Service (DED), Sustainability of cacao agroforestry systems in Sapecho, Bolivia |
| Oct 02- Jan 03 | Student Assistant at the Agroecology, GAUG |
| July 00- Jan 03 | Voluntary Work at the fair trade shop in Göttingen |

| **Practical experience (contin.)** | |
|---|---|
| Oct 98-May 02 | Student Assistant at the Department of Plant Ecology, GAUG |
| Aug 94-Aug 95 | Internship (Freiwilliges ökologisches Jahr) at an environment organisation (Bund für Umwelt und Naturschutz, BUND) in Kiel, Germany |

| **Language skills** |
|---|
| German (mother tongue), English (very good working knowledge), French (intermediate), Spanish (basic knowledge), Bahasa Indonesia (basic knowledge) |

## Publications

Juhrbandt, J., Duwe, T., Barkmann, J., Gerold, G., Marggraf, R. (2010). Structure and management of cocoa agroforestry systems in Central Sulawesi across an intensification gradient. In: Tscharntke, T., Leuschner, C., Veldkamp, E., Faust, H., Guhardja, E., Bidin, A. (Eds.), Tropical Rainforests and Agroforests under Global Change: 115-140.

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Schippers, B., Juhrbandt, J., Faust, H., Schwarze, S., Barkmann, J. (2007). Effects of the Interaction of Migration, Financial and Social Capital on the Adoption of Agricultural Innovation and on Social Stratification in Central Sulawesi (Indonesia). Book of Abstracts, Tropentag 2007, Witzenhausen, Germany, 9-11 October 2007, S. 189.

Göttingen, May 2010 Jana Juhrbandt

## Appendix III: Questionnaires (on enclosed CD)

## Appendix IV: LINGO Models (on enclosed CD)