5. SCENARIO STUDIES OF LAND USE IN NUNUKAN, EAST KALIMANTAN (INDONESIA): DRIVERS, LOCAL LIVELIHOODS AND GLOBALLY RELEVANT CARBON STOCKS

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Introduction

Global warming is caused by the rapid increase of green-house-gasses in the atmosphere, especially through carbon dioxide emission from the use of fossil fuels as well as forest and peatland conversion. Net emissions of carbon dioxide to the atmosphere can be reduced through effective protection of remaining terrestrial C stocks, and by sequestration in regrowing vegetation, where carbon is stored as biomass, necromass or soil organik matter and peat. The global atmospheric circulation system is a 'public good', and global impacts of local carbon emissions or its net storage are the basis of the current discussion on emission control and on the Clean Development Mechanism. Tropical forests are a major store of carbon, which is under threat as the conversion of natural to financial capital is the most rewarding livelihood option, in the form of logging and its subsequent degradation. Externally driven processes to 'cream off' local resources, coupled to a lack of tenure security for local people are thought to be the main factors in forest depletion - but legal or illegal logging provides jobs and local employment that is at risk with logging bans (Casson and Obidzinski, 2002). Alternative livelihoods that are compatible with protection or enhancing of carbon stocks require a long term vision on, supported by security of access to, the landscape level resources, but they need to be based on sufficiently rewarding (self) employment at any point in time.

Carbon extraction is an externality (a consequence not taken into account by the decision makers) of human activities that are part of livelihood strategies and its consequences can only be sensed at blurred global resolution as a "creeping normalcy"[1], resulting in a "consequences amnesia" in society. Thus, when feedback loops are put in place through initiatives to maintain carbon stocks through incentives to people on the ground, it is important that we first understand people's livelihoods, as they reflect their knowledge on survival and their perception about risk and benefit.

When existing options are dominated by carbon-harvesting-based livelihoods, efforts are needed to find carbon-saving livelihoods that still benefit local people. The FORMACS Project aimed to achieve both benefits: improving people's well-being while increasing carbon sequestration in an ex-logging area of Nunukan, East Kalimantan, by promoting two main alternatives: Community Based Natural Resource Management (CBNRM) and Low External Input Sustainable Agriculture (LEISA), see Chapter 1.

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[1] Slow trends concealed within noisy fluctuations (Diamond, 2005)

The basic requirements of offering (self) employment at attractive returns to labour for the existing population density, while meeting subsistence needs for food, clean water and other services can be met in multiple ways. A consistent way of comparing scenarios of change and their predicted impacts on carbon stocks and income is needed.

According to Peterson *et al.* (2003), scenario planning is a systematic methods for thinking creatively about possible complex and uncertain futures. The central idea is to consider a variety of possible futures that include many of the important uncertainties in the system rather than to focus on the accurate prediction of a single outcome. It begins with identification of a central issue or problem. This problem is then used as a focusing device for assessment of the system; assessment is combined with the key problem to identify key alternatives.

In assessing the accomplishment of the project in meeting its main goal, three important questions were raised:

1. can the project alleviate people's poverty while increasing carbon stocks in the area?,
2. can people adopt CBNRM and LEISA and perceive them as their new profitable livelihoods?,
3. are there tradeoffs between global environmental benefits and local objectives? (Tomich, *et al.*, 2001).

Certainly, these questions cannot be answered within the time frame of the project, since they deal with larger scales and longer time frames. They require a systematic approach that is able to extrapolate the assessment results from plot to landscape, from household to community, and from the present to an uncertain future.

Models can be used as a tool to do *ex ante* (prospective) analysis (Fig. 5.1). Models represent a conceptualisation of our current understanding of the interactions in a system, based on hypotheses on the underlying processes. Responsible use of models in societal negotiation processes requires that models are evaluated through confronting the data patterns resulting from simulation with the data patterns from direct observation. While the basic scheme of 'drivers', 'responses' and 'consequences' applies to many types of model, including the ones that are essentially regression equation (in Y = a + b X, X is the driver, b is the response and Y the consequence). Here we are particularly interested in models where the responses include feedback loops themselves and

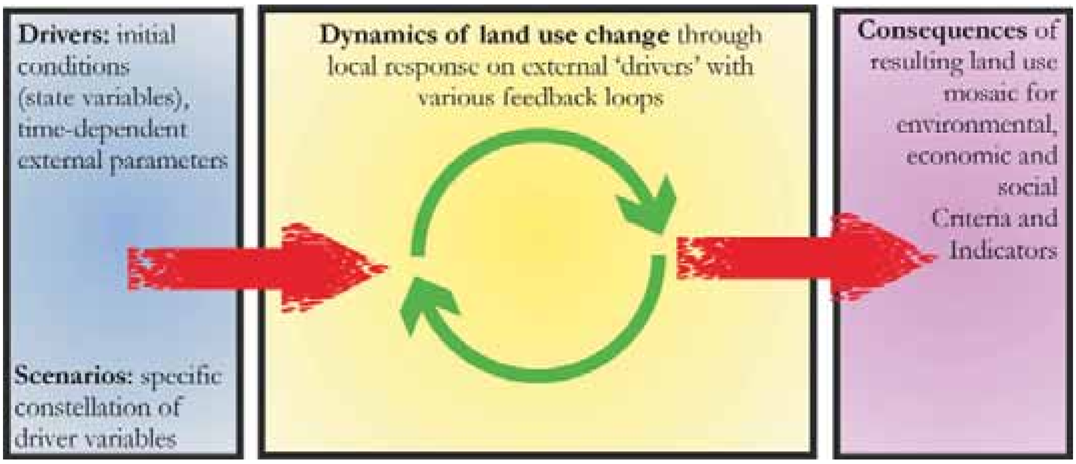


Figure 5.1. Generic structure of a model that translates 'driver' or exogenous variables to the time bound responses in a landscape, which has consequences ('externalities' in as far as they are not part of the feedback loops in the dynamic section) for criteria and indicators of system performance; scenarios refer to specific combinations of driver variables that represent changes in higher level systems.

represent levels of 'endogenous' structure. Such models can degenerate to essentially regression models if the validation step involves extensive curve fitting on the overall model. Such curve fitting may enhance the precision of the model in interpolation mode, but will reduce the confidence we have in use of the model for extrapolation to new circumstances.

This paper describes an application of the FALLOW Model (van Noordwijk, 2002) in exploring possible patterns of tradeoffs between local benefits (income per capita) and global risks (carbon stocks) for the FORMACS project case in East Kalimantan. Prior to that, the model's validity is tested using data from the study site.

Objectives

1. Exploration of scenarios for the drivers of land use change, their plausible impact on local land use decisions and income per capita and logical consequences for carbon stocks.
2. Test of the suitability of the FALLOW model for this purpose.

Core of the FALLOW Model

The FALLOW Model is a spatially explicit model of landscape dynamics (Figure 5.2). It is expected to capture annual dynamics of people's livelihoods on a landscape by simulating: (i) how those livelihoods extract natural stocks, (ii) how the natural stocks replenish, (iii) how people learn about the

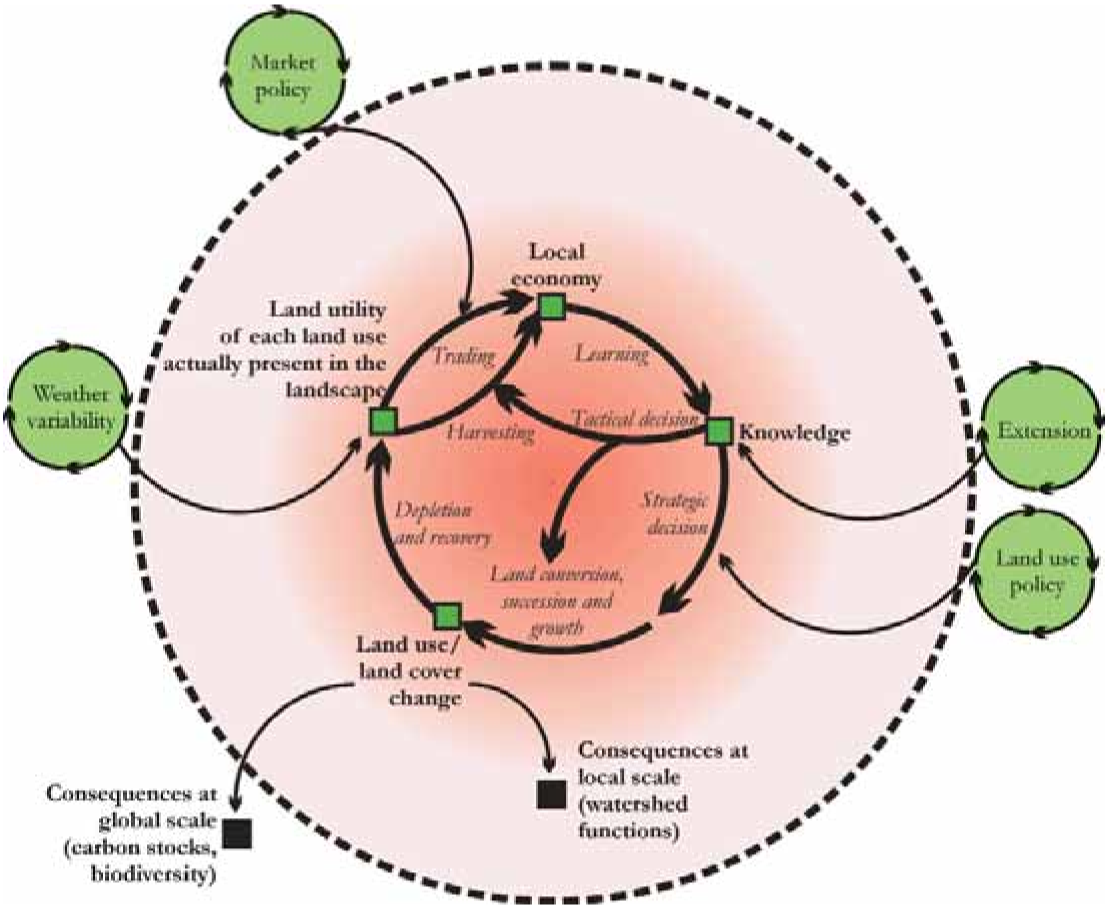


Figure 5.2. Key relationships considered in the main dynamic loop of the FALLOW model (land utility, local economy and land use decision) that determine the spatial pattern of land cover, and the modules that translate this pattern into consequences for environmental service functions such as C storage. External 'drivers' (small loops) may take a role in the dynamics by affecting local response through trading (e.g. market policy made by distant agents), knowledge (e.g. extension conducted by distant agents), decision-making process (e.g. land use policy made by distant agents) or land utility (e.g. weather variability as results of global climatic processes).

benefits of existing livelihood options, (iv) how they make deliberate decisions regarding utilization of human and natural capitals, and (v) what are the consequences on such landscape dynamics processes.

Extraction of natural stocks and their renewal

Livelihood strategies are ultimately tested by the long-term survival of the decision makers (Diamond, 2005). Where the decision makers have the opportunity to move to other locations or activities after local exhaustion of resources, we need to expand the boundaries of the system under consideration.

Sustainable use of natural stocks (including carbon) depends on achieving a balance between the rate of renewal and the rate of harvest after an initial phase of benefiting from the accumulated stocks currently in the system. However, depletion of natural stocks below the level where renewal is efficient has been part of human legacy in many parts of the world. Overexploitation can be based on lack of awareness (a true 'externality' in the decision making) or lack of care (too low weighting in the decision making) for the known consequences.

With regards to the degree of harvesting carbon, we may have livelihood options that extract carbon stocks in relatively big amount (e.g. logging and land clearing for agriculture), in medium amount (e.g. agroforestry, monoculture plantation), in small amount (e.g. NTFP), and in almost zero amount (e.g. off farm jobs). Logging extracts large amount of forests' carbon through tree extraction and induced mortality of damaged trees. Agriculture not only depletes aboveground carbon stock through land clearing, but also reduces belowground carbon stocks, as the return of organic residues to the soil is less than the rate of decomposition.

In the Trenbath Model that forms the building foundation of FALLOW (van Noordwijk, 2002), it is assumed that soil fertility is rapidly depleted during cropping periods and can be restored slowly during fallow periods. Agroforestry and monoculture plantations extract small amount of carbon during production/development periods, but the extraction is relatively big during land-clearing/regeneration periods.

Replenishment of aboveground carbon stock depends on vegetation processes of growth and succession, which is constrained by (i) access of the vegetation to resources such as light, nutrients or water, (ii) by the species composition of the vegetation and (iii) by developmental processes (e.g. aging). In man-made ecosystems (e.g. monoculture plantations, agroforests), some of these limiting factors can be controlled through management (e.g. pruning, weeding, space arrangement, etc.).

Belowground carbon stocks (i.e. soil organic matter) are replenished through carbon organic inputs from litter produced by aboveground stocks, depending on residence time in the litter layer that defines the chance for decomposition. Most agriculture practices have no chance to self-recover their inherent soil fertility. In modern agricultures, fertilizer application is the preferred but costly solution in maintaining soil fertility. Conclusively, replenishment of natural stocks depends on land management or people's decision to fallow their lands.

Perception on livelihood benefits and learning styles

The model assumes there are two payoff types used by people in measuring livelihoods' benefits: (i) expected returns to labour ($/person.day) and (ii) expected returns to land ($/ha). People's measures of livelihoods' benefits are expressed as expectation, expressing their knowledge on perceived risk and perceived benefit as they learnt from their own experience (experiential learning). Thus, perceptions of risk and benefit are not always measured using a bank interest rate as the standard to measure future uncertainty.

In their autonomous-learning, people may differ in their learning styles. In FALLOW model, this is reflected in "knowledge-updating fractions", which express the fraction of new information that will be considered to update their current knowledge – or alternatively, in the amount of past knowledge that is retained. Some people may tend to rely on the most recent information more than on previous experience, but others may behave in the opposite way. A village may be composed of relatively conservative people who tend to conserve their existing knowledge and some fraction of relatively progressive people who tend to quickly trust the most recent information as the future belief (*almanac*) and forgetting the past.

When the success rate of all peoples decisions is visible within the community, it gives a chance for others to learn from common experience. Thus, knowledge evolution at village scale is formed by two contrasting type of learning people: conservatives and experimenters. Knowledge may also be updated by audio-visual information through education and extension. At a larger scale, people's knowledge in one place can be influenced by people's knowledge elsewhere. Especially where tree-based production systems are involved, with their long lag times between planting and production, the rate of diffusion of innovations within and among local communities is an important determinant of the overall impact.

Having an explicit role for 'extension' in this modelling approach allows us to make progress on the complex domain of 'attribution' of the change in complex systems to specific actors - as is often needed in impact assessment. In innovation diffusion theory, experimenters are termed as early adopters, occupying relatively small fraction of population in a community, while conservatives are termed as early majority, late majority or laggards, dominating the community (Gladwell, 2000). The term 'innovator' in this theory is considered as extension agent in FALLOW model.

Allocation of land and labour over land use options

Selecting land use practices from available options is a matter of deliberation on the risk-benefit balance of each option. Thus, it is much influenced by people's knowledge and their learning style. The model distinguished between strategic decisions (multi-year consequences) on 'land use systems' and tactical decisions on labour allocation across the land uses actually present in the farmed landscape.

Land will be allocated for each land use option in relation to expected returns to land ($/ha). At higher expected returns to land ($/ha), people tend to allocate a higher fraction of their available space for this type of practice. When expected returns to land ($/ha) exceed the actual returns to land of the existing plots ($/ha), people will expand the land to satisfy their expectation. In some cases, land expansion is not driven by market, e.g. expansion of food crop agriculture is determined by food requirement. Moreover, decisions to fallow or to renew the plot is affected by people's measure in defining marginal land, when the actual returns to land on a plot ($/ha) is less than the expectation.

In the FALLOW model, the allocation of the available labour resource in any time step is linked to the currently expected returns to labour ($/person.day) for all options considered. At higher expected returns to labour ($/person.day), people tend to allocate higher fraction of their available labour for this type of survival. A simple proportionality between expected returns and resource allocation can be used, as well as decision schemes that are skewed towards the 'best bet' (as currently conceived) option. In the model labour allocation to local food production can exceed the 'rational choice' based on expected relative returns to labour, reflecting risk avoidance behaviour aimed at avoiding food-crises.

In selecting a plot for expanding their lands, people will consider some spatial determinants that depend on the plot's attractiveness. It is related to the current plot's utility values (*e.g.* soil fertility, yields), expansion-costs (e.g. travelling-related distance, slope, and easiness for land-clearing), land control (*e.g.* distance from settlement and distance from existing plots) and land tenure (private or public lands).

Methodology

To use FALLOW Model as a tool to simulate the dynamics of landscape people's livelihood in Nunukan, the following steps were carried out:

- selecting a validation site;
- parameterising the model;
- validating the model; and
- performing simulations based on plausible scenarios.

Results

Validation site

Before applying the model, validation was conducted to evaluate model performance in capturing land use change dynamics. A subset of the area in Sebuku with a size of 24,656 ha was used as a site to validate and apply the

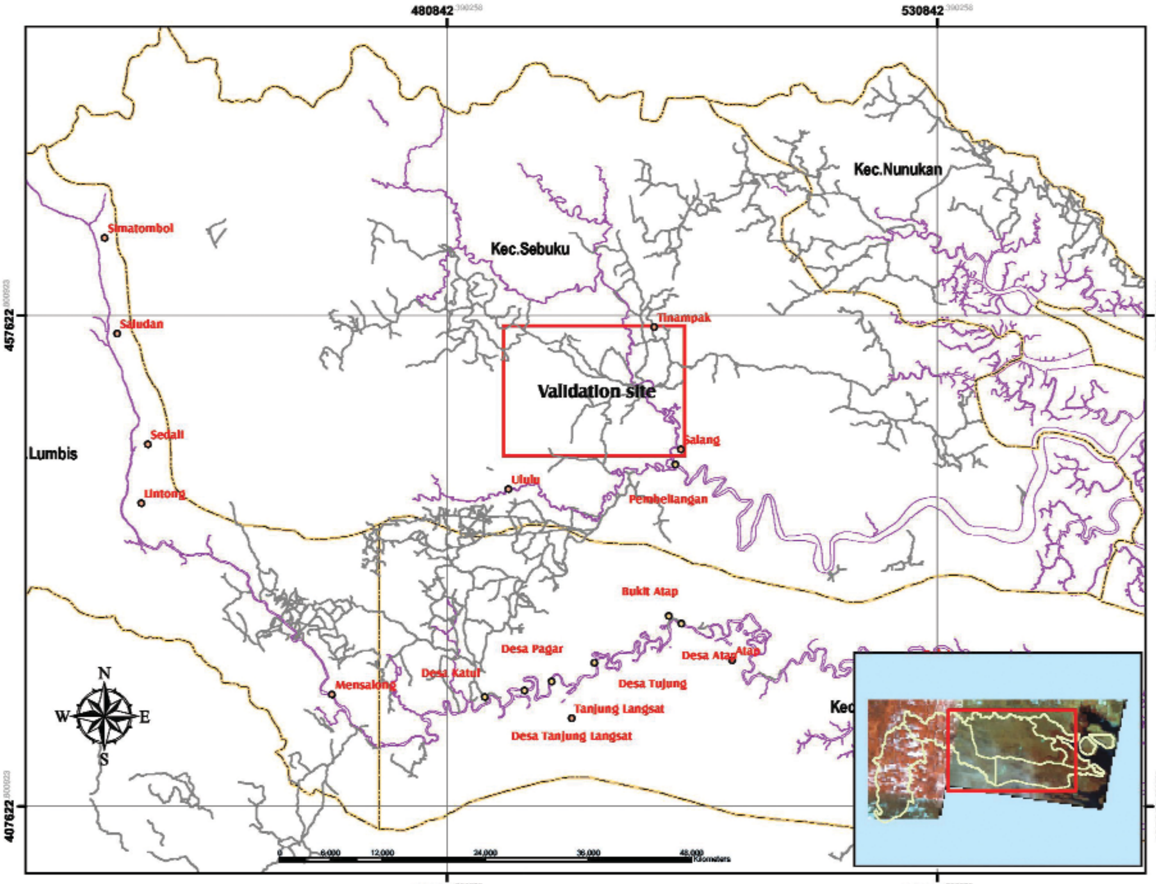


Figure 5.3. Validation site for modelling exercise within the study area of Sebuku-Sembakung, Nunukan. The site covers the area of 24,656 ha in Sebuku.

model (Figure 5.3). This site was chosen because of its relatively cloud-free condition as captured by the Landsat images in 1996 and in 2003 (see Widayati *et al.* in Chapter 4). The land cover map of the site in 1996 was used for model initialisation. Eight-year simulation result was then compared to the land cover map in 2003. Logging, agriculture and agroforestry are the dominant land use options in this area.

Model parameterization

Most parameters were derived from field and household surveys conducted by the project (see Chapter 2 by Wijaya *et al.* for detail on socio-economic survey results and Chapter 3 by Rahayu *et al.* for biophysical survey results). Other parameters were estimated from secondary data.

Forests dynamics

Average of total above ground biomass from fallowed plots at 1, 2, 3, 4, 5, 6-10, and >10 years old, as well as from primary forests was used to determine time bounds of natural forests succession. The assumed age for primary forests is 325 years old (estimated

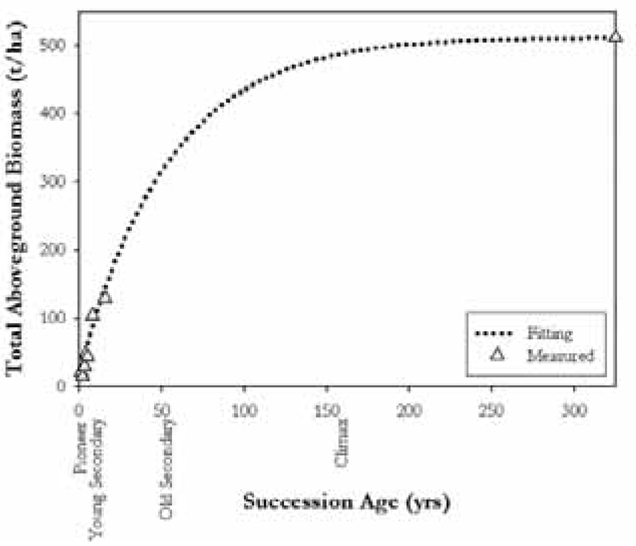


Figure 5.4. Total aboveground biomass as a function of age to derive parameters related to vegetation succession in natural forests.

Table 5.1. Length of time (in years) for different stages of logged-over-forest and statistic of its aboveground biomass

State	Time Bound (yrs after the first logging)	min (t/ha)	max (t/ha)	mean (t/ha)	sd (t/ha)
Logged-over 1	2	406.1	644.7	528.6	119.5
Logged-over 2	7	248.9	654.6	390.5	228.9
Logged-over 3	21	411.4	523.4	467.4	79.2
Logged-over 4	41	256.7	575.0	438.8	164.1

Table 5.2. Parameters describing natural forest succession and statistic of its aboveground biomass

State	Time Bound (yrs)	min (t/ha)	max (t/ha)	mean (t/ha)	sd (t/ha)
Pioneer	1	17.3	96.7	59.71	26.94
Young Secondary	10	104.8	316.6	224.03	62.85
Old Secondary	51	320.1	487.5	429.05	47.86
Climax	159	488.0	510.8	505.00	6.16

from Mackinnon *et al.*, 2000) at this age gap level rejuvenation reaches an equilibrium. Figure 5.4 shows measured biomass (triangles) and its fitting model (dotted line), estimated using general asymptotic function $y=ymax(1-exp[-\beta x^{\gamma}])^{\eta}$ (Vanclay, 1994). The best fitting curve was obtained for $y_{max}= 511.394$, $\beta= 0.006$, $\gamma= 1.220$, $\eta= 0.650$, with RMSE=12.40. Time bounds for logged-over forests were parameterised using data from field survey (Table 5.1). Table 5.2 summarizes the statistic (min, max, mean and sd) of total aboveground biomass in natural forest. For the initialization at pixel level we used a normal distribution with the mean and standard deviation as indicated, truncated at observed minimum and maximum.

As shown by Table 5.1, time after the first logging (years) didn't correspond directly to aboveground biomass' increment in logged-over forests. Thus, the increment of aboveground biomass in forests was not estimated based on succession age (as dAGBiomass/dt), but based on current state of its aboveground biomass relative to maximum aboveground biomass in primary forests ($AGBiomass/AGBiomass_{Ref}$). An asymptotic curve was applied to construct a relational graph between aboveground biomass increment and $AGBiomass/AGBiomass_{Ref}$, with $y_{max}=0.003$, $\beta=1$, $\gamma=1.6$, $\eta=-1.2$, and RMSE=0.02 (Figure 5.5). The aboveground biomass increment is defined as $[AGBiomass_t-AGBiomass_{t-1}]/ AGBiomass_{t-1}$.

The fraction of tree-biomass was estimated from its correlation to total aboveground biomass, based on an asymptotic curve with $y_{max}=0.90$, $\beta=0.001$, $\gamma=2.27$, $\eta=1$, and RMSE=0.13 (Figure 5.6). Tree-standing stocks (m^3/ha) is estimated as 1.48 times from its tree-biomass (t/ha), based on the correlation shown in Figure 5.7. In this case, tree-standing stocks (m^3/ha) was estimated using a cylindrical factor (cf) of 1. Tree standing stocks are defined as the component of tree (mostly timber) that is harvestable.

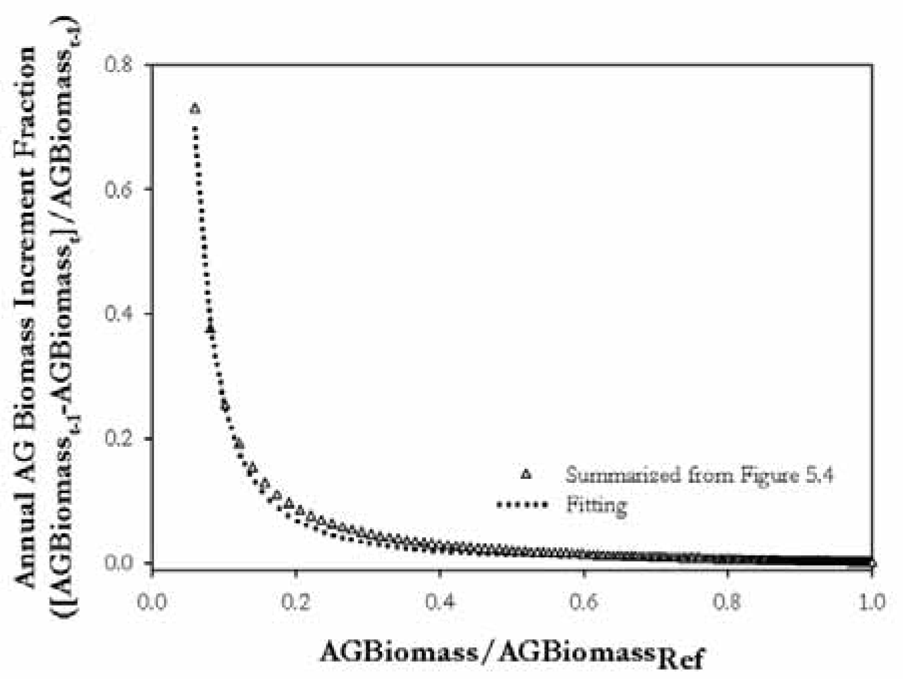


Figure 5.5. Annual increment of aboveground biomass in natural and logged-over forests was estimated from its current state relative to maximum aboveground biomass in primary forests (510.8 t/ha, see Table 5.2).

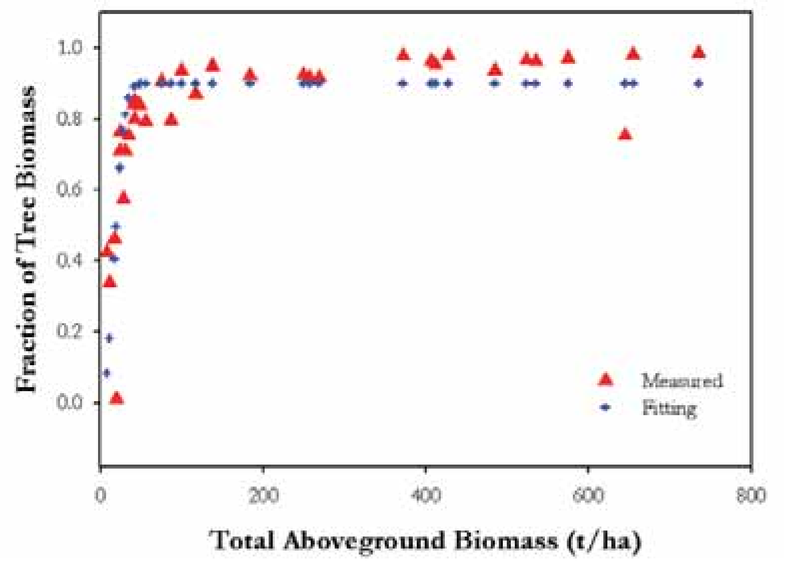


Figure 5.6. Curve fitting to estimate the tree components of forests' total biomass.

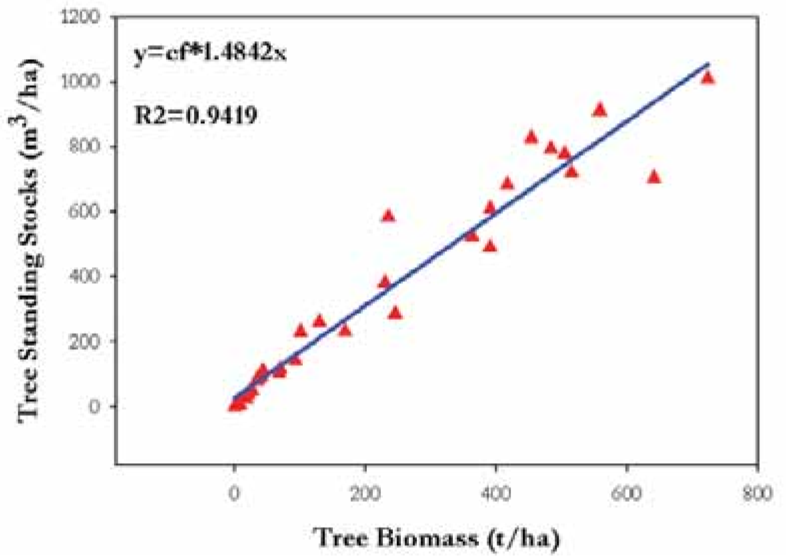


Figure 5.7. Tree standing stocks (harvestable wood) in forests as a function of tree biomass.

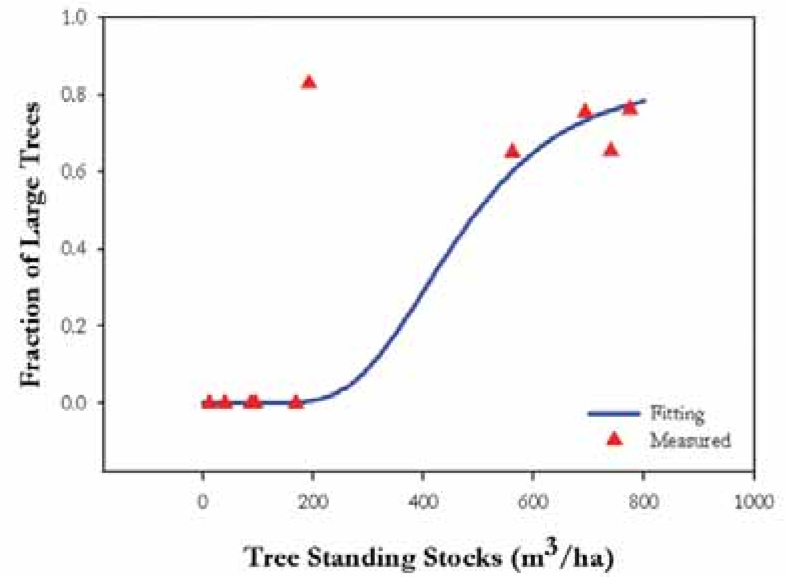


Figure 5.8. Fraction of harvestable trees (large tree) that exist in the forest as a function of standing stock.

Logging is assumed to extract large trees. Fraction of large trees (dbh > 30 cm) was estimated from its standing stocks (m^3/ha), based on asymptotic curve with $y_{max}=0.83$, $\beta=0.005$, $\gamma=1.05$, $\eta=15$, and RMSE=0.25 (Figure 5.8). Measured data were the replicate-average from primary forests, fallowed plots and logged-forests. A clear outlier was given by the measured data from fallowed plots at 6-10 years old. It probably reflects remnant large trees that have survived during the land clearing and cropping stage and are found at low density in the fallow system with a tree diameter that differs substantially from the surrounding vegetation.

Agroforesty systems dynamics

Average total above ground biomass from agroforestry plots at 0-10, 11-20, 21-30 years old was used to determine the time bounds on agroforestry development. Figure 5.9 shows measured biomass (triangles) and its fitting model (dotted line), based on asymptotic curve with $y_{max}=172.87$, $\beta=0.2$, $\gamma=0.95$, $\eta=1.1$, and RMSE=7.68. Table 5.3 summarizes the statistic (min, max, mean and sd) of agroforestry systems biomass in each development stage. For the initialization at pixel level we used a normal distribution with the mean and standard deviation as indicated, truncated at observed minimum and maximum.

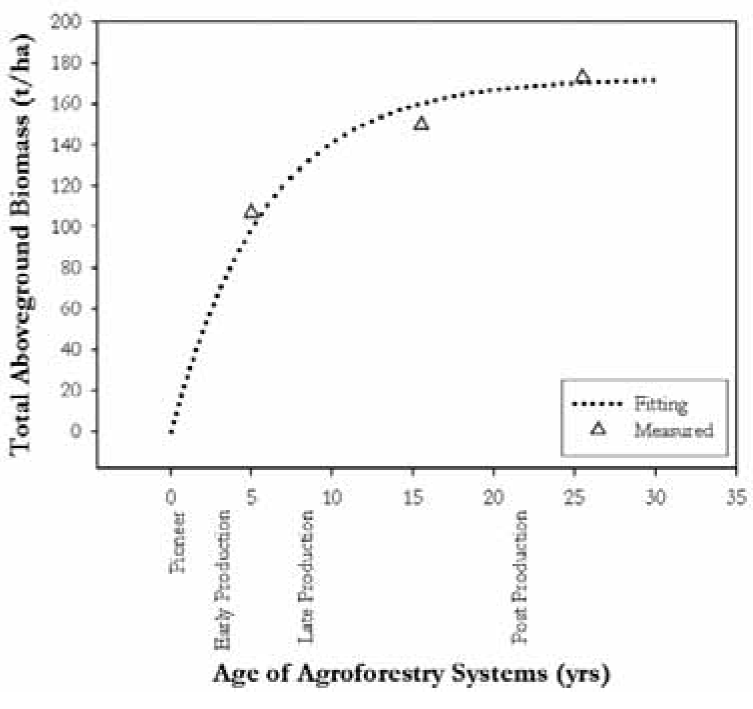


Figure 5.9. Total aboveground biomass as a function of age in agroforestry systems.

Table 5.3 Parameters describing agroforestry development and statistics of its aboveground biomass

State	Time Bound (yrs)	min (t/ha)	max (t/ha)	mean (t/ha)	sd (t/ha)
Pioneer	0	0.0	49.4	25.29	24.74
Early production	3	68.9	120.3	96.81	20.36
Late Production	8	128.5	166.8	153.21	12.27
Post Production	21	167.7	171.7	170.11	1.32

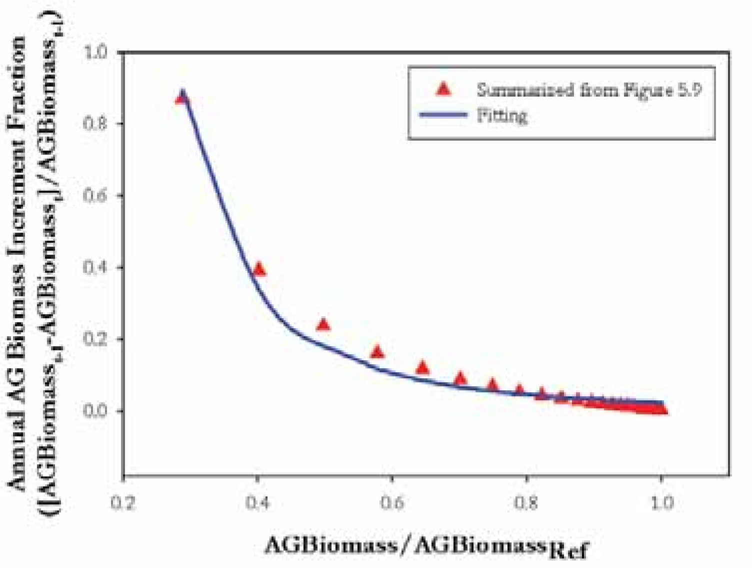


Figure 5.10. Annual increment of aboveground biomass in agroforestry system was estimated from its current state relative to maximum aboveground biomass in the oldest agroforesty system (171.7 t/ha, see Table 5.3).

The annual increment of aboveground biomass in agroforests was estimated based on current state of its aboveground biomass relative to maximum aboveground biomass in old agroforests (AGBiomass/AGBiomass$_{Ref}$). An asymptotic curve was applied to construct relational graph between aboveground biomass increment and AGBiomass/ AGBiomass$_{Ref}$, with y_{max}= 0.0014, β=0.09, γ=2.7, η=1.11, and RMSE=0.09 (Figure 5.10). The aboveground biomass increment is defined as [AGBiomass$_t$-AGBiomass$_{t-1}$]/AGBiomass$_{t-1}$.

Yields from agroforestry systems depend on tree-biomass and age. The fraction of tree-biomass was estimated from its correlation to

Table 5.4. Six dominant species that composed agroforestry (mixed-fruit garden) in Sebuku.

Rank	Sebuku	
	Species	Occurrence Probability
1	Coffe	0.37
2	Rambutan	0.31
3	Langsat	0.31
4	Elai	0.29
5	Banana	0.11
6	Durian	0.11

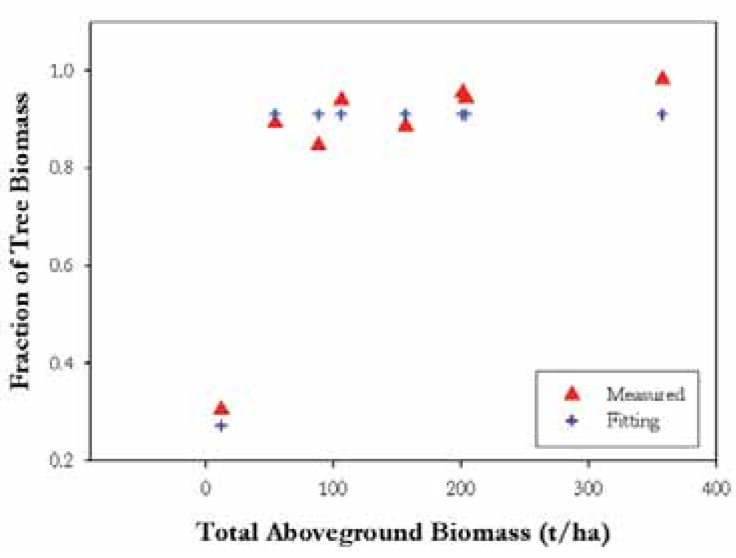


Figure 5.11. Curve fitting to estimate the tree components of agroforestry systems' total biomass.

total aboveground biomass, based on asymptotic curve with y_{max}=0.91, β=0.0055, γ=2, η=2.1, and RMSE=0.04 (Figure 5.11).

The main type of agroforestry systems found in Nunukan is mixed-fruits garden. In parameterizing agroforestry yields, six predominant species, i.e. *rambutan*, banana, *elai* (wild durian), *langsat*, coffee and durian, were selected based on their probabilities of occurrence, summarized from household survey results (Table 5.4).

Annual yield from each species (t/ha/year) was estimated as fraction relative to its aboveground biomass. Yield fractions of tree species (*rambutan*, *elai*, *langsat*, coffee and durian) were estimated based on tree-biomass, while banana is estimated from non-tree aboveground biomass (Table 5.5). Aging factors were added as modifiers at each development stage. In this study, aging factors of 0.1, 1, 0.75, 0.2 are used as yields modifiers at pioneer, early production, late production and post production stages respectively.

Table 5.5. Agroforestry systems' yields were estimated from tree-biomass and non-tree aboveground biomass.

Species	Rambutan	Banana	Elai	Langsat	Coffee	Durian
Biomass (t/ha)	15.25 (tree)	1.26 (non tree biomass)	8.60 (tree)	12.22 (tree)	2.66 (tree)	24.96 (tree)
Yield (kg/ha)	318	303	1321	222	38	895
Yield fraction	0.0209	0.2397	0.1536	0.0182	0.0145	0.0358

Table 5.6. Statistic of initial soil organic matter (t/ha) at various land cover types.

Land cover type	Soil organic matter (t/ha)			
	min	max	mean	sd
Pioneer forests	0.00	38.30	22.42	14.58
Young secondary forests	40.23	57.95	53.20	4.81
Old secondary forests	58.02	59.65	59.27	0.42
Primary forests	59.65	59.73	59.71	0.02
Logged-over forests 1	59.22	59.93	59.65	0.37
Logged-over forests 2	56.23	59.94	57.68	1.98
Logged-over forests 3	59.26	59.76	59.51	0.35
Logged-over forests 4	56.51	59.86	58.67	1.87
Pioneer agroforests	0.00	29.62	16.56	15.12
Early production agroforests	35.56	45.90	41.55	4.11
Late production agroforests	47.06	51.29	49.91	1.34
Post production agroforests	51.38	51.72	51.58	0.11

Table 5.7. Annual depletion rate and conversion efficiency of rice fields.

Fallow age (yr)	Total biomass (t/ha)	Estimated SOMC Stock	Depleted SOMC	Rice yield (t/ha)	Depletion Rate	Conversion Efficiency
1	2.44	3.67	0.47	0.80	0.41	1.68
2	5.05	6.27	0.81	2.43	0.04	2.99
3	5.32	6.52	0.84	3.14	0.02	3.73
4	5.50	6.67	0.86	2.96	0.04	3.43
5	5.83	6.96	0.90	3.06	-	3.40
				Average crop conversion efficiency		3.04
				Average depletion rate		0.13

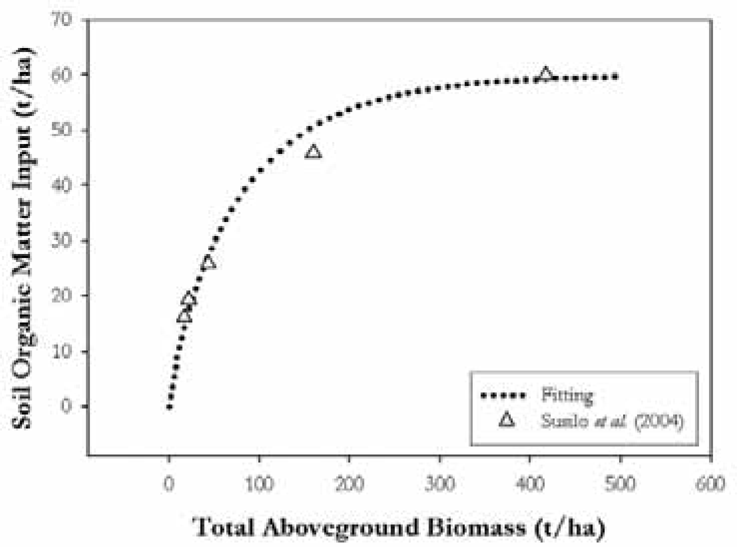


Figure 5.12. Relational curve between total aboveground biomass and soil organic matter input. This pattern was summarized from belowground biomass assessment in various land use systems in Jambi, Sumatera by Susilo, *et al*. (2004).

Soil fertility and agriculture productivity

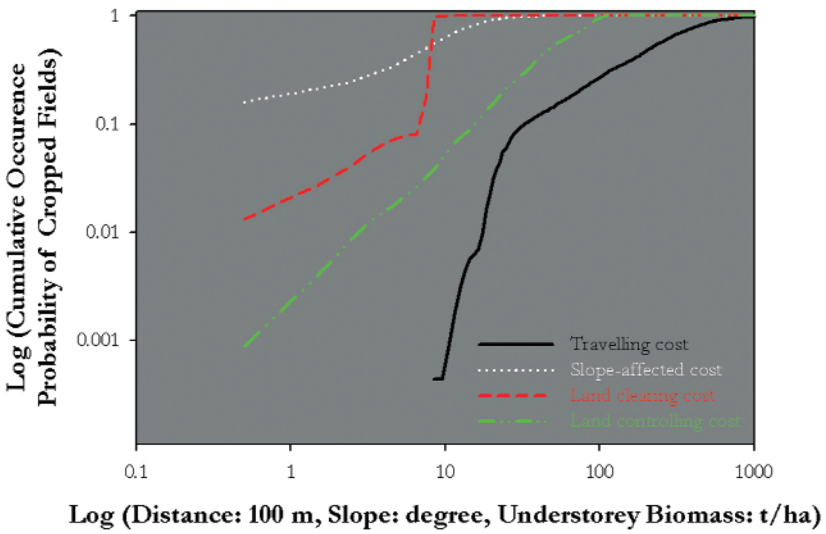
Assumptions underlying the estimate of annual organic matter input to the soil in various land cover types in Jambi, Sumatera (Susilo *et al*, 2004) are used to estimate soil organic matter input from aboveground biomass (Figure 5.12). Belowground stocks were initialised using this relational curve, as summarized in Tabel 5.6. Food crop (rice) productivity was estimated from fallow plots (*jakaw*) as summarized in Table 5.7.

People's knowledge and deliberation

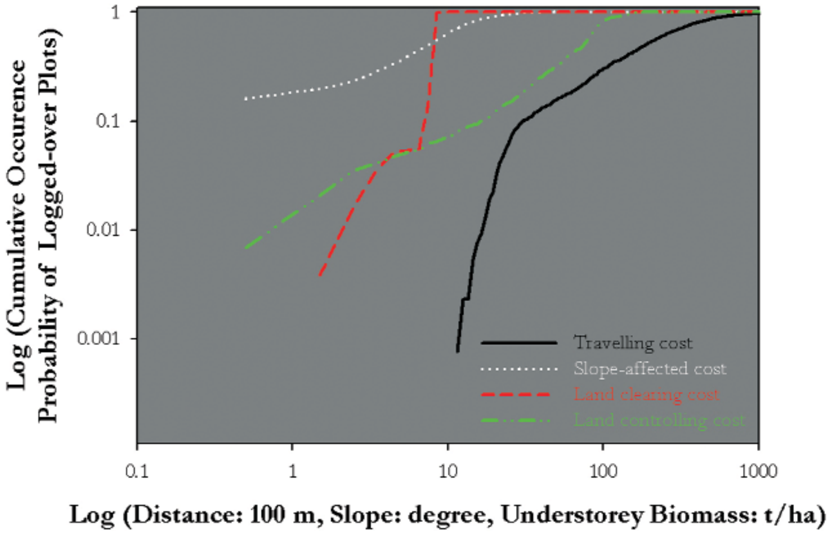
Not all parameters to initialize people's perception on livelihoods' benefits were derived directly from the socio-economic survey data. Some of the parameters were estimated by combining available information with secondary data (summarized in Table 5.8). Expected return to labour on food-crop agriculture was estimated from data on food-crop agriculture area as captured by land cover map in 1996 (6 ha), and socio-economic data from household survey: annual labour input per ha (person.day ha^{-1} yr^{-1}), rice yield average per ha (317 kg/ha) and rice price (Rp. 4,250/kg). The last two values were also used to estimate expected returns to land on food-crop agriculture. The same methods was applied to estimate expected returns to labour and expected returns to land on agroforestry. Expected return to labour on logging was directly assessed from household survey data. Expected return to land on logging was estimated from data on logged-over area in 1996 (47 ha), average timber yields in new logged-over plots (772 m^3/ha), timber price (Rp. 99,276/m^3) and possible labour involved in logging activity (with estimated fraction equals to 0.35). It is assumed that 1% of human population have knowledge updating rate equals to 0.75, while the rest is 0.25. The initial strategy between those two agents is assumed to be at Nash-equilibrium state, thus both agents have the same knowledge at the initial state.

Table 5.8. People's perception on livelihoods' benefits in Sebuku.

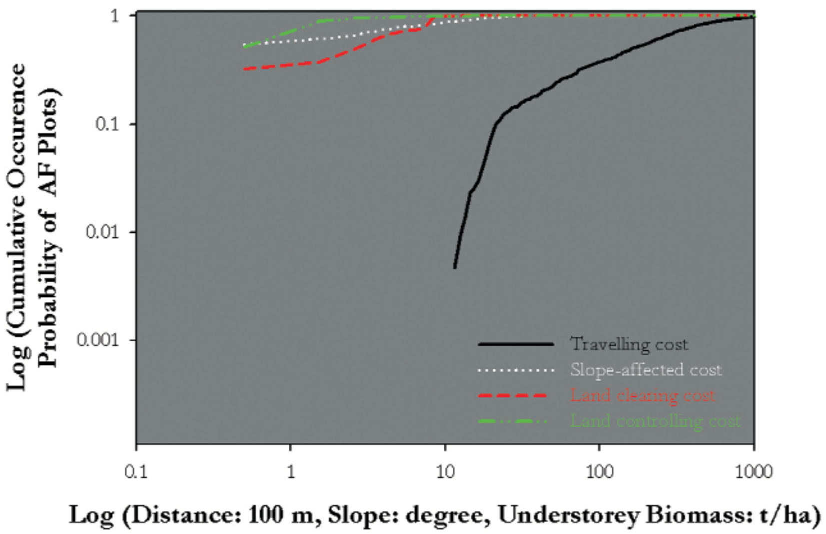
Livelihood	Expected Return To Labour (IDR/person.day)	Expected Return to Land (IDR/ha)
Food-crop Agriculture	18,380	1,348,194
Agroforestry (mix-fruit garden)	41,127	4,574,014
NTFP (gaharu)	3,968	N.A.
Logging	34,673	61,311,413
Off Farm	13,292	



(a) Agriculture



(b) Logging



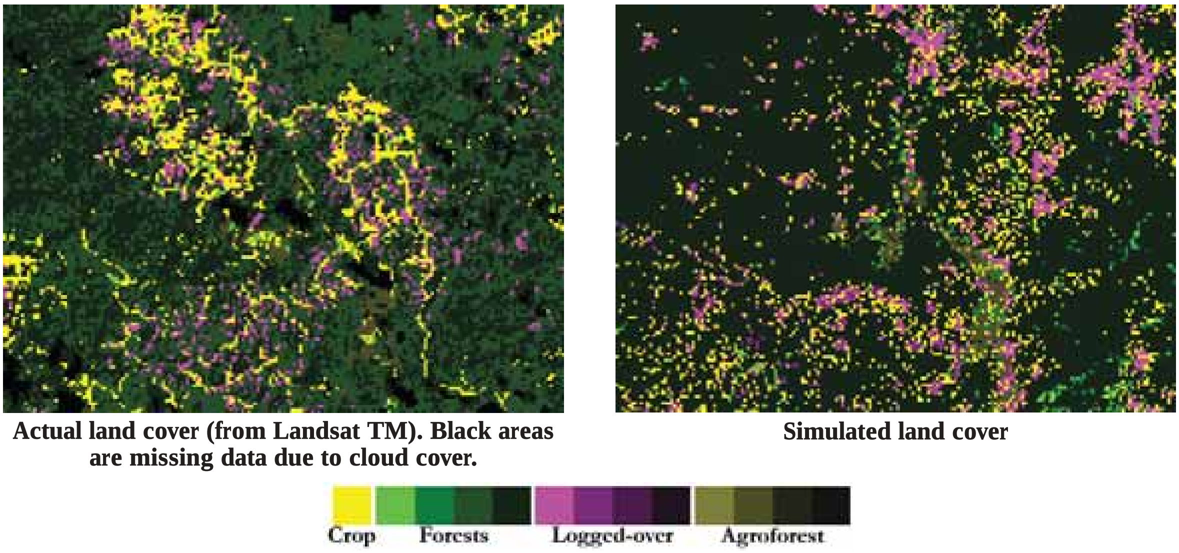
(c) Agroforestry

Figure 5.13. Spatial properties, determining people's deliberation in land expansion. Calculation procedure adopted from Costanza (1989) was used to calculate the strength of each spatial determinant, which is reflected by exponentially weighted average over all determinants' values: (a) in agriculture land expansion, effect of traveling-cost was 0.0122, slope-related cost was 0.5243, land-clearing-related cost was 0.4812, and land control-related cost was 0.0685; (b) in logging expansion, effect of traveling-cost was 0.0130, slope-related cost was 0.5240, land-clearing-related cost was 0.4695, and land control-related cost was 0.0717; and (c) in agroforestry expansion, effect of traveling-cost was 0.0246, slope-related cost was 0.8006, land-clearing-related cost was 0.7535, and land control-related cost was 0.9319.

Spatial analyses were carried out using land cover maps, slope map and distances maps (*i.e.* road, river, settlement), to estimate the effects of spatial properties in determining people's deliberation in selecting plots for expansion, which summary is presented in Figure 5.13.

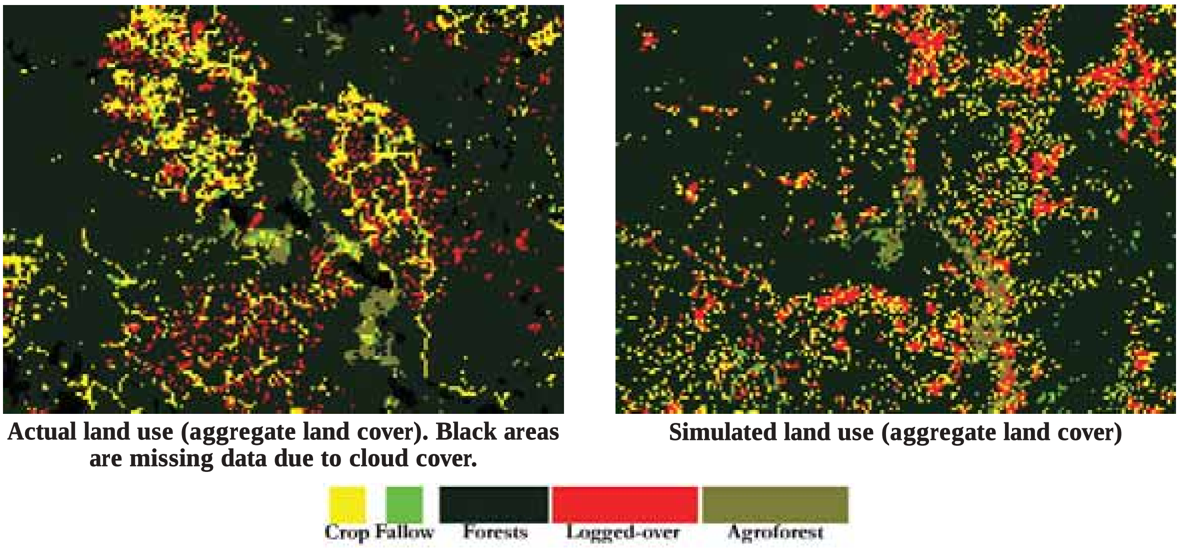
Model validation

Validation was conducted to measure similarity of landscape pattern in 2003 between simulation result and the reference (landcover map, derived from Landsat TM – see chapter 4). The model was validated at three different levels: (1) at detailed nominal level, by measuring similarity of landcover


Actual land cover (from Landsat TM). Black areas are missing data due to cloud cover.

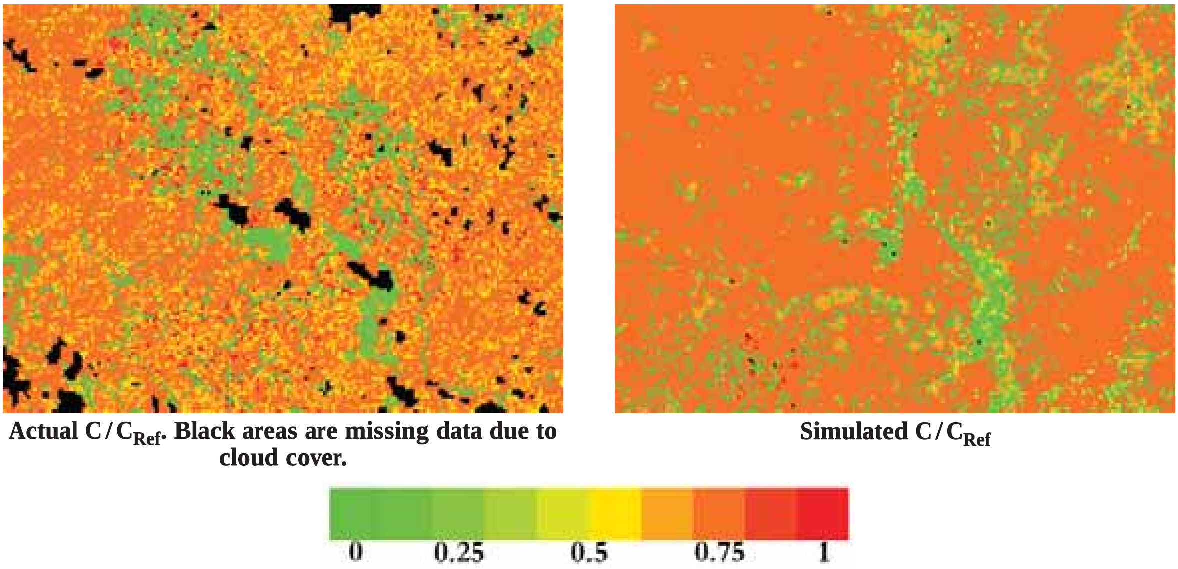
Simulated land cover

Figure 5.14. Actual land cover map of Sebuku area in 2003 (left), compared to the simulated (right). At detail nominal level, spatial fit of simulated data to the actual was only 37% (see Figure 5.17).


Actual land use (aggregate land cover). Black areas are missing data due to cloud cover.

Simulated land use (aggregate land cover)

Figure 5.15. Actual land use map of Sebuku area in 2003 (left), compared to the simulated (right). These maps were resulted by aggregating land cover maps, where pioneer forests was separated from forests and reclassify into fallowed lands. At aggregate nominal level, spatial fit of simulated data to the actual increased to 70% (see Figure 5.17).



Actual C/C_{Ref}. Black areas are missing data due to cloud cover.

Simulated C/C_{Ref}

Figure 5.16. Estimated actual C/C_{Ref} based on land cover map and statistic from carbon field survey (left), compared to simulated C/C_{Ref} (right). In this case C/C_{Ref} was aboveground carbon stocks relative to the reference (primary forests). At detail quantitative level, spatial fit of simulated data to the actual was 80% (see Figure 5.17).

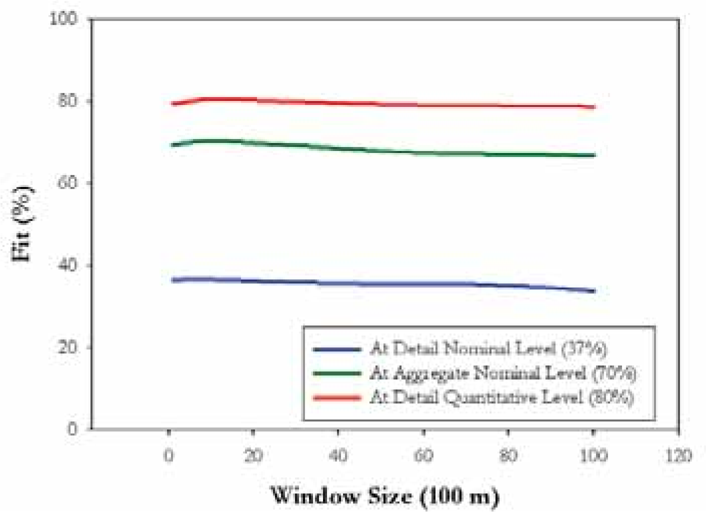


Figure 5.17. Fit between simulated and actual maps, measured at multiple resolution, ranging from 100 m to 10 km sampling windows' sizes (the procedure was adopted from Costanza, 1989). At detail nominal level (land cover comparison), overall fit was 37%. At aggregate nominal level (land use comparison), overall fit increased to 70%. At detail quantitative level (C/C_{Ref} comparison), overall fit reached 80%.

maps; (2) at aggregate nominal level, by measuring similarity of land use maps; and (3) at detail quantitative level by measuring the similarity of C/C_{Ref}. Maps used for validation are shown in Figure 5.14-5.16. Validation's procedure was adopted from Costanza (1989), by measuring the similarity of spatial patterns at multiple resolutions. The results are presented in Figure 5.17. At detail nominal level (land cover comparison, Figure 5.14), the fit of the model was 37% (Figure 5.17). When validation was done at aggregate level (land use comparison, Figure 5.15), the model's fit increased to 70% (Figure 5.17). The model achieved 80% fit (Figure 5.17) when validation was done at detail quantitative level (Figure 5.16).

Baseline and effects of population increase

This section discussed the predicted change in systems characteristics if current trends continue acts as a dynamic baseline. Extra-

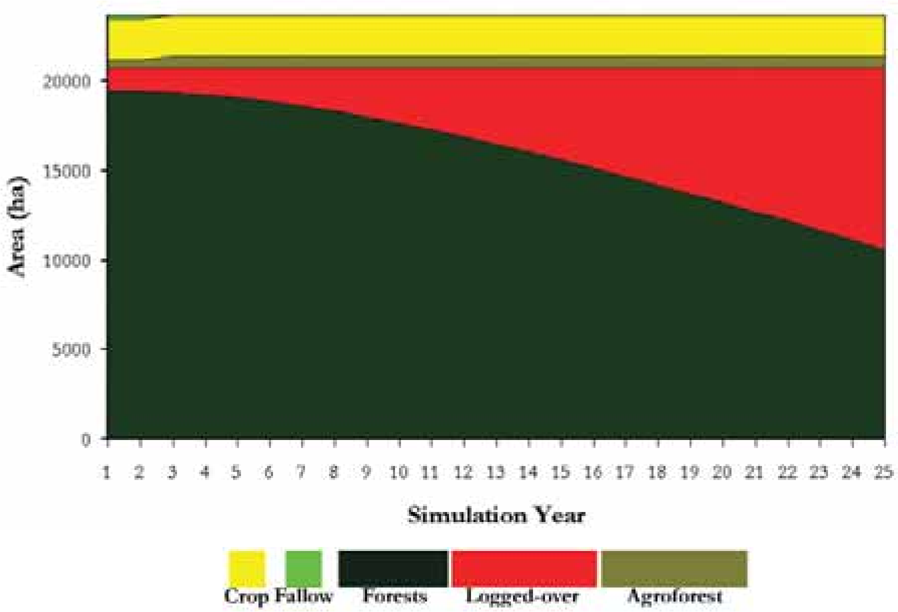


Figure 5.18. Simulated landscape dynamics in Sebuku from 2003 to the next 25 years using the current parameters setting, where logging is perceived as the most lucrative livelihood, depleting forests' carbon stocks.

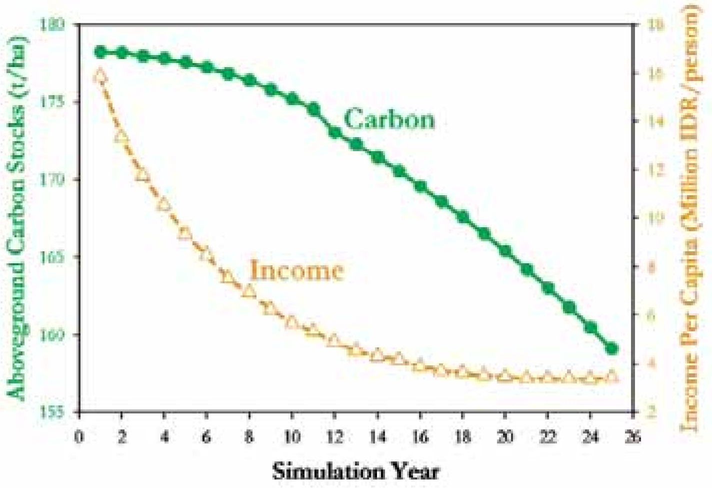


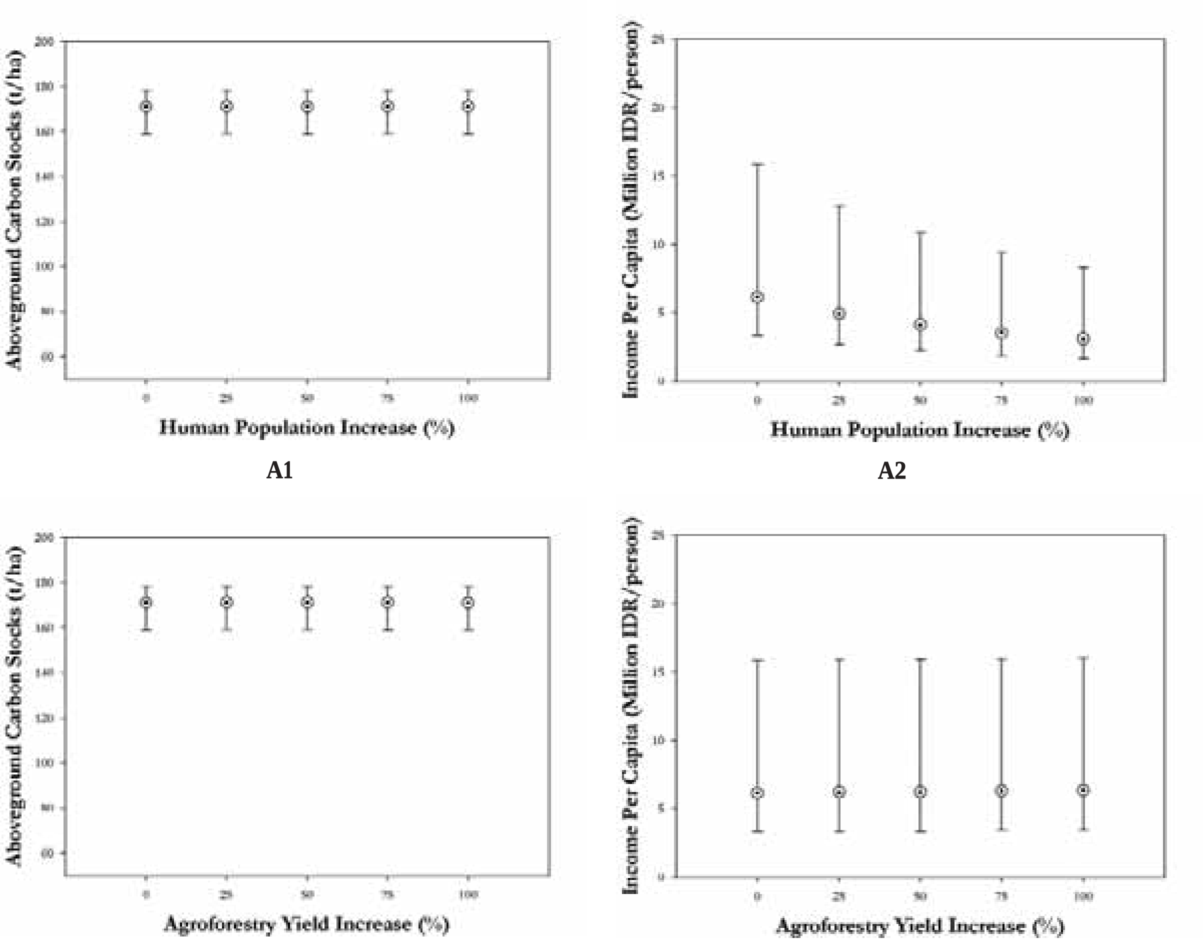
Figure 5.19. Using the current parameters setting, possible trend of landscape dynamics in Sebuku area for 25-year simulation period (initialised using land cover map 2003), resulted declining curves on both benefit indicators: income per capita (million IDR/person) and above ground carbon stocks (t/ha).

polation in time with the parameters that appear top provide an acceptable fit for the changes over the last 10 years, suggest that logging will remain to be perceived as the most profitable livelihood option over the next 25-year period (Figure 5.18). Thus, the model expects a 'baseline' of further depletion of timber and associated carbon stocks, in combination with a decline in income as the best opportunities for logging become depleted (Figure 5.19).

The decline in income will be faster if we assume an increase in the human population (Figure 5.20 A2), but growing population will not substantially increase logging intensity, resulting in similar patterns of carbon stock decline compared to the baseline scenario (Figure 5.20 A1).

Table 5.9. Scenarios used for simulations to explore all patterns of trade off between income per capita and plot average carbon stocks.

No.	Scenario	Key Parameters
1	Agroforestry yield improvement	Agroforest's yield per ha was 25%-100% increased from the current setting
2	Agroforestry market improvement	Price of agroforest products was 25%-100% increased from the current setting
3	Reducing timber market	Accessibility to timber market was 25%-100% reduced from the current setting



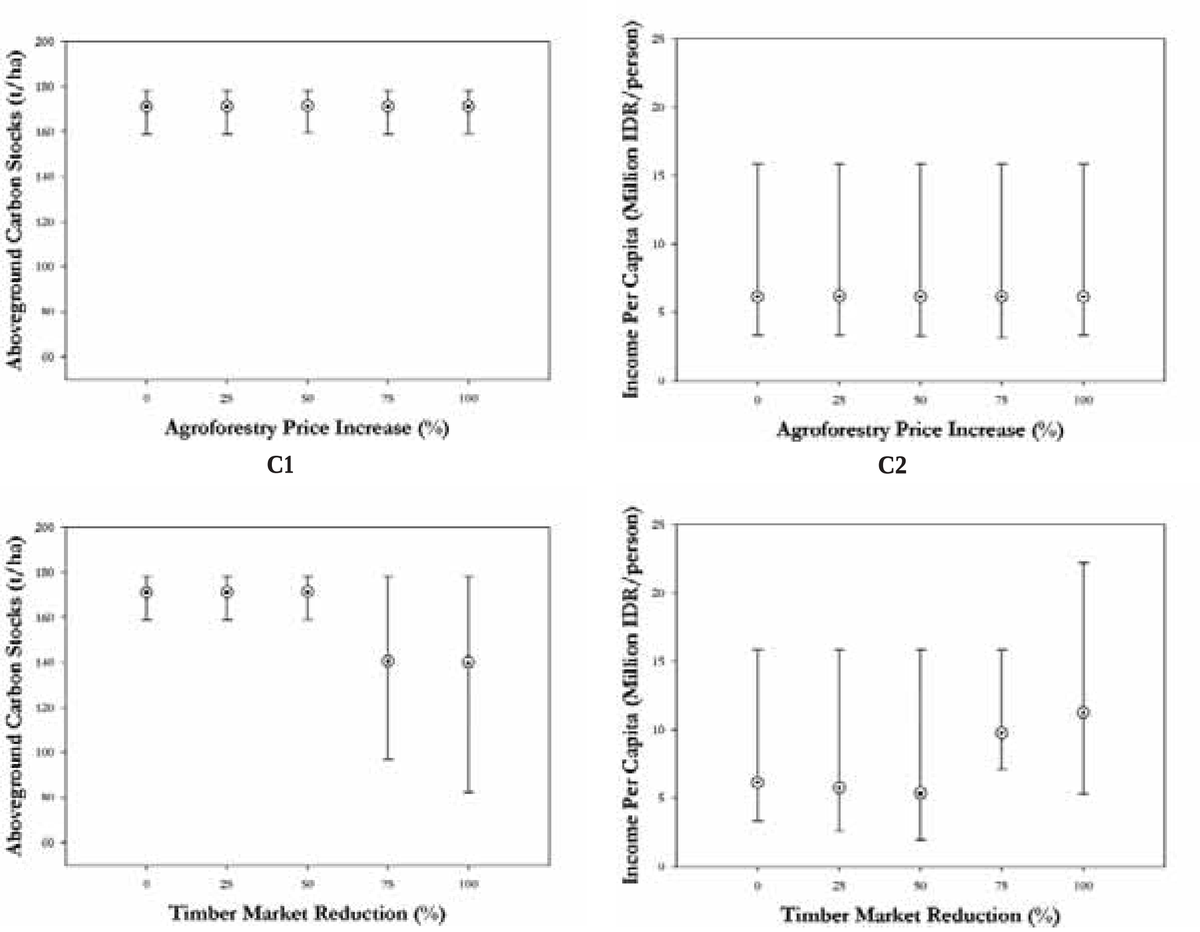
A1

A2

B1

B2

Figure 5.20. As simulated by the model, increase on human population reduced livelihood's benefit (A2), while carbon stocks remained the same as current trend (A1). Efforts to improve agroforestry profitability by increasing the yield and through better market development did not correspond to adoptability of agroforestry, when natural capital for logging activities was still promising to earn better payoffs, thus both income per capita (B1, C1) and carbon stocks (B2, C2) remained the same as current trend. Reducing timber market by 25%-50% from the current setting (full capacity) reduced people's main income (D2) without changing the current trend on carbon stocks' depletion (D1). When timber market reduction was increased by 75%-100%, people adopted agriculture and agroforestry to compensate income lost from logging, thus increasing carbon depletion (D1) and creating better income level (D2).



C1 C2

D1 D2

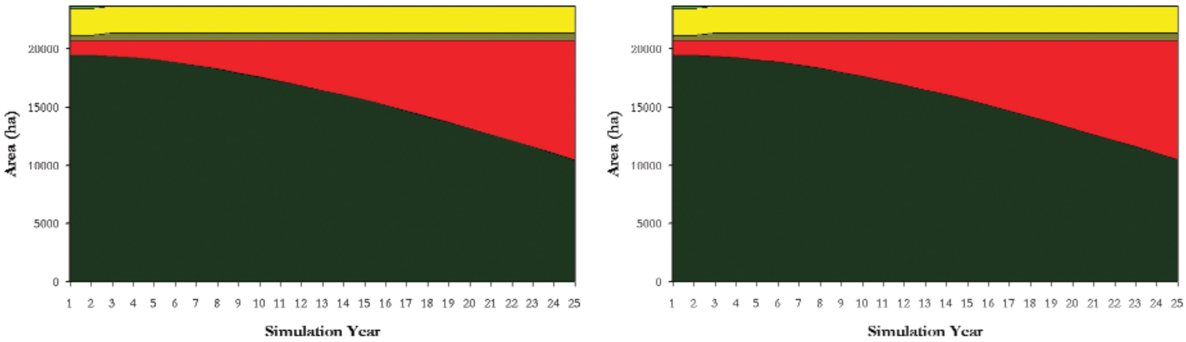
Figure 5.20. As simulated by the model, increase on human population reduced livelihood's benefit (A2), while carbon stocks remained the same as current trend (A1). Efforts to improve agroforestry profitability by increasing the yield and through better market development did not correspond to adoptability of agroforestry, when natural capital for logging activities was still promising to earn better payoffs, thus both income per capita (B1, C1) and carbon stocks (B2, C2) remained the same as current trend. Reducing timber market by 25%-50% from the current setting (full capacity) reduced people's main income (D2) without changing the current trend on carbon stocks' depletion (D1). When timber market reduction was increased by 75%-100%, people adopted agriculture and agroforestry to compensate income lost from logging, thus increasing carbon depletion (D1) and creating better income level (D2).

Scenario-based simulations

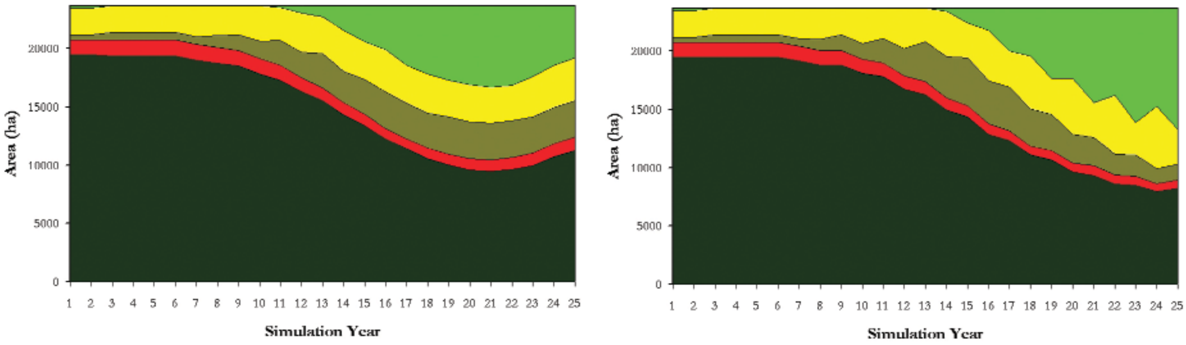
The actual landscape pattern in 2003 was used as a base for simulating the next 25 years based on scenarios described in Table 5.9. Scenario 1 and 2 were intended to explore adoptability of agroforestry on the landscape when its profitability was improved. The last scenario was aimed at exploring people's adaptive behaviour, when timber market disappeared from the landscape.

Efforts to improve agroforestry profitability by increasing its yields and improving its market (increasing the price) did not substantively change its adoptability on the landscape, resulting the same tradeoff patterns, compared to current setting (Figure 5.20 B1,B2,C1,C2).

Reducing the timber market by 75%-100% apparently influenced people's income significantly, enforcing people to adopt agroforestry and agriculture as alternative



(A) timber market 25% reduced **(B) timber market 50% reduced**

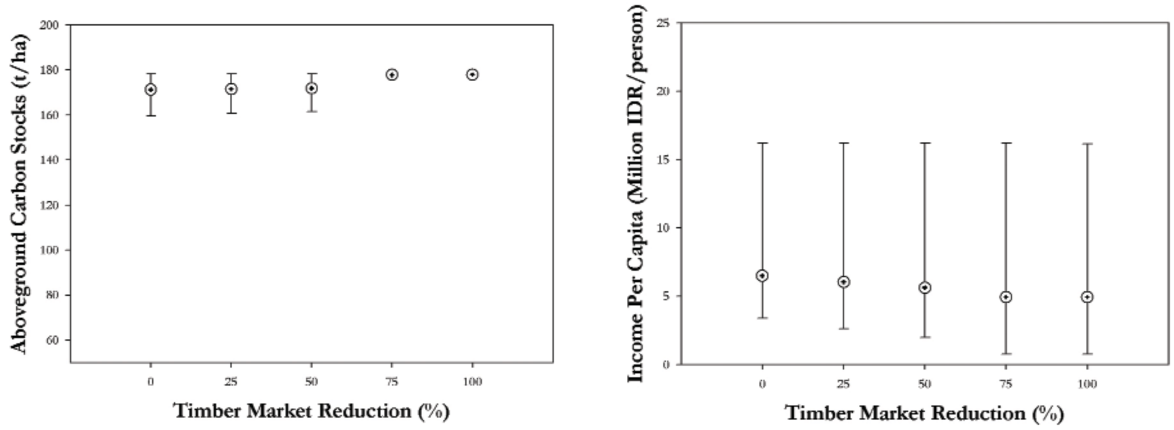


(C) timber market 75% reduced **(D) no timber market**

🟨 Crop 🟩 Fallow ⬛ Forests 🟥 Logged-over 🟫 Agroforest

Figure 5.21. People still expected logging to give good earning for them, although timber market was reduced by 25%-50% from the current setting (A and B). When timber market reduction was increased by 75%-100%, people adopted agriculture and agroforestry to compensate benefit lost from logging activities.

Combined effect when agroforestry was improved and timber market was reduced



A **B**

Figure 5.22. At current human population (4,046 inhabitants), when agroforestry was improved by 100% increasing its yield and its price from current setting, it could maintain carbon stocks when timber market was reduced at least by 75% (A), at the same income reduction risk as the current trend (B).

options that increased earning (Figure 5.21), increasing income by 58%-83% (Figure 5.20 D2) and depleting carbon stock by only 18% from the current setting (Figure 5.20 D1).

When scenario 1 and scenario 2 were combined with scenario 3, where agroforestry yield and agroforestry price were increased by 100% at various timber market reduction levels, carbon stocks was maintained when timber market was reduced at least by 75% (Figure 22 A) at the same income reduction risk as the current trend (Figure 22 B).

Discussion

In line with the objectives, we will review the suitability and weaknesses of the FALLOW model for the current purpose, and will formulate tentative conclusions regarding the plausible impact of scenarios for the drivers of land use change on income and carbon stocks in Nunukan.

How "model goodness of fit" can be better measured?

In carbon monitoring context, landscape dynamics model like FALLOW can be used as assessment tool with relatively low transaction costs. When its goodness of fit is well tested, it can be used as a tool to develop scenario-based planning. This study shows that at detail level of validation to compare landscape pattern similarity using nominal values, FALLOW Model gave relatively low goodness of fit (37%), but its fit increased as the validation level was scaled-up at coarser aggregate or it was done using quantitative indicators (giving the fits of 70% and 80% respectively).

If we compare simulated and actual data in term of area proximity (not spatial pattern similarity) at aggregate level (land use comparison), we will have relative area difference of simulated data to the actual with the average equals 11.15%, ranging from +2.45% at forested area to +28.6% at agroforestry plots (Table 5.10). Thus, the model gives "acceptable" estimation in term of area proximity. In this case, area proximity can be considered to overpower spatial pattern similarity, since consequences on carbon stocks are additive.

In validating the model, in term of spatial pattern similarity of its simulated data, land cover maps derived from Landsat TM imageries were used as the reference to represent direct observed data. In fact, using Landsat TM, detail age stratification of land cover (eg. secondary forests is stratified further into young and old) could not be done at its resolution (30-m). Thus, incorrect assumption on land cover's age estimation resulted in low spatial pattern fit. Although "ecological distance" between two nominal values is relatively close (say between old secondary forest and primary forest), it was not considered in the fit calculation procedure. When error on age estimation was reduced through land cover reclassification

Table 5.10. Goodness of fit in term of area at aggregate nominal level (land use comparison).

Land use type	Actual area in 2003 (ha)	Simulated area in 2003 (ha)	Area difference of simulated data relative to the actual (%)
Agriculture	2269	2397	5.64
Fallow	211	217	2.84
Forests	19481	19959	2.45
Logged Forests	1297	1507	16.19
Agroforests	430	553	28.60

into more aggregate level (land use), a better fit could be achieved. High-fit achievement when validation was done using quantitative value (C/C_{Ref}) suggests that quantitative values are better than nominal values in explaining "ecological distance".

Low spatial pattern similarity of simulated land cover maps can also be affected by lack of spatial determinants considered in the study. Figure 5.23 clearly shows that actual spatial patterns of agricultural land in 2003 apparently do not really follow the spatial patterns of road and river. But since road and river maps at relatively coarse resolution are the only spatial information available to parameterize the model, it is obvious that spatial patterns of agricultural land as simulated by the model have relatively high spatial dependence on road and river (Figure 5.24). Probably, the "real" spatial determinants affecting land expansion appeared at very high

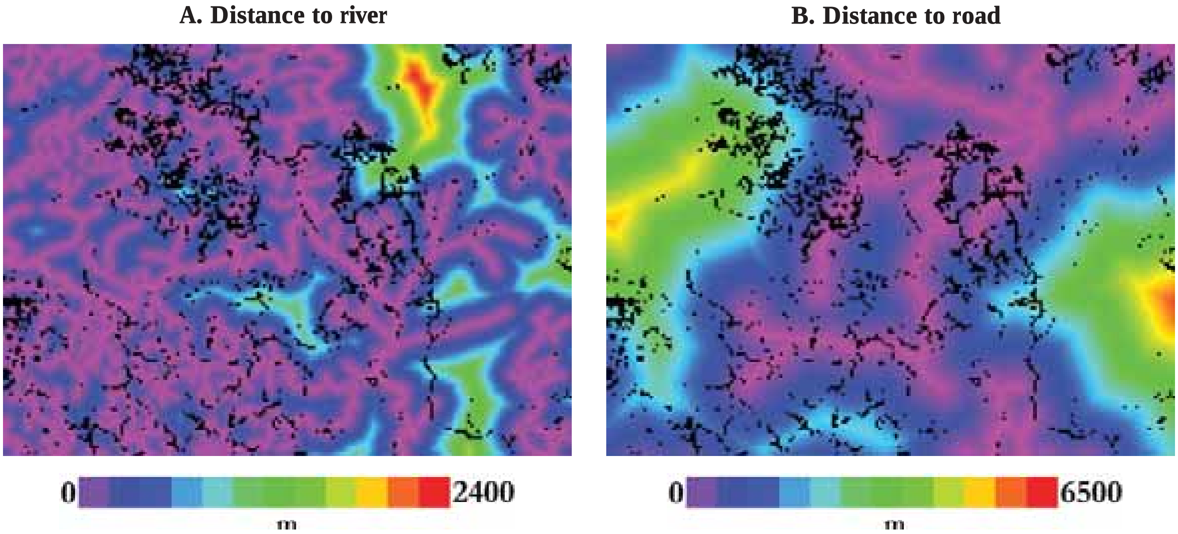


Figure 5.23. Cropped fields in Sebuku as observed by Landsat TM in 2003 (black pixels), overlaid with distance to river map (A) and distance to road map (B). Spatial patterns of cropped fields didn't follow the patterns of either river or road.

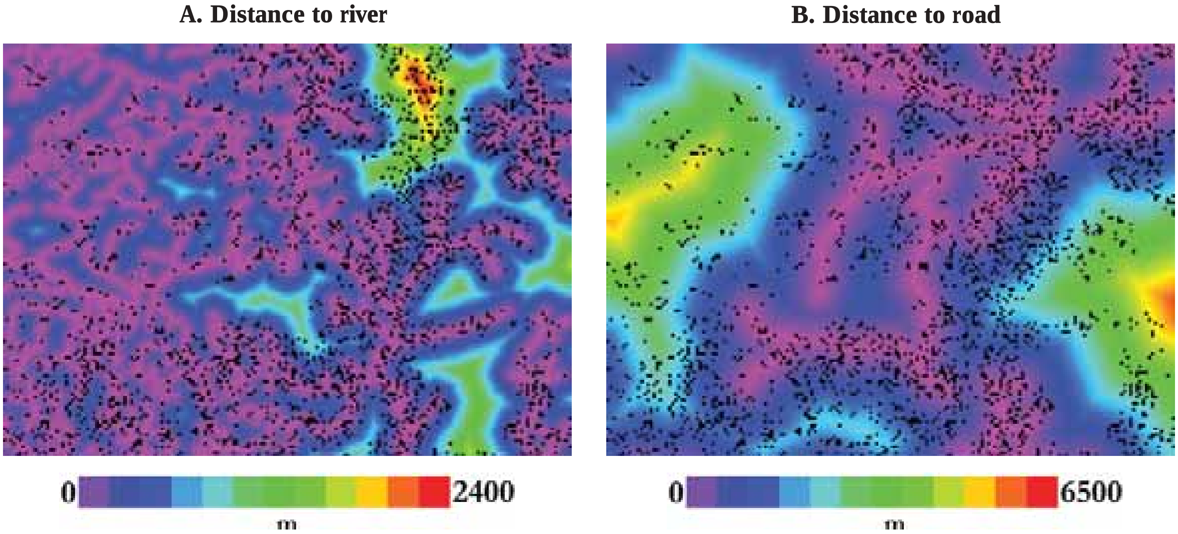


Figure 5.24. Simulated cropped fields in Sebuku in 2003 (black pixels), overlaid with distance to river map (A) and distance to road map (B). Spatial patterns of simulated cropped fields were agglomerated surrounding river or road.

resolution, e.g. the form of foot paths. Thus, for future works, we suggest to initialize and validate the model by ground truthing or by using high-resolution satellite imageries (*e.g.* QuickBird), instead of initializing and comparing it with other low-resolution models (*i.e.* land cover maps interpreted from Landsat TM).

Carbon-income tradeoffs in a forested landscape

When a landscape is still dominated by forests, like in Sebuku, livelihoods of local people are very dependent on forest resource. From all individual scenarios (scenario 1-scenario 3), depletion of carbon stocks could not be avoided. When the timber market is reduced, people will move to agriculture and agroforestry, which means other types of deforestation with worse consequences on carbon sequestration. But on a limited area when timber market reduction occured simultaneously with agroforestry improvement, carbon stocks could be maintained while income was not reduced too much. Thus, reducing land-use-change carbon emission while increasing local benefit on this area should be done by means of promoting CBNRM (by adopting *e.g.* reduced impact logging) while improving agroforestry simultaneously.

Conclusion

The model's goodness of fit is only 37% at detailed nominal level (pixel-level land cover comparison), but it is 70% at the more aggregate nominal level (land cover fractions comparison), and 80% at detailed quantitative level (C/C_{Ref} difference) directly relevant for the C-stock scenarios.

The model gives "acceptable" estimation in term of area proximity at aggregate nominal level.

Spatially explicit landscape dynamics models, like FALLOW, should be initialized and validated through ground truthing or by using higher-resolution of maps, instead of confronting them with other low resolution models.

The dynamic baseline for Nunukan suggests that both income and landscape level carbon stocks are decreasing, as non-sustainable logging remains the most profitable land use option

To simultaneously achieve global and local benefits, CBNRM and LEISA should work hand in hand: a substantial increase in profitability of agroforestry options will be needed before this practice can be an ‘alternative to illegal logging’ and compete with the attractiveness of logging, along with an effective way of reducing lumber sales; the time lag involved in the profitability of agroforestry suggests that active promotion and extension are important in the race against time, but only if in fact there are land use options to be promoted that will actually benefit the farmers.

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APPENDIX

Appendix 1. Carbon stocks measured and timber stocks estimated in sample plots at Sebuku and Sembakung district, Nunukan, East Kalimantan.

Sampling Date	Village	Position		Land Use Type	Age (years)	Tree biomass (Mg ha^{-1})	Necromass (Mg ha^{-1})	Understorey (Mg ha^{-1})	Litter (Mg ha^{-1})	Timber stocks[1] (m^3/ha)
		50 N	UTM							
20-Jan-04	Sujau	479475	436480	Logged-over forest	0-3	515.4	1.3	1.3	17.1	720.23
20-Jan-04	Sujau	479509	436626	Logged-over forest	0-3	484.5	1.4	9.4	149.5	793.17
20-Jan-04	Sujau	479820	436793	Logged-over forest	0-3	390.7	1.7	2.0	11.7	489.05
12-Dec-03	Sekikilan	498603	451246	Logged-over forest	4-10	229.8	3.0	3.0	13.0	379.82
12-Dec-03	Sekikilan	unrecorded	unrecorded	Logged-over forest	4-10	245.5	2.2	4.7	15.5	284.90
12-Dec-03	Sekikilan	498668	451221	Logged-over forest	4-10	640.6	1.1	1.6	11.2	703.01
19-Dec-03	Atap	503632	427741	Logged-over forest	11-30	453.5	10.8	2.3	18.2	*na*
12-Dec-03	Atap	503594	427669	Logged-over forest	11-30	505.3	9.0	1.1	8.0	777.94
19-Dec-03	Atap	503625	427654	Logged-over forest	11-30	391.6	3.0	1.2	15.6	608.56
25-Jan-04	Lubok	483286	419551	Logged-over forest	31-50	378.3	5.1	2.1	11.0	826.80
25-Jan-04	Lubok	unrecorded	unrecorded	Logged-over forest	31-50	235.0	8.5	1.1	12.1	584.08
25-Jan-04	Lubok	unrecorded	unrecorded	Logged-over forest	31-50	558.1	2.5	0.7	13.6	910.82
Feb-04	Tau Baru	484843	457500	Primary Forest	-	723.3	0.9	0.2	10.7	1009.54
Feb-04	Tau Baru	484793	457809	Primary Forest	-	417.9	0.5	0.0	9.2	682.60
Feb-04	Tau Baru	484817	457684	Primary Forest	-	363.1	0.4	0.2	7.9	524.47
Feb-04	Sekikilan	498670	457071	Imperata	-	0.0	0.0	4.6	5.6	*na*
Feb-04	Sekikilan	498617	457120	Imperata	-	0.0	0.0	4.2	4.4	*na*
Feb-04	Sekikilan	498472	451989	Imperata	-	0.0	0.0	4.6	4.5	*na*
Feb-04	Sekikilan	498503	451968	Jakaw	1	0.2	1.5	5.8	11.4	*na*
Feb-04	Sekikilan	498527	451997	Jakaw	1	7.7	1.9	1.6	5.5	5.15
Feb-04	Sekikilan	498472	451989	Jakaw	1	16.0	0.3	2.6	9.1	27.20
25-Dec-03	Manuk Bungkul	497447	422652	Jakaw	2	3.7	0.8	1.5	5.0	6.10
25-Dec-03	Manuk Bungkul	497436	422662	Jakaw	2	3.2	0.6	2.0	1.8	3.45
25-Dec-03	Manuk Bungkul	497419	422649	Jakaw	2	18.1	0.9	1.5	3.2	23.70
07-Mar-04	Manuk Bungkul	497235	422041	Jakaw	3	26.0	0.2	0.8	7.5	49.98
07-Mar-04	Manuk Bungkul	496957	421936	Jakaw	3	16.9	0.0	1.0	6.0	27.67
07-Mar-04	Manuk Bungkul	496957	421854	Jakaw	3	21.6	0.1	1.0	7.8	38.81
14-Dec-03	Tanjung Harapan	479474	417051	Jakaw	4	31.9	1.1	1.9	7.4	110.03
14-Dec-03	Tanjung Harapan	479522	416983	Jakaw	4	43.7	0.7	1.0	9.8	*na*
14-Dec-03	Tanjung Harapan	479365	416983	Jakaw	4	33.5	1.2	0.8	6.4	78.78

[1] Timber stocks is estimated from the number of trees found in each plot. *na* means no trees were found in the sample plot

Appendix 1. (Continued)

Sampling Date	Village	Position		Land Use Type	Age (years)	Tree biomass (Mg ha^{-1})	Necromass (Mg ha^{-1})	Understorey (Mg ha^{-1})	Litter (Mg ha^{-1})	Timber stocks[1] (m^3/ha)
		50 N	UTM							
	Tanjung Harapan	480505	417490	Jakaw	5	34.7	0.2	1.4	5.0	82.73
	Tanjung Harapan	480414	417590	Jakaw	5	35.8	0.0	1.4	4.9	82.10
	Tanjung Harapan	480295	417693	Jakaw	5	40.1	0.2	1.1	6.5	91.58
26-Feb-04	Lubok	486091	419350	Jakaw	7	67.6	0.0	0.9	6.2	101.91
26-Feb-04	Lubok	485993	419545	Jakaw	7	93.2	0.0	0.2	6.2	142.49
26-Feb-04	Lubok	485760	419370	Jakaw	7	129.7	0.6	0.9	5.6	259.08
Feb-04	Sekikilan	499390	451863	Jakaw	15	168.7	0.0	3.2	11.4	231.55
Feb-04	Sekikilan	499463	451897	Jakaw	15	101.3	1.1	5.4	8.7	230.05
Feb-04	Sekikilan	499390	451863	Jakaw	15	69.2	1.7	8.4	7.5	114.53
04-Mar-04	Pagaluyon	480921	418031	Agroforest	9	3.7	0.0	1.6	6.9	na
04-Mar-04	Pagaluyon	480897	418102	Agroforest	9	192.4	2.9	1.4	4.7	na
04-Mar-04	Pagaluyon	480754	418099	Agroforest	9	28.3	0.0	2.9	6.8	na
08-Mar-04	Manuk Bungkul	497694	423055	Agroforest	10-20	192.7	0.0	1.1	10.1	na
08-Mar-04	Manuk Bungkul	497686	423021	Agroforest	10-20	75.0	0.6	1.5	11.5	na
08-Mar-04	Manuk Bungkul	497725	422993	Agroforest	10-20	138.5	0.0	1.1	16.8	na
28-Feb-04	Sujau Lama	479978	439228	Agroforest	21-30	351.4	0.0	1.1	5.2	na
28-Feb-04	Sujau Lama	479984	439236	Agroforest	21-30	48.5	0.0	1.1	4.8	na
28-Feb-04	Sujau Lama	480025	439257	Agroforest	21-30	100.0	0.0	1.3	5.3	na
25-Feb-04	Apas	499884	440098	Padi - Jakaw	1	0.0	0.0	2.4	0.0	na
02-Mar-04	Kunyit	496304	436179	Padi - Jakaw	2	0.0	0.0	5.1	0.0	na
06-Mar-04	Manuk Bungkul	498191	422694	Padi - Jakaw	3	0.0	0.0	5.3	0.0	na
02-Mar-04	Lubok Buat	483997	418862	Padi - Jakaw	4	0.0	0.0	5.5	0.0	na
01-Mar-04	Lubok Buat	485469	418436	Padi - Jakaw	5	0.0	0.0	5.8	0.0	na
09-Feb-04	Pagaluyon	480985	418710	Padi - Jakaw	6	0.0	0.0	12.0	0.0	na

Appendix 2. Tree species found in sample plots

A. Primary forest

No	Local Name	Latin name	Familly
1	Adau (medang perupuk)	*Lophopetalum* sp.	Celastraceae
2	Balingkudung (Salingkawang)	*Buchanania* sp.	Anacardiaceae
3	Banggeris	*Koompassia* sp.	Leguminosae
4	Bayur	*Pterospermum* sp.	Sterculiaceae
5	Bengkirai	*Shorea laevis*	Dipterocarpaceae
6	Bintangal (bintangur)	*Calophyllum* sp.	Guttiferae
7	Dara-dara (mendarahan)	*Knema* sp.	Myristicaceae
8	Gading-gading (kayu gading)	*Muraya paniculata*	Rutaceae
9	Gimpango (limpato)	*Prainea limpato*	Moraceae
10	Ipil	*Intsia* sp.	Leguminosae
11	Jambu-jambu	*Syzigium* sp.	Myrtaceae
12	Kapur	*Dryobalanops sumatrensis*	Dipterocarpaceae
13	Kayu hitam	*Diospyros transitoria*	Ebenaceae
14	Keruing	*Dipterocarpus alatus*	Dipterocarpaceae
15	Kulit (medang wangi)	*Beilschmiedia micrantha*	Lauraceae
16	Lapak (kayu lilin)	*Aglaia leptantha*	Meliaceae
17	Meranti kuning	*Shorea* sp.	Dipterocarpaceae
18	Meranti merah (Adat)	*Shorea* sp.	Dipterocarpaceae
19	Meranti merah (tua)	*Shorea* sp.	Dipterocarpaceae
20	Meranti Putih	*Shorea* sp.	Dipterocarpaceae
21	Nyantuh (nyatoh)	*Chrysophyllum* spp.	Sapotaceae
22	Pala bukit	*Myristica crassa*	Mytisticaceae
23	Pampalang (empilung)	unknown	unknown
24	Rengas	*Gluta curtisii*	Anacardiaceae
25	Serangan batu (seranggap)	*Hopea* sp.	Dipterocarpaceae
26	Talisoy (talisei)	*Terminalia subspathulata*	Combretaceae
27	Talutu (taluto)	unknown	unknown
28	Tengkawang (biasa)	*Shorea pinanga*	Dipterocarpaceae
29	Ulin	*Eusideroxylon zwageri*	Lauraceae

B1. Logged-Over-Forest aged 0 - 10 years

No	Local Name	Latin name	Familly
1	Adau (medang perupuk)	*Lophopetalum* sp.	Celastraceae
2	Alag-alag (alanagni)	*Myristica guatteriifolia*	Myristicaceae
3	Bab	unknown	unknown
4	Bak (mersawa terbak)	*Anisoptera costata*	Dipterocarpaceae
5	Balingkudung (Salingkawang)	*Buchanania* sp.	Anacardiaceae
6	Balinsakat (balindakat)	*Artocarpus atilis*	Moraceae
7	Banggeris	*Koompassia* sp.	Leguminosae
8	Bangunyung (kayu melati)	*Teijsmanniodendron ahernianum*	Verbenaceae
9	Bengkirai	*Shorea laevis*	Dipterocarpaceae
10	Bidang (medang mata buaya)	*Cryptocarya griffithiana*	Lauraceae
11	Binatol (Binatoh)	*Shore argentifolia*	Dipterocarpaceae
12	Bintangal (bintangur)	*Calophyllum* sp.	Guttiferae
13	Dara-dara (mendarahan)	*Knema* sp.	Myristicaceae
14	Durian	*Durio zibethinus*	Bombacaceae
15	Gading-gading (ky. Gading)	*Muraya paniculata*	Rutaceae
16	Gimpango (limpato)	*Prainea limpato*	Moraceae
17	Intut	*Palaquium quercifolium*	Sapotaceae
18	Jambu-jambu (jambu hutan)	*Syzygium* sp.	Myrtaceae
19	Jarum	*Dysoxylum* sp.	Rubiaceae
20	Jelutung	*Dyera costulata*	Apocynaceae
21	Juangi (juani)	unknown	unknown
22	Kabuton	unknown	unknown
23	Kapur	*Dryobalanops sumatrensis*	Dipterocarpaceae
24	Kayu hitam	*Diospyros transitoria*	Ebenaceae
25	Keruing	*Dipterocarpus alatus*	Dipterocarpaceae
26	Kulit (medang wangi)	*Beilschmiedia micrantha*	Lauraceae
27	Lapak (kayu lapan)	*Astronia macrophylla*	Melastomataceae
28	Lapak (kayu lilin)	*Aglaia leptantha*	Meliaceae
29	Lobo (lomo)	*Atuna racemosa*	Chrysobalanaceae
30	Majau (meranti majau)	*Shorea johorensis*	Dipterocarpaceae
31	Mengkuom (mengkuang)	*Dysoxylum densiflorum*	Meliaceae
32	Meranti merah (tua)	*Shorea* sp.	Dipterocarpaceae
33	Meranti Putih	*Shorea* sp.	Dipterocarpaceae
34	Nyantu (jelutung paya)	*Dyera polyphylla*	Apocynaceae
35	Pilipikan (lilipga)	*Hopea iriana*	Dipterocarpaceae
36	Pisang-pisang	*Alphonsea* sp.	Annonaceae
37	Plaju (Pilajau)	*Myristica crassa*	Anacardiaceae
38	Rengas	*Gluta curtisii*	Anacardiaceae
39	Sedaman	*Macaranga* sp.	Euphorbiaceae
40	Selangan batu (seranggap)	*Hopea* sp.	Dipterocarpaceae
41	Sepetir	*Copaifera palustris*	Leguminosae
42	Telantang (terentang)	*Campnosperma* sp.	Anacardiaceae
43	Tengkawang biasa	*Shorea pinanga*	Dipterocarpaceae
44	Terap hutan	*Artocarpus* sp.	Moraceae
45	Tigalangan	unknown	unknown
46	Tipulu	*Artocarpus teysmannii*	Moraceae
47	Ulin	*Eusideroxylon zwageri*	Lauraceae

B2. Logged-over-forest aged 11-30 years

No	Local Name	Latin name	Familly
1	Bayur	*Pterospermum* sp.	Sterculiaceae
2	Bengkirai	*Shorea laevis*	Dipterocarpaceae
3	Dara-dara	*Knema* sp.	Myristicaceae
4	Ipil	*Intsia* sp.	Leguminosae
5	Kapur	*Dryobalanops sumatrensis*	Dipterocarpaceae
6	Keruing	*Dipterocarpus alatus*	Dipterocarpaceae
7	Meranti merah	*Shorea* sp.	Dipterocarpaceae
8	Pala-pala	*Myristica crassa*	Myristicacea
9	Rambutan	*Nephelium lappaceum*	Sapindaceae
10	Resak	*Shorea maxima*	Dipterocarpaceae
11	Resak bukit	*Cotylelobium lanceolatum*	Dipterocarpaceae
12	Sedaman	*Macaranga* sp.	Euphorbiaceae
13	Tailan (Jabon)	*Anthocephalus chinensis*	Rubiaceae
14	Ulin	*Eusideroxylon zwageri*	Lauraceae

B3. Logged-over-forest aged 31-50 years

No	Local Name	Latin name	Familly
1	Dara-dara (mendarahan)	*Knema* sp.	Myristicaceae
2	Gaharu (gaharu buaya)	*Gonystylus bancanus*	Thymelaceae
3	Kapur	*Dryobalanops sumatrensis*	Dipterocarpaceae
4	Meranti Kuning	*Shorea* sp.	Dipterpcarpaceae
5	Meranti Merah	*Shorea* sp.	Dipterpcarpaceae
6	Meranti merah (tua)	*Shorea curtisii*	Dipterpcarpaceae
7	Meranti Putih	*Shorea* sp.	Dipterpcarpaceae
8	Meranti rawa	*Shorea hemsleyana*	Lauraceae
9	Nyatoh	*Chrysophyllum* spp.	Sapotaceae
10	Pala	*Myristica crassa*	Myristicacea
11	Patag (petai hutan)	*Parkia* sp.	Fagaceae
12	Sadaman	*Macaranga* sp.	Dipterpcarpaceae
13	Tengkawang biasa	*Shorea pinanga*	Dipterpcarpaceae
14	Ulin	*Eusideroxylon zwageri*	Lauraceae

C1. Agroforestry syestems aged 0-10 years

No	Local Name	Latin name	Familly
1	Durian	*Durio zibethinus*	Bombacaceae
2	Gmelina	*Gmelina arborea*	Verbenaceae
3	Kemiri	*Aleurites moluccana*	Euphorbiaceae
4	Langsat	*Lansium domesticum*	Meliaceae
5	Mangga	*Mangifera indica*	Anacardiaceae
6	Nangka	*Artocarpus heterophyllus*	Moraceae
7	Rambutan	*Nephelium lappaceum*	Sapindaceae

C2. Agroforestry syestems aged 11-30 years

No	Local Name	Latin name	Familly
1	Baling Kudung	*Buchanania* sp.	Anacardiaceae
2	Bayur	*Pterospermum* sp.	Sterculiaceae
3	Bunyu	*Mangifera* sp.	Anacardiaceae
4	Cempedak	*Artocarpus integer*	Moraceae
5	Kutang	unknown	unknown
6	Durian	*Durio zibethinus*	Bombacaceae
7	Elai	*Durio malacensis*	Bombacaceae
8	Gamal	*Gliricidia sepium*	Leguminosae
9	Gambil (siri-sirian)	*Pternandra azurea*	Melastomataceae
10	Gambiran	*Glochidion rubrum*	Euphorbiaceae
11	Jambu-jambuan	*Syzygium* sp.	Myrtaceae
12	Kelapa	*Cocos nucifera*	Palmae
13	Klamuku (rambutan hutan)	*Nephelium cuspidatum*	Sapindaceae
14	Kopi	*Coffea* sp.	Rubiaceae
15	Langsat	*Lansium domesticum*	Meliaceae
16	Lindungu	*Bruguiera* sp.	Rhizophoraceae
17	Lepeu	*Bauhinia semibifida*	Leguminosae
18	Mangga	*Mangifera indica*	Anacardiaceae
19	Perupuk	*Lophopetalum* sp.	Celastraceae
20	Pinang	*Areca catechu*	Palmae
21	Polod (aren)	*Arenga pinata*	Palmae
22	Rambutan	*Nephelium lappaceum*	Sapindaceae
23	Sedaman	*Macaranga* sp.	Euphorbiaceae
24	Talisei	*Terminalia subspathulata*	Combretaceae
25	Tato	unknown	unknown
26	Terap	*Artocarpus* sp.	Moraceae
27	Tibangu	unknown	unknown
28	Tinggegayang	unknown	unknown
29	Tolonsob	*Pterocymbium tinctorium*	Sterculiaceae
30	Tontianak	unknown	unknown

D1. *Jakaw* systems aged 0 - 10 years.

No	Local Name	Latin name	Familly
1	Ambalu logon	*Anthocephalus* sp.	Rubiaceae
2	Abung	*Ficus* sp.	Moraceae
3	Apas-apas	unknown	unknown
4	Bayur	*Pterospermum* sp.	Sterculiaceae
5	Benua	*Macaranga triloba*	Euphorbiaceae
6	Bintangur	*Calophyllum* sp.	Guttiferae
7	Bolo	*Alphonsea* sp.	Annonaceae
8	Bumbungalin	unknown	unknown
9	Dara - dara	*Knema* sp.	Myristicaceae
10	Emas	unknown	unknown
11	Gita	*Ficus glomerata*	Moraceae
12	Gadigading	*Muraya paniculata*	Rutaceae
13	Pulai	*Alstonia* sp.	Apocynaceae
14	Intut	*Palaquium quercifolium*	Sapotaceae
15	Ipil	*Intsia* sp.	Leguminosae

D1. *Jakaw* systems aged 0 - 10 years. *(Lanjutan)*

No	**Local Name**	**Latin name**	**Familly**
16	Jabon	*Anthocephalus chinensis*	Rubiaceae
17	Jambu-jambu	*Syzigium* sp.	Myrtaceae
18	Junod	*Aniba* sp.	Lauraceae
19	Kapur	*Dryobalanops sumatrensis*	Dipterocarpaceae
20	Kekatung (MM)	*Shorea curtisii*	Dipterocarpaceae
21	Keling	*Artocarpus ovatus*	Moraceae
22	Kibalow	*Shorea argentifolia*	Dipterocarpaceae
23	Kucing (MM)	*Cratoxyllum* sp.	Guttiferae
24	Kutang	unknown	unknown
25	Kusiak	unknown	unknown
26	Lai	*Durio malacensis*	Bombacaceae
27	Lindungu	*Bruguiera* sp.	Rhizophoraceae
28	Manik -Manik	unknown	unknown
29	Ogot	unknown	unknown
30	Sedaman	*Macaranga* sp.	Euphorbiaceae
31	Susunod	unknown	unknown
32	Tali/Balinsakad	*Artocarpus atilis*	Moraceae
33	Talisei	*Terminalia subspathulata*	Combretaceae
34	Talutu	unknown	unknown
35	Tambalogon	*Bombax ceiba*	Bombacaceae
36	Tanakal	unknown	unknown
37	Tatalad	unknown	unknown
38	Tindaka	unknown	unknown
39	Tinggegayang	unknown	unknown
40	Togop	unknown	unknown
41	Tolonsop	*Pterocymbium tinctorium*	Sterculiaceae
42	Ulin	*Eusideroxylon zwageri*	Lauraceae
43	Pisang hutan	*Musa* sp.	Musaceaea

D2. *Jakaw* systems aged more than 10 years.

No	**Local Name**	**Latin name**	**Familly**
1	Abung	*Ficus* sp.	Moraceae
2	Apulakit	unknown	unknown
3	Bayur	*Pterospermum* sp.	Sterculiaceae
4	Bintangur	*Calophyllum* sp.	Guttiferae
5	Bislang	unknown	unknown
6	Bubuanak	unknown	unknown
7	Bulinti	unknown	unknown
8	Kaputan	unknown	unknown
9	Kubi	unknown	unknown
10	Langsat	*Lansium domesticum*	Meliaceae
11	Lepeu	*Bauhinia semibifida*	Leguminosae
12	Pisang-pisang	*Alphonsea* sp.	Annonaceae
13	Rambutan	*Nephelium lappaceum*	Sapindaceae
14	Sadaman	*Macaranga* sp.	Euphorbiaceae
15	Tanakal	unknown	unknown
16	Terap	*Artocarpus* sp.	Moraceae
17	Tibangu	unknown	unknown
18	Tolonsop	*Pterocymbium tinctorium*	Sterculiaceae
19	Ulin	*Eusideroxylon zwageri*	Lauraceae

Appendix 3. Listing of sample points for the regression of aboveground C stock on NDVI

No.	Easting	Northing	Location	Landcover	Carbon density measured (Mg ha-1)*	NDVI03
1	498670	457071	Kalun Sayan	Imperata	2.06	44
2	497447	422652	Manuk Bungkul	2-yr-old abandoned jakaw	2.32	45
3	497436	422662	Manuk Bungkul	2-yr-old abandoned jakaw	2.32	45
4	496304	436179	Kunyit	2-yr cropped jakaw, rice	2.27	52
5	498191	422694	Manuk Bungkul	3-yr cropped jakaw, rice	2.40	59
6	497419	422649	Manuk Bungkul	2-yr-old abandoned jakaw	8.82	64
7	485760	419370	Tanjung Harapan	6-10-yr old abandoned jakaw	58.75	65
8	496957	421936	Manuk Bungkul	3-yr-old abandoned jakaw	8.02	66
9	496957	421854	Manuk Bungkul	3-yr-old abandoned jakaw	8.02	66
10	480505	417490	Tanjung Harapan	5-yr-old abandoned jakaw	16.28	66
11	480414	417590	Tanjung Harapan	5-yr-old abandoned jakaw	16.78	66
12	498527	451997	Sekikilan	1-yr-old abandoned jakaw	4.18	67
13	480985	418710	Tanjung Harapan	6-10-yr cropped jakaw	5.41	67
14	497235	422041	Manuk Bungkul	3-yr-old abandoned jakaw	12.06	67
15	498603	451246	Sekikilan	4-10-yr logged over area	104.78	67
16	503632	427741	Atap	11-30-yr logged over area	205.12	68
17	499463	451897	Sekikilan	> 10-yr old abandoned jakaw	48.03	69
18	499390	451863	Sekikilan	> 10-yr old abandoned jakaw	77.38	69
19	503625	427654	Atap	11-30-yr logged over area	176.78	69
20	479509	436626	Sujau	0-3-yr logged over area	222.25	69
21	503594	427669	Atap	11-30-yr logged over area	227.89	69
22	479475	436480	Sujau	0-3-yr logged over area	232.49	70
23	497686	423021	Manuk Bungkul	Agroforest 11 - 20 yrs	34.45	71
24	497725	422993	Manuk Bungkul	Agroforest 11 - 20 yrs	62.83	71
25	497694	423055	Manuk Bungkul	Agroforest 11 - 20 yrs	87.21	71
26	485993	419545	Tanjung Harapan	6-10-yr old abandoned jakaw	42.05	72

* c-stock measured from tree biomass and understorey