

Carbon Stocks Monitoring in Nunukan, East Kalimantan: A Spatial and Modelling Aproach

Report from Carbon Monitoring Team of The Forest Resources Management for Carbon Sequestration (FORMACS) Project

Edited by
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WORLD AGROFORESTRY CENTRE

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Cover photos:

Front Cover: Left: A farmer of Nunukan conducting a carbon sampling activity (*CARE International Indonesia*); Middle: A monoculture pepper plantation in Lubok Buat Village, Sembakung (*Kusuma Wijaya*); Right: A *jakaw* systems during fallow period along the Sembakung river (*Kusuma Wijaya*); Background: Forest of Nunukan (*CARE International Indonesia*)

Back Cover: Left: Logged wood ready for transportation, Sebuku River (*Kusuma Wijaya*); Middle: *Jakaw* systems just after slash and burn, Tanjung Harapan Village, Sembakung (*Kusuma Wijaya*); Right: A rain-fed paddy field (*CARE International Indonesia*)

Inside Cover: Local children playing with canoe along the Sembakung river, an agroforestry system in the background (*Kusuma Wijaya*)

Lay-out & cover design: Dwiati Novita Rini

TABLE OF CONTENTS

PREFACE

This report compiles a number of studies conducted by the Carbon Monitoring team under the Forest Resources Management for Carbon Sequestration (FORMACS) Project. This project was funded by CIDA and implemented by CARE International Indonesia in Nunukan, East Kalimantan. The report describes the process of a Rapid Carbon Stocks Appraisal (RaCSA) approach that is developed by the World Agroforestry Centre (ICRAF).

There are four main activities carried out under the Rapid Carbon Stocks Appraisal approach:

- A household socio-economic survey that describes the livelihood strategies, especially those pertaining to land use and the key drivers of change
- Carbon stocks measurement of representative land cover units
- Remote Sensing imagery and spatial analysis of land-use/land cover change
- Modelling of carbon stock dynamics in the landscape in response to plausible 'scenarios' or changes in the key driver variables

The activities were carried out by three organisations: Hatfindo, World Agroforestry Centre (ICRAF) and CARE International Indonesia. Hatfindo and Buana Khatulistiwa were responsible for the land cover and land use change analysis including map production. ICRAF designed the socio-economic survey, provided the protocol to measure carbon stocks, assisted the land cover analysis and performed the modelling analysis. CARE International Indonesia conducted the household survey and carbon measurements in the field.

We would like to thank CARE International Indonesia field staffs who took care of the field work, measurements and data collection for this report: Abdul Azis, Ansori, Basuki Budi Santoso, Darmawan Setia Budi, Debit Losong, Dewi Maharani, Eko Sugiharto, Iwantoro, Joned, Jimmy Sukaputra, Nurhayati, Pery, Rico Sukaswanto, Welly Brodus. Special thanks are also due to Susilo Ady Kuncoro who provided comments on Chapter 1 and Iwan Kurniawan for sharing his ideas on spatial pattern similarity (Chapter 5).

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The editors

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1. INTRODUCTION: WHY MONITOR CARBON IN NUNUKAN?

Betha Lusiana, Garry A. Shea and Meine van Noordwijk

Land Use Change as Source of CO_2 Emission

In the last two decades climate change has become a prominent issue for the global community. During the last century the mean temperature of the earth has increased by 0.6 ºC and the rate of change appears to increase. An increase of the atmospheric concentration of the greenhouse gases (GHG), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are identified as the main factor causing global warming. During the last decade net CO_2 emission doubled from 1400 million Mg year^{-1} to 2900 million Mg year^{-1}. Meanwhile, the CO_2 concentration in the atmosphere in 1998 was 360 ppmv, up from a value of 280 ppmv a century earlier, with a yearly increment of 1.5 ppmv (Houghton *et al*., 2001).

The elevated CO_2 concentration in the atmosphere is largely caused by human activities, particularly land use change and use of fossil fuel for transport, power generation and industrial activities. Accumulatively, the use of fossil fuel and forest conversion to other land use have both been responsible for about half of the human-induced CO_2 emission to the atmosphere, but the current impact is in a ratio of 3:1. Burning fossil fuel means returning carbon to the atmosphere that was fixed by plants in the geological past. Forest conversion and land use change imply that carbon stored as plant biomass or in (peat) soils is released to the atmosphere through burning ('slash and burn') or decomposition of organic matter above and below ground. Logging removes stored carbon from the landscape, often resulting in rapid return to the atmosphere, depending on the use of wood. It is estimated that between 1990 - 1999, land use change has contributed around 1.7 Gt year^{-1} to total CO_2 emission (Watson *et al*., 2000).

Acknowledging this global problem of human-induced ('anthropogenic') climate change, the Rio de Jainero Conference of 1992 identified CO_2 emissions to the atmosphere as one of the major global environmental issues of concern. World leaders adopted the United Nations Framework Convention on Climate Change (UNFCCC) that sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. The Kyoto protocol that came into force on February 17 2005 was developed as the first concrete step towards implementing efforts to stop the growth in emissions and return net emissions from the industrialized countries to below 1990 levels. As land use change can be both a source and a sink of atmospheric CO_2, the rates of deforestation and the regrowth of woody vegetation are part of the global debate.

Activities and projects that enhance afforestation and reforestation (AR) or avert deforestation (ADEF) can both reduce net CO_2 emissions, but have a different policy context from changes in fossil fuel use. AR activities are defined as human-induced conversion of non-forest land use to forest, through planting seedlings and/or promotion of natural seed sources. ADEF projects are defined as activities that prevent carbon emission by protecting a forest threatened by deforestation or degradation. Smith and Scherr (2003) provide an in-depth study on risks and benefits of both projects. The Kyoto protocol makes a distinction between industrialized ('Annex I') countries who are obliged to account for all changes in carbon stocks as well as fossil fuel emissions, and developing countries without current obligation to reduce net emissions. In the debate on the global regulatory framework of net greenhouse gas emissions the relative merits of ADEF and AR in developing countries are still contested, as are the *de facto* opportunities to influence these processes. Especially for ADEF, there is little experience of how it can be achieved.

The Forest Resources Management for Carbon Sequestration (FORMACS) Project

The Forest Resources Management for Carbon Sequestration (FORMACS)[1] Project, funded by CIDA and implemented by CARE International Indonesia is an example of an ADEF project. FORMACS focuses its work on managing existing forest resource for carbon sequestration and storage by adopting socially acceptable programs of community-based management. Specifically, it promotes sustainable livelihoods through sustainable agriculture, agroforestry and sustainable forest management practices for the maintenance of existing carbon stocks and for the sequestration of atmospheric carbon. Community based project, such as agroforestry, small-scale plantations, agroforests and secondary forest fallows have the highest potential for providing local livelihood benefits along with enhanced carbon storage and pose the fewest risks to communities (Smith and Scherr, 2003).

The FORMACS project study area is in Kabupaten Nunukan of East Kalimantan Province, Indonesia, specifically in Sebuku and Sembakung sub-district. The Nunukan area was a suitable and potential area to implement an ADEF project because of the following factors:

1. Forest conversion

Indonesia is ranked 9th amongst all the countries worldwide in GHG emissions (Brookfield, Potter and Byron, 1995) and over half of its emissions are due to forest conversion for agriculture, plantations, and timber production. Approximately 2 million ha of forest is currently being logged or converted each year, releasing an enormous amount of previously bound carbon into the atmosphere and reducing sequestration capacity. Although in the Kabupaten Nunukan forest conversion has not been extensive (within the project area, it is limited to transmigration areas), there are proposals for forests to be converted for plantations (primarily oil palm), agriculture, shrimp ponds (coastal mangrove) or mining. Proposals for converting forests to other land use pose a risk to carbon sinks, and may have other negative environmental impacts. In 1990 the district still had a forest cover of 98%. The mean population density in the district of 5 persons km^{-2} is substantially below the average for Kalimantan of 34 persons km^{-2}.

Community Based Natural Resource Management (CBNRM) has the potential to limit forest conversion and maintain the forests for multiple uses, including timber production, production of non-timber forest products, conservation of biodiversity, providing a corridor between protected areas,

[1] See http://www.rcfa-cfan.org/english/profile.19.htm for more information abut this project.

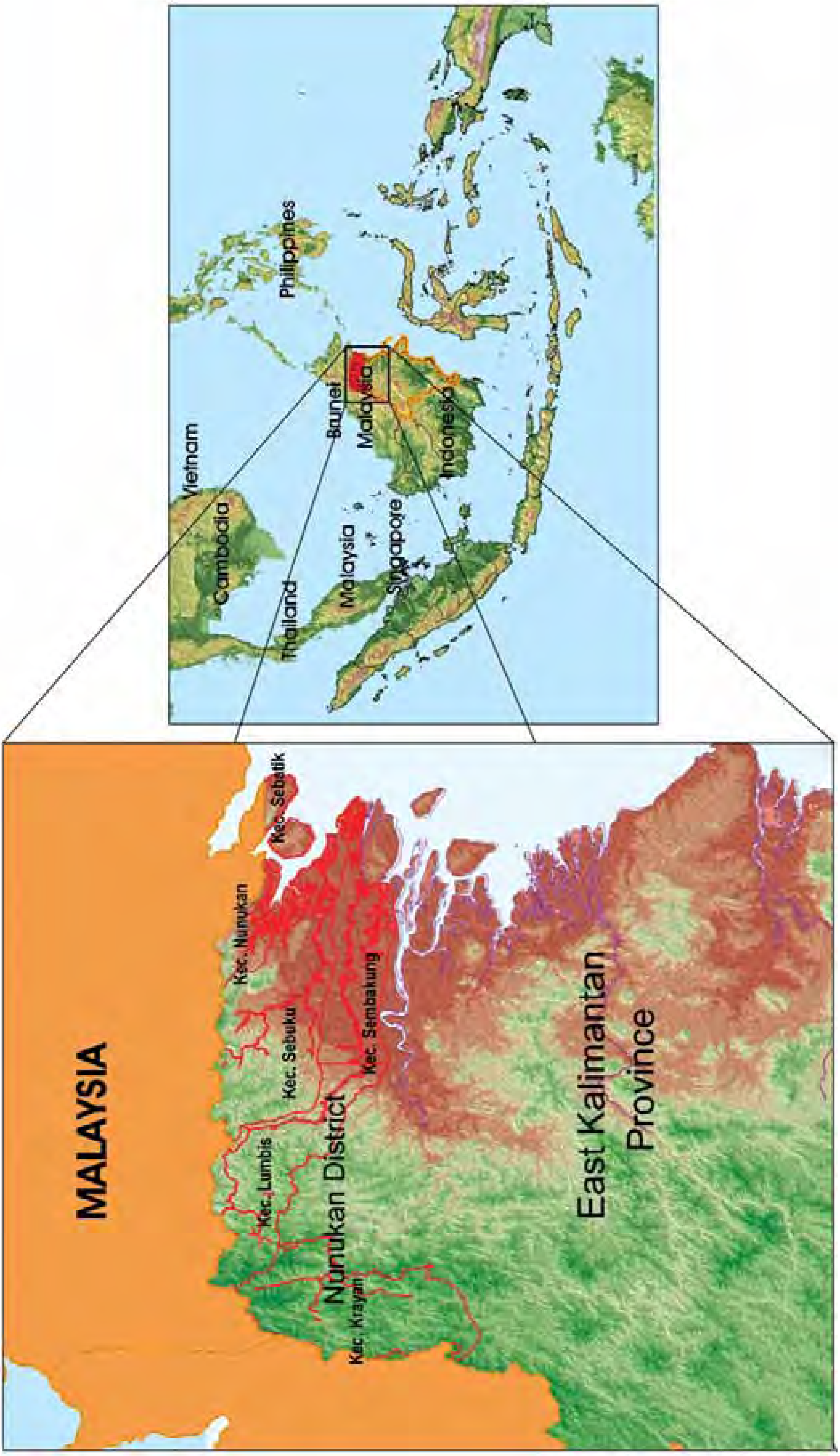


Figure 1.1. Map of Nunukan, East Kalimantan. The study site of the FORMACS project

maintaining watershed functions and maintenance of carbon stocks.

2. Illegal logging

It is estimated that more than 70% of the timber used in and exported from Indonesia comes from illegal logging, and that illegal logging is destroying at least 700,000 ha of tropical forests a year. Illegally logged timber is being smuggled to Malaysia where it is processed and exported to the US, Japan, Europe and China. Approximately five million cubic metres of timber flows into Malaysia each year (EIA and Telapak Indonesia, 2001). Besides causing loss of biodiversity and ecological damage to the ecosystem, illegal logging also leads to economic and health costs resulting from fires associated with land use change and land clearing which often follows illegal logging. A low-end estimate of royalties, reforestation fund and export taxes payments that are not being paid to the Government of Indonesia (GOI) on timber stolen each year amounts to US$600 millions[2].

The situation in the Kabupaten Nunukan mirrors the national problem and reflects the same issues. The situation is magnified by the District's close proximity to the state of Sabah in East Malaysia. Saw logs continue to flow over the border in spite of the ban on log exports.

The FORMACS Project addressed the issue of illegal logging at the village, sub-district and district level, where it can most likely have impacts. At present, forests under concessions granted to large companies are viewed as open-access resources where people are competing to get a share of the resources before someone else takes the resources. The way forward is to change this concept to community-based forest management, where the forests are allocated to indigenous communities. The resources will then have recognized local owners, with adat regulation of the use rights of the resources, and the people will guard their own resources. This will mean indigenous communities working in cooperation with local law enforcement and government agencies.

The forest lands adjacent to most villages have been logged-over by forest companies, and the availability of timber is on the decline. Once the area has been completely logged and the most valuable commercial timber removed, illegal logging becomes less an issue. As the local people know that they can no longer depend on illegal logging for a livelihood, sustainable agriculture and community-based forestry activities, are perceived as viable alternatives. CBNRM will be able to provide the people with economic alternatives to illegal logging and to shift forest management from large-scale industrial forest management, to small-scale multi-purposed management which combines timber production with the conservation of biodiversity, the maintenance of ecosystem functions, and carbon sequestration.

3. Fire

Large-scale fires and droughts have devastated parts of East Kalimantan over the past two decades. Although fires occur yearly, large-scale fires are related to the ENSO (El Niño Southern Oscillation), which currently has a three to five year cycle. During the fire event in 1997/1998, the amount of carbon released to the atmosphere as a result of burning peat and vegetation in Indonesia was estimated between 0.81 and 2.57 Gt (Page *et al.*, 2002). This is equivalent to 13-40% of the mean annual global carbon emissions from fossil fuels, and contributed greatly to the largest annual increase in atmospheric CO_2 concentration detected since records began in 1957 (Houghton *et al.*, 2001) The majority of

[2] Press release from the World Bank on Decalaration of Forest Law Enforcement and Governance http://siteresources.worldbank.org/INTINDONESIA/FLEG/20172547/FLEG+Conference+Press+Release.pdf. Accessed on 21 March 2005

these fires occurred in managed or degraded lands: agriculture, logged-over forests, scrub forest and grassland (Tacconi, 2003). Almost all fires were started intentionally to clear land for planting, primarily for large plantations, but also for slash and burn agriculture. Arson was also a factor, as local people used fire as a weapon to resolve conflicts (Tomich *et al*., 1998).

Generally, few fires are able to invade good quality forest, due to its higher humidity levels and low levels of dry undergrowth for fuel, but in the later phase of the 1997/1998 fire event in Kalimantan unlogged forests fell victim as well. Addressing issues related to forest conversion, degradation of forests from legal and illegal logging and preserving areas of natural forests as natural fire breaks are important for the maintenance of carbon stocks within existing sinks and increasing carbon sequestration in logged-over forests.

4. Land tenure and local institutional capacity

Land tenure, especially in relation to forest lands, is not clearly defined in the Kabupaten Nunukan, and this threatens the existence of forests as carbon sinks. This situation is similar to the land tenure situation throughout East Kalimantan. Security of tenure is a pre-requisite for CBNRM, since it provides the incentive for maintaining the resource and for reforestation. Land use planning and subsequent regulation of land tenure by the community together with government institutions provides the basis for land use activities such as agriculture, agroforestry, reforestation, industrial plantations and natural forest management. This process results in the legalizing of participatory land use plans and adat-based land tenure on state-owned land. Thus, the FORMACS Project is approaching the land tenure issue through building the capacity of local government and people on land use planning and institutional capacity as well as facilitating dialogue between the two parties. The new paradigm in governance, District Autonomy, provides a conducive condition that enables local government and local people to reach mutual and beneficial understanding.

5. Current agricultural practices

Current farming systems are based mainly on slash and burn agriculture, and the use of steep slopes and land adjacent to rivers and streams. In the past, when natural forests were extensive and under-utilized, shifting cultivation was a viable and sustainable land use system. However, this changed in the 1960s when most of the lowland forests in Kalimantan (and other parts of Indonesia) were declared 'state forests' and given to forest companies in the form of forest concessions. Under this system, the government recognized lands under permanent cultivation (food crops and tree crops) as agricultural lands belonging to traditional communities, but did not recognize long-term fallows as agricultural lands belonging to the community. Thus, in the Project area, the best way for traditional communities to gain recognized use rights for land is to plant tree crops along with food crops (mixed cropping) and leave the trees to grow once the field is no longer used for food crops. This is important since target villages are located in an area with considerable potential for agricultural development. The proposed Trans-Kalimantan Highway will transect the area, opening it up for development. If the local people fail to take advantage of the economic potential of the area and establish use rights through the planting of trees, outside people will.

The FORMACS Project aims to help local people establish use rights over their traditional lands, and develop the economic potential of the land, while maintaining carbon stocks. To achieve this the FORMACS Project, in cooperation with local communities, developed agroforestry, tree-crop agriculture and low external input sustanable agriculture (LEISA) technologies that also complement the effort for community-based forest management. The use of these technologies will also reduce the use of fire as a tool in local land use systems, reducing fire risks.

6. Lack of economic alternatives

According to the Indonesian Bureau of Statistics, in 1998 mining (31.7%) and manufacturing (42.8%) are the most important inputs to the Gross Domestic Regional Product of East Kalimantan. The majority of the medium and large-scale manufacturing sector is based on wood and pulp products. Although the province is extremely wealthy in natural resources, the local population is largely marginalized with little access to proper health care, education and extension services for improving agricultural production. Cutting timber has been seen as the answer to economic problems by both local communities and local governments. This was the case in the Sebuku and Sembakung area where, until recently, household incomes were largely dependent on illegal logging, and food supplies from small-scale agriculture. However, the supplies of commercial size timber are being exhausted at a rapid rate, and it is now difficult for villagers to gain sufficient income from timber to meet their family's basic needs.

Villagers and district government are aware that timber can no longer be relied upon as the sole source of family income. At this point in time, agricultural development is the main alternative for generating local resources. However, because of distance and transportation costs, agricultural options are also limited.

The FORMACS Project and its partners carried out research on local commodities and marketing that served to identify commodities that are suitable for the project area. Opportunities for ecotourism based on conservation of resources, including biodiversity, were also explored through workshops and awareness campaigns. District government and local people are becoming more aware of the potential benefits that can come from the conservation of natural ecosystems.

Figure 1.2 described schematicaly the framework of FORMACS activities. Simply put, FORMACS activities are based on providing the local people with better livelihood options that can suppress drivers of forest conversion and will lead to poverty reduction as well as carbon stocks increment.

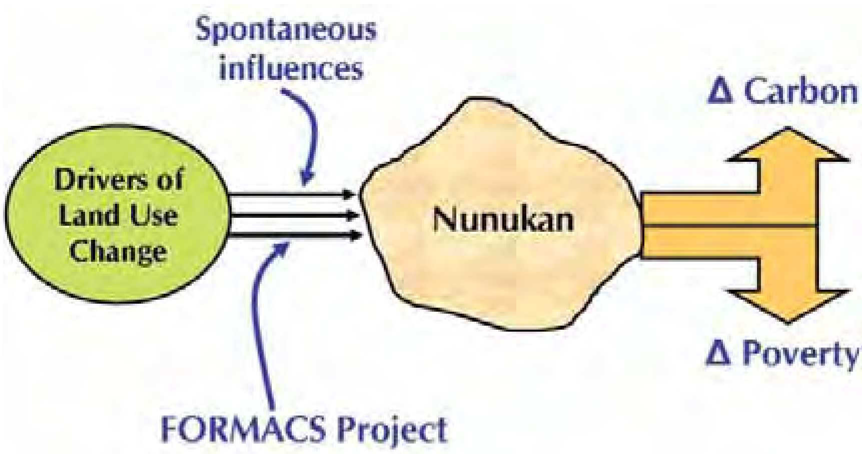


Figure 1.2. Schematic diagram of the FORMACS project framework

Carbon Monitoring Activities in Nunukan

FORMACS recommended agroforestry, tree-crop agriculture and low external input sustainable agriculture (LEISA) technologies as options to the farmers in managing their land. The rationale of this recommendation is that these options would provide sustainable livelihood for the farmers as well as increase or maintain carbon sequestration.

The performance of these recommended land use systems that are expected to function as carbon sinks need to be asssesed and monitored. This process is dealt with in carbon monitoring activities. As the project interventions were targeting the district as a whole and there are many interactions in land use change linked to the opportunities for the local community to obtain returns to their labour, the assessment of net effects of project interventions has to be done at (sub) district scale.

Ponce-Hernandez *et al.* (2004), developed methods, models and software tools to assess carbon stocks and design scenarios using projects in Mexico and Cuba as an example. Their methods integrate the use of biophysical assesment and land use change models.

The FORMACS project implemented the Rapid Carbon Stocks Appraisal (RaCSA)[3] approach to monitor carbon stocks in Nunukan. The carbon monitoring activity using the RaCSA approach has three main objectives:

1. To estimate carbon stocks in Nunukan for the main land use practices at plot level as well as their integration at landscape level.
2. To assess the performance of existing land use systems managed by farmers in Nunukan as carbon sinks.
3. To appraise landscape carbon stocks dynamics in Nunukan in relation to 'drivers' of change, as a basis for selecting interventions that enhance people's welfare as well as the carbon stocks of the area.

To achieve these objectives four activities were carried out:

1. Socio-economic survey at household level. This was conducted in Sebuku and Sembakung sub-district, to explore the land use systems managed by farmers in the area as well as their productivity and profitability. The productivity and profitability of a land use system are considered as part of the main factors that drives farmers to practice it in his land. Thus, these factors also determine the amount of carbon sequestered or maintained over time.
2. Carbon stocks measurement at plot level. Samples plot were set up at each existing land use systems in the study area. Carbon stocks were measured and will become the basis for assessing the performance of each land use systems to function as carbon sinks.
3. Land use/land cover change using remote sensing analysis.
   Satellite images were obtained and analyzed to produce land cover maps of Nunukan. Land cover change are estimated using land cover maps from two different periods. Using the result from plot level study of carbon stocks (activity 2), landscape level carbon stocks and its changes over a period of time can be estimated.
4. Landscape simulation modelling.
   To predict the dynamics of landscape carbon stocks, a landscape simulation model FALLOW[4] was applied. This model

[3] Rapid Carbon Stocks Appraisal (RaCSA) is developed by ICRAF to assess carbon stocks in a landscape. ICRAF has also developed Rapid Hydrological Appraisal (RHA) to asses hydrological function of a watershed and the impacts of land use change on key functions. Currently being tested and developed is a Rapid (Agro)Biodiversiy Appraisal (RaBA) method to asses biodiversity of a landscape from local well as external perspectives. These are three basic tools that can be used to assess environmental services of a given area.

[4] FALLOW (Forest, Agroforest, Low-value Land Or Waste-land?) is a landscape dynamic model developed by ICRAF. For more information see http://www.worldagrofrestrycentre.org/sea/products/models

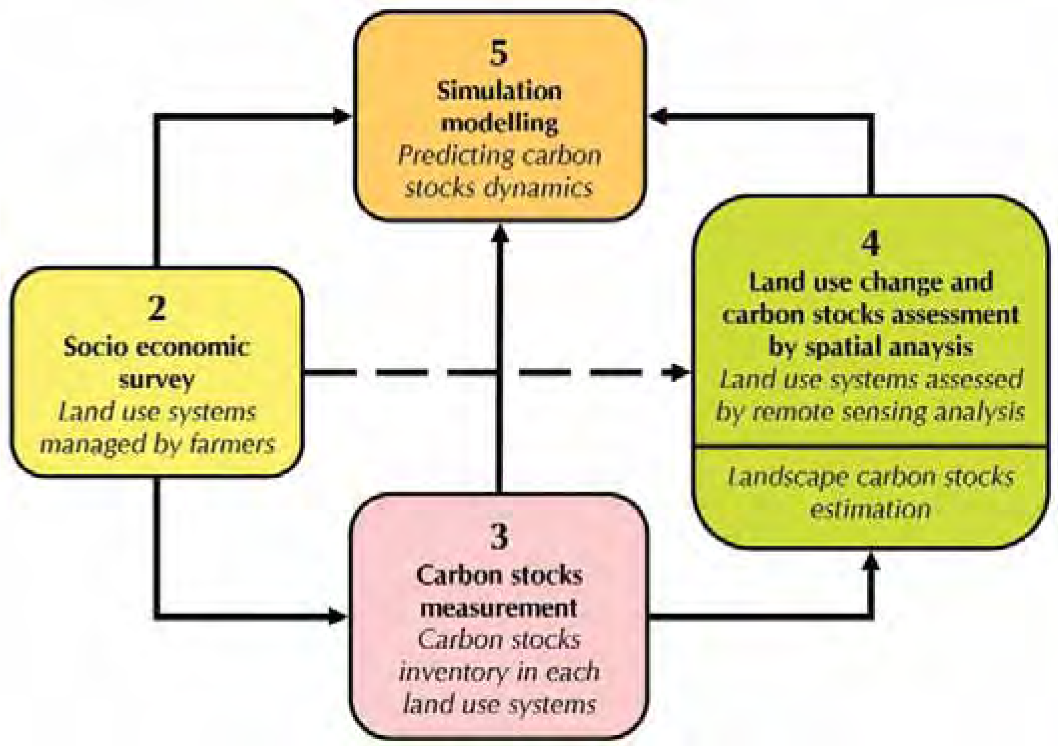


Figure 1.3. Link between the various chapters in this report (number in the figure refers to chapter number in this report).

simulates the impact of farmers decision in managing their land to the landscape carbon stocks dynamics. A range of possible pathways that farmers may decide to act in response to existing opportunity were evaluated.

The four activities within the RaCSA activity are compiled in this report. Figure 1.3 shows how the various activities and chapters in this report are linked together.

Chapter 2 provides a background on Nunukan as the study site for this project and describes the main land use systems that exist and managed by farmers. Carbon stocks measured in the various land use systems is reported in Chapter 3. This chapter also analyzed the performance of each land use systems in sequestering carbon over time. In addition to that, the chapter documented tree species found in each land use systems.

Chapter 4 describes carbon stocks assesment at landscape level using remote sensing analysis. A simulation modelling activity that integrates all the results obtained from Chapter 2, 3 and 4 is reported in Chapter 5. The activity simulates the carbon stock dynamics as the landscape changes over time due to farmers behaviour in adjusting their options to manage their land.

The studies reported here is an example of an integrated approach to carbon monitoring being applied in the field. The outcomes of this activity, that is estimation carbon stocks dynamics over a range of possible pathways, are expected to provide a starting point for dialogue with farmers on the range of options that are beneficial for their livelihood and environment. It is also a starting point for dialogue with policy makers at local as well as national level, on providing the local people with policies that enable them to manage their land and its surroundings in sustainable ways.

2. LIVELIHOOD OPTIONS AND FARMING SYSTEMS IN THE FOREST MARGINS OF NUNUKAN, EAST KALIMANTAN

Kusuma Wijaya, Nessy Rosdiana and Betha Lusiana

Introduction

The relationship between peoples' livelihood and their management of natural resources has been the main focus of organizations dealing with conservation and sustainable use of natural resources. Agriculture and forests provide an essential contribution to the resilience of many indigenous resource use systems. Forest products constitute a source of emergency food for people living in the forest margins, while economic valuable forest products provided cash through the sale of their products. In the past, natural resource extraction was aimed only to fulfill peoples' basic needs in subsistence economy, although exchange and market are older than what often presumed (Levang *et al.*, 2005). However, population pressure, process of commercialization (as consequence of economic growth) and political-economic conditions are drivers that have changed the way people managing their natural resource (Bilsborrow and Okoth-Ogendo, 1992).

Levang *et al.* (2005) discussed the importance of forest for the local community, the Punan hunter gatherers, living in East Kalimantan. Using the Punan case as an example, the paper critically questioned the widely accepted belief that forest people depend on forests for their livelihoods and rapid pace of deforestation will lead them to poverty.

Protection of the environment is crucial to deal with global concern such as global warming. At the regional and local level, concern is raised about improving livelihoods of local communities as a result of on-going changes within society at local and global levels. The FORMACS (Forest Resource Management for Carbon Sequestration) Project in Kabupaten Nunukan, East Kalimantan is aimed to bridge both global and local concerns. It focuses on providing the indigenous people with sustainable livelihood options at the same time sustaining the function of forest ecosystems in maintaining the carbon stocks, as one of the way to mitigate global warming problem. Consequently, an understanding of forest land use decisions by the local people is an important part of the project.

This paper described the result of a rapid household socio-economic survey conducted in the forest margin villages of Kabupaten Nunukan. The objective of the survey is to gain information on the socio-economic background of farmers and the systems they managed in their landscape. Combined with secondary data, this study will be able to provide information on:

1. Profile of farmers
2. Farmers activities to sustain their livelihood
3. The land use systems managed by farmers and the products and income derived.

This information will be used to simulate the dynamics of the landscape over time as a result of changes in the way people manage their natural resources, with implications for farmers livelihood in Chapter 5 of this report.

Methods

A rapid socio-economic survey was conducted in the FORMACS study area, Kecamatan Sebuku and Sembakung of Kabupaten Nunukan. The respondents were 51 households from 10 villages within the area: Kalun Sayan, Sekikilan, Sujau and Tau Baru village in Sebuku and Atap, Katul, Lubok Buat, Manuk Bungkul, Tanjung Harapan, and Tujung village in Sembakung. The survey used purposive sampling aimed at obtaining information from farmers that manage the main land use systems existing in the area.

General Condition of Kabupaten Nunukan

Geographic position and area

Kabupaten Nunukan is located in East Kalimantan, strategically positioned as bordering area to Malaysia, in the north to Sabah and in the west to Sarawak (Table 2.1).

When it split from the large Bulungan district, Kabupaten Nunukan was divided into five Kecamatan (District): Kecamatan Krayan, Lumbis, Sembakung, Nunukan dan Sebatik,

Table 2.1. Geographic position of Kabupaten Nunukan

Geographic Position:		
Latitude	:	3° 30' 00" – 4 °24'55" East
Longitude	:	115° 22' 30" – 118° 44' 54" North
Borders of region:		
- North	:	Sabah, Malaysia
- East	:	Celebes Sea
- South	:	Kabupaten Bulungan and Kabupaten Malinau
- West	:	Sarawak, Malaysia

Source: http://www.nunukankaltim.go.id/

comprising of 212 villages. In 2003, the Pembeliangan became Kecamatan Sebuku. The total area of Kabupaten Nunukan is around 14243 km^2. The FORMACS study areas of Sebuku and Sembakung districs are 3778 km^{-2} and 2263 km^{-2}, respectively, representing around 42% of the area of Kabupaten Nunukan.

Table 2.2. Area of districs in Kabupaten Nunukan (values in brackets refer to percetage of area)

No.	Districts	Area (ha)	
1.	Nunukan	144 265	(10.1)
2.	Sebatik	24 341	(1.7)
3.	Sebuku	377 774	(26.5)
4.	Sembakung	226 294	(15.9)
5.	Lumbis	291 615	(20.5)
6.	Krayan	360 044	(25.3)
	TOTAL	**1 424 334**	

Source: Hatfindo Prima (2004)

Population dynamics

The population of Kabupaten Nunukan in 2002[1] was 84 786 persons with an annual population growth of 3.24%. Based on these data, the population density of Kabupaten Nunukan is about 6 person km^{-2}. Kecamatan Sebatik and Nunukan are the most populated districts, providing place for 72% of Nunukan population (BPS Kabupaten Nunukan, 2002) with population density of 6.81 and 26.87 person km^{-2}, respectively (Kabupaten Nunukan Dalam Angka, 2001).

A recent survey conducted by CARE International observed that Sebuku district comprise of 21 villages with a total population of 4064 persons in which 54% are male and 46% are female. Sembukung district cover 18 villages with total population of 6010 persons, with similar proportion of male and female as Sebuku.

[1] Result of a socio-economic survey conducted by Regional Planning Agency (BAPPEDA) and Central Statictics Bureau (BPS) Kabupaten Nunukan in August 2002

Climate and topography

Temperature measured in Nunukan (the capital of Kabupaten Nunukan) on average is 27.4°C. The lowest temperature is recorded for June, with average of 23°C and the highest for April and September of 32.2°C.

Average total yearly rainfall is 2326.7 mm year^{-1} and the average total monthly rainfall is 194 mm month^{-1}. The highest monthly rainfall is in May with an average of 367 mm and the lowest monthly rainfall in July with 88 mm. Humidity ranges between 82% to 87%, with average wind velocity at 2.5 m s^{-1}.

The terrain in Kabupaten Nunukan is dominated by a mountain range in the west and lowland peneplain in the east. Steep mountain terrain lies to the north-west, a part of the mountain range, that form the main watershed of the island of Borneo with altitude ranging from 1500 m to 3000 m above sea level. The middle part of Nunukan is hilly with undulating to flat landform towards the east. The hilly area in the south has elevation between 500 - 1500 above sea level. The slopes of mountainous area are around 30%, while in hilly area they range from 8 - 15%.

Soil

Soils in the western part of Nunukan and part of Nunukan and Sebatik islands are red-yellow Pdodzolics with low fertility status and shallow top soil. The peneplain along the river and coast consists of grey sedimentary soil of Gleysols.

The dominant soil structure in Nunukan consists of sub angular block with rigid to very rigid soil consistency and few pores distributed only at top soil. Effective soil depth is from shallow to very shalow with acidity ranging from 3.5 - 4.5. Soil drainage is poor, especially in the peneplain along the river. The soils generally have low suitability for oil palm.

The mountain range area is prone to soil erosion, especially in areas without vegetation. The swamps areas are wet almost throughout the year.

Watersheds

There are two main watersheds in Kabupaten Nunukan: (i) Sebuku watershed which is located in Sebuku district and (ii) Sembakung district which is located in Sembakung and Lumbis districts. Both Sebuku and Sembakung rivers have high debit of water all year through. Rivers located in Kabupaten Nunukan are listed in Table 2.3.

Tabel 2.3. Rivers in Kabupaten Nunukan

No.	River	Length (km)
1	Sembakung	278
2	Sulanan	52
3	Sumalungun	42
4	Sepadaan	32
5	Itay	146
6	Sebuku	115
7	Agisan	62
8	Tikung	50
9	Tabut	30
10	Simenggaris	36

Source: BAPPEDA Propinsi Kalimantan Timur

Land use

Land use in Nunukan can be classified into four main types:

1. Settlement area

Most people live in the peneplain area, 2 - 10 m above sea level, and only a few live in upland/highland area. Most settlements are along the coast, rivers or existing roads.

2. Paddy rice area

Paddy rice area mostly located behind the settlement, in a zone about 100 - 500 m wide in the mainland area or 50 - 150 m from the river or coastline. Nunukan still has vast area that has potential for rice fields.

3. *Upland/dryland agriculture systems (Ladang)*

Upland rice and other food crops are more inland in the upper part of paddy field area.

4. *Plantation (cash crop) area*

The main cash crop area is located in Sungai Pancang, around Kecamatan Sebatik. Cacao, coffee, clove, coconut and banana can grow well in this area. Another potential area for coffe and clove is around the Sebuku river.

Household Survey Results

Demographic patterns

The household respondents were mostly head of the family (father/husband), except for two households in Sembakung that were represented by a member of the family (mother/wife). Table 2.4 and 2.5 describes the demographic profile of respondents and the ethnical background. The total number of persons surveyed (respondents and their extended family) in both villages are 275 persons, all under 64 years old with ratio of male to female respondent is around 1:1. From 51 households surveyed, 42 are nuclei[2] families and the rest include extended family. The average family size is 5 person per family. Fifity-six percent of the people surveyed are in their productive age (15 - 64 years old). The dependency ratio[3] in Sebuku is 0.63, slightly lower than 0.87 of Sembakung.

The distribution of ethnical group in Sebuku and Sembakung hardly differs. The main ethnics group are Dayak Agabag and Tidung, respectively composing 85% and 10% of total persons surveyed. The rest are from ethnics group of Flores, Bugis, Timorese, Javanese and Chinese (Table 2.5). Around 50% of the family-heads have stayed in the area longer than 20 years and only 10% have stayed less than or equal to 10 years. The Chinese were born in the area (local people),

Table 2.4. Demographic profile of respondents and its extended family in Sebuku and Sembakung Sub-districts

			Sebuku	Sembakung	Total
1	Number of households (persons)		26	25	51
	Total member of households (persons)		134	141	275
2	Distribution of respondents by family size	1 – 4 person	0.50	0.36	0.43
		5 – 8 person	0.39	0.56	0.47
		> 9 person	0.11	0.8	0.10
	Average family size		5	6	5
3	Distribution of respondents by age	< 15 years	0.43	0.45	0.44
		15 – 64 years	0.57	0.55	0.56
		> 64 years	0	0	0
4	Dependency ratio[3]		0. 63	0.83	0.80

Source: BAPPEDA Propinsi Kalimantan Timur

[2] Nucleus family refers to family with parents (mother and/or father) and children. Extended family includes other member in the family such as relatives or house helpers.

[3] The dependency ratio indicates the number of individuals of working age in relation to the non-working age population (children and the elderly).

Table 2.5. Distribution of ethnics in Subuku and Sembakung

Ethnics	Family Head		Family members	
	Sebuku	Sembakung	Sebuku	Sembakung
Dayak agabag	25(0.49)*	20(0.39)	101(0.45)	88 (0.39)
Tidung	1(0.02)	5(0.09)		21 (0.09)
Chinese			1(0.004)	3 (0.01)
Flores			1(0.004)	1 (0.004)
Bugis			5(0.02)	
Timoresse				1 (0.04)
Javanesse				2 (0.09)
Total	**26**	**25**	**108**	**116**

* For Family-head, number in brackets refer to proportion to the number of households.
For Family-Members, they refer to proportion tom the number of family members.

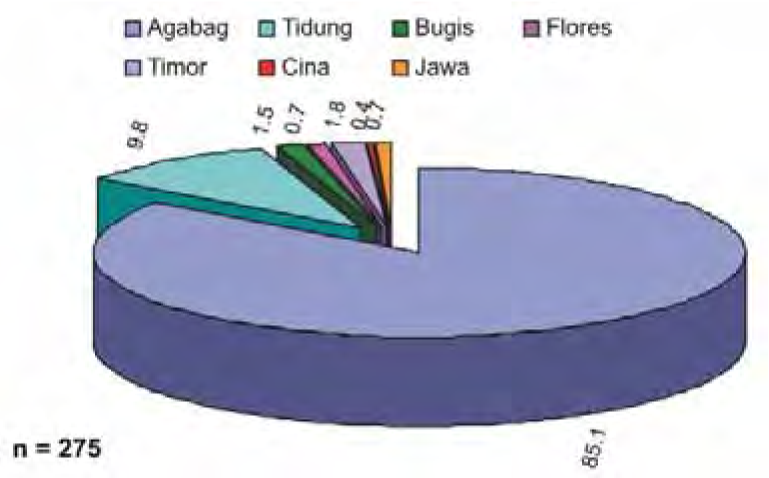


Figure 2.2. Distribution of ethnics in FORMACS study area

while people from Flores, Bugis and Timor are migrants who stayed in the area to find better living conditions; some used to work in Malaysia.

The level of formal education of respondents are relatively low. Around 35% of respondents never received schooling, only 4% received high school education and none above high school education.

Livelihood options

Agriculture activities are the main source of income for people living in the rural area of Nunukan. Especially those who live around the river where the soil is fertile. Activities that involve extracting non-timber-forest-product (NTFP) extraction are the next main source of income (Table 2.6).

Table 2.6. Level of education of respondents (in years of schooling)

Year of school	Proportion of respondents		
	Sebuku	Sembakung	All
≤ 6 years	0.85	0.64	0.75
> 6 years	0.15	0.12	0.37

Results of the household survey shows that only one respondent has non-agricultural activities as his main occupation (Table 2.8). Around 27% of respondents have off-farm activities as additional source of income, such as making boat, logging, opening a shop or as village official. Farming is still the main source of income for people in the study area.

Table 2.6. The main economic activities in villages of Nunukan

Activities	Products	Type of activities
1. Farming: crops	Cassava, banana, vegetables	Subsistence
2. Fishing	Fish (lampan, jelawat, pait, gedawang dan saluang), shrimps dan freshwater crabs.	Subsistence
3. Farming: livestock	Chicken and pigs	Subsistence
4. Gathering	Durian (*Durio zibethinus*), rambutan (*Nephelium lappaceum*), cempedak (*Artocarpus integer*), honey, gaharu[4] dan timber logging	Subsistence and commercial
5. Hunting	Deer and birds	Subsistence

Source: Monografi Desa-desa Kabupaten Nunukan (2001)

Table 2.7. Jobs carried out by respondents and their extended family

Job Categories	Specific activities
Farmer	planting crop based systems, tree-based systems or livestock
Teacher	-
Business Entrepreneur	opening small shops, selling timber
Village official	health worker, village office staff
Services	carpenter, swiftlet nests guard,
Logging activities	harvesting timber

[4] Gaharu is a fragrant resin that is produced by Aquilaria spp. (Thymelaeaceae) when subjected to fungal attack. Gaharu is also known as agarwood, eaglewood or aloeswood.

Table 2.8. Occupation of the head of family in the households surveyed

Job Type	Number of respondents		
	Sebuku	Sembakung	Total
Main Occupation			
Farmer	25 (98)	25 (100)	50 (99)
Teacher	1 (2)		1 (1)
Secondary occupation			
Trade	1 (2)	1 (2)	2 (4)
Village official	2 (4)	1 (2)	3 (6)
Services	1 (2)	4 (8)	5 (10)
Logging activities	2 (4)	2 (4)	6 (12)

* Number in brackets refer to percentage of respondents within each area

Only few respondents (4%) recognized logging activities as their secondary occupation. Nevertheless, around 55% of respondents acknowledge that they occasionally conduct logging activities and receive income from it. This information was derived when they were asked how much income they have received from selling timber from the forest (see section on Income).

A study by Kamelarczyk (2004) in Malinau District[5], East Kalimantan focus on the impacts of small-scale forest licenses, known as Timber Extraction and Utilisation Permits (IPPK = Ijin Pemungutan dan Pemanfaatan Kayu), on rural livelihood of three forest dwelling communities. The study revealed that the average estimate of households engaged in forest product harvesting are 46% timber harvesting, 70% for hunting, fishing 85%, gaharu collection 20%, rattan collection 35% and for fruits collection 47%.

Land tenure and ownership

In Nunukan, land is owned individually or through community (as communal land). Table 2.9 decribes the tenure systems of Dayak Agabag ethnic groups, that composed

[5] Before 1999, Malinau and Nunukan area belonged to the same district called Bulungan.

Table 2.9. Tenure systems and land allocation of Dayak Agabag community

	Land Ownership	
	Individual	**Communal**
Land Use Type	Settlement, Kebun and Ladang	Swiftlet (*Coccalia* sp.) caves, river and forest
Methods of obtaining rights	Opening forest, inheritance	Adat, community agreement
Land size	0.5 – 1.5 ha per household	10 – 10 000 hectares
Boundary Mark	Trees/plants	Natural boundary (river, hill mountain)

Source: Dokumen Amdal Kabupaten Nunukan, 2002

around 85% of the people surveyed. The household study, only focussed on the land owned individually by farmers.

Every household in the survey owned at least one plot. The highest number of plots owned by a household is 4 plots (2 respondents; Table 2.9). Sixty-three percent of respondents owned only one plot. The total number of plot surveyed is 75 plots.

Most of the plots were obtained by inheritance (Table 2.10), reflecting that most respondents are not new to the area (at least second generation). Opening land from forest is the next methods of obtaining the land.

Tabel 2.10. Distribution of plots owned by household

Number of plots	Number of Households		
	Sebuku	**Sembakung**	**Total**
1	19 (37)	13 (25)	32 (63)
2	6 (12)	10 (20)	16 (31)
3		1 (2)	1 (2)
4	1 (2)	1 (2)	2 (4)
Total Plots	35 (51)	40 (49)	75 (100)

* Number in brackets refer to percentage of plots.

Table 2.11. Methods in obtaining land

	Percentage of plots within each village		
	Sebuku	**Sembakung**	**Total**
Inheritance	49	45	47
Opening land	25	42	35
Purchase	3	-	1
Bequested	23	10	16
Sharecropping	-	3	1

Farming systems

Overall there are four main farming systems in the survey: rain-fed paddy, smallholder plantation, *jakaw* and agroforestry systems. Rain-fed paddy is the only crop-based systems found in the area, the rest of the systems are tree-based systems. Table 2.10 provides the general description of the tree-based systems.

There are two types of smallholder plantation: monoculture pepper and oilpalm. Oilpalm has only recently been introduced to the area and the trees are still in their early stage. The oil palm is mixed with upland rice.

Around 35% of the plots originated from forest, mostly opened into tree-fruit based agroforestry systems. This systems is also the main system that is currently found in the area, around 83% of total plots (Table 2.13), managed by 98% of households. The agroforestry systems combined coffee trees or fruit trees such as rambutan and langsat with annual crops such as long bean, maize and groundnut. The agrofrestry systems covered 63.1 ha or 71% of the total area of farming systems owned by respondents (Figure 2.3).

Most of the plots (69%) have semi-commercial purpose, serving household needs for own consumption as well as for providing income. Only less than 3% of farming systems have exclusively commercial purpose.

Average plot size in Sebuku is 1 ha while in Sembakung it is slightly higher at 1.4 ha. Land-holding size in Sebuku is 1.3 ha while in Sembakung is 2.16 ha.

Table 2.12. Characteristics of tree-based systems

Farming systems	Description
Smallholder plantation	Oil palm plantation, pepper (*Piper nigrum*) monoculture
Jakaw	A fallow rotation systems where farmers slash and burn logged-over-forest then plant upland rice for several seasons. When the yield are no longer acceptable, farmers will leave the plot to fallow.
Agroforestry Systems	A fruit-based systems, where farmers plant fruit trees in logged-over-forest between remnant trees of low-commercial values. During its early stage, farmers plant cassava or vegetables, such as long bean (*Vigna unguinculata*), chili (*Capsicum frustescens* and *Capsicum annum*), groundnut (*Arachis hypogaea*), melon (*Cucumis melo*), watermelon (*Citrullus lanatus*), *Brassica rapa*, eggplant (*Solanum melongena*).

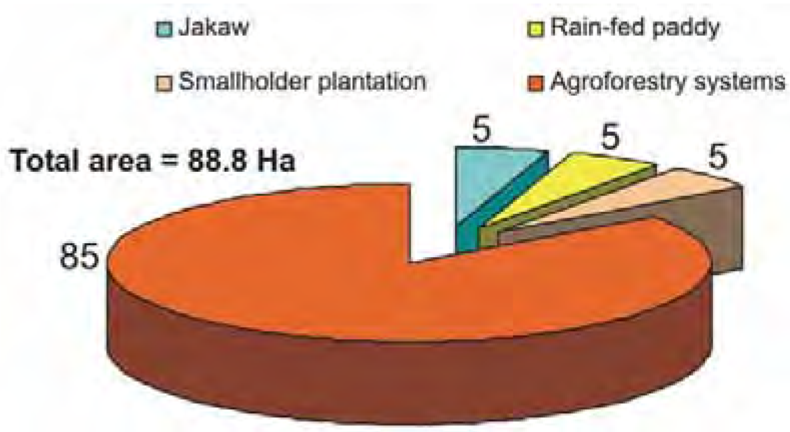


Figure 2.3. Distribution of farming systems by area (in percentage)

Table 2.13. Number of plots and average size of farming systems in Sebuku and Sembakung.

Farming Systems	Number of plots			Average plot size (ha)		
	Sebuku	Sembakung	Total	Sebuku	Sembakung	Total
Rain-fed paddy field	-	3 (4)	3 (4)	-	1.3	1.3
Smallholder plantation	1 (1)	2 (3)	3 (4)	2	1.5	1.7
Jakaw	1 (1)	6 (8)	7 (9)	1	0.6	0.6
Agroforestry systems	33 (44)	29 (39)	62 (83)	1	1.4	1.2
Total plots	35 (46)	40 (54)	75 (100)	1	1.4	1.2

* Number in brackets refer to percentage of plots.

Input and revenue

Input for farming systems are categorized into two components: labour and non-labour. Non labour includes fertilizer, pesticides and herbicides. In the study area, non-labour inputs are hardly used by farmers, except in smalholder plantations and several plots of agroforestry systems.

The total labour input for the farming systems in the study area ranges from 113 to 149 persons days year^{-1}hectare^{-1}. For tree-based systems, land preparation activities are required only at the beginning of the systems. Thus, the total labour input for these systems after the first year will be reduced by 23 - 36%. In tree-based systems, plot maintenance is the main component of labour input, ranging from 47 - 61% of the total labour input.

The labour requirement for harvesting and post-harvest activities in monoculture pepper systems seems to be under-reported. Pepper is a plant that once mature will bear fruit continously. Thus, it is likely that harvesting activities are included as part of plot maintanance activities.

The oil palm systems, being in their the early stage, are planted together with upland rice. The amount of labour required for harvesting shown in Table 2.14 is for harvesting upland rice (see revenue derived from each systems in Table 2.15).

Table 2.15 shows a rough estimate of revenue derived from each systems and the fraction of marketable otput that will actually become hard cash earned by households. Only 3% of the plots in the study area has purely commercial purpose and around 46% has semi commercial pupose. Products like cassava and rice are mainly for own consumption.

Household income and expenditure

The main source of household income in Sembakung area is from on-farm activities (Table 2.16). The on-farm income is derived from marketable products only. Products that were consumed by households are not included.

For respondents in Sebuku, the sources of income are from on-farm activities as well as from forest. In Sebuku, income from forest contribute to around 56% of total household income, in contrast to 7% in Sembakung. This difference occurs because the quality of forests that exist in Sembakung is very low. Most of Sembakung forest has been exploited by a timber-concession or is being converted to oil-palm or industrial timber plantation, planted with *Acacia mangium* (CARE, 2005).

Tabel 2.14. Labour input for each land use systems (in person days ha^{-1} $year^{-1}$)

Farming Systems	Plot Preparation	Plot Maintenance	Harvesting and Post-Harvest activities	Total
Rain-fed paddy field	33	24	56	113
Jakaw (cropping phase)	36	77	24	136
Smallholder plantation				
Monoculture pepper	50	87	5	142
Oil palm	55	70	24	149
Agroforestry systems	27	70	17	114

* Number in brackets refer to percentage of plots.

Tabel 2.15. Revenue derived from farming systems

Farming Systems	Products	Revenue*) (Rupiah[6] $year^{-1}$ ha^{-1})	Fraction of marketable output
Rain-fed paddy field	Upland rice	2,640,000	0
Jakaw (cropping phase)	Upland rice, timber for own use	1,091,000	0
Smallholder plantation			
Monoculture pepper	Pepper	750,000	1
Oil palm (immature phase)	Upland rice, banana	505,000	0.88
Agroforestry systems	Upland rice, cassava, coffee, fruits, vegetables	1,964,000	0.75

* Revenue is defined as average yield of products derived from each farming systems, multiplied by estimated price. Products consumed by households are also included in the calculation.

[6] The exchange rate at the time when the survey was conducted was approximately Rp 8,900 per US$.

On the other hand, non-agricultural activities in Sembakung on average generated income 88% higher compared to activities in Sebuku. This shows different strategies between the two village in meeting their needs, influenced by existing resources.

The different livelihood options that exist in the two sub-districts studied influence the income per capita and income per household (Table 2.17). Sebuku has a higher household income and income per capita compared to respondents in Sembakung.

In Sebuku, two respondents received income from timber-IPPK fee; on average Rp. 1,250,000 per month or Rp. 15,000,000 per year. In Malinau (Kamelarczyk, 2004), a community living in a forest dwelling of Tanjung Nanga in 2001 received Rp 100 million in compensation for the timber extracted until 2000. The timber fee received by each households there ranged from Rp. 1,950,000 to Rp. 6,282,000.

The national indicator of poverty for rural area for Indonesia is Rp. 105,888 per person per month (BPS, 2003). While the regional indicator for East Kalimantan is Rp. 145,460 per person per month. On average, the income per capita for Sebuku and Sembakung village is above this level. But, looking at individual household, 4% of households in Sebuku is below the regional poverty indicator and 1% below the national poverty indicator. For Sembakung repondents, the percentage of households below the poverty indicator is higher, 44% below the regional indicator and 28% below the national indicator.

Around 46% of household expenditure is allocated for food. Transportation seems to be quite an important component of expenditure reaching 16% of the overall expenditure. Proportion of expenditure allocated to health is around 8%, unfortunately, similart to the proportion allocated to smoking. In terms of ratio of expenditure to income, around 33% of income is used for household expenses (Table 2.18). Despite the difference in average

Table 2.16. Household income by its source

Source	Sebuku		Sembakung		All	
	Fraction of households (%)	Average Income *) (Rp/month)	Fraction of households (%)	Average Income (Rp/month)	Fraction of households (%)	Average Income (Rp/month)
On-farm activities	**100**	**722,000**	**100**	**468,000**	**100**	**598,000**
Forest	**92**	**1,466,000**	**16**	**580,000**	**54**	**1,334,000**
Timber	*76*	*1,018,000*	*12*	*700,000*	*44*	*975,000*
Timber fee (IPKK)	*8*	*1,250,000*	-	-	*4*	*1,250,000*
NTFP	*60*	*791,000*	*8*	*110,000*	*34*	*711,000*
Fishing and Hunting	**4**	**150,000**	**20**	**103,000**	**12**	**111,000**
Other non-agricultural activities	**32**	**681,000**	**64**	**1,282,000**	**48**	**1,064,000**

* The average income is rounded off to the nearest thousands rupiah.

Tabel 2.17. Household income of respondents

	Sebuku	Sembakung	Total
Average household income (Rp/month)	2,299,000	1,288,000	1,804,000
Income per capita (Rp/person/month)	446,000	228,000	334,000

* Income is rounded off to the nearest thousands rupiah.

income between the two subdistricts the relative allocation or expenditure categories is the the same

Discussion

The household survey was intended to understand the livelihood options that exist in the forest margin of Nunukan. This understanding is crucial to recognize and comprehend the decision that farmers make to manage their landscape.

The result from two sub-districts in Nunukan clearly show differences in livelihood options, especially the quality of the remaining forest. Income of farmers in Sebuku is derived from on-farm activities and forest products, while for farmers in Sembakung the income is derived mostly from on-farm activities. Our current rapid study in two sub-district in Nunukan revealed that in an area where forest of good quality is still abundant, income generated from forest can contribute to 56% of household income.

Timber is certainly the most attractive forest product in the areas and logging is the most attractive off-farm activity. Logging activities also produced a higher revenue compare to on-farm activities. Existing literature provides hardly any information on the household economics of timber logging activities, although most literature does acknowledge logging activity (legal or illegal) a part of livelihood options for people living in the forest margin of Kalimantan (Levang, 2002). It is difficult to obtain an estimate on how much logging contributes to income at household level. Most existing literatures discuss the economics of timber logging, illegal or legal, at timber concession, regional or national levels (Casson and Obidzinsky, 2002; Resosudarmo and Dermawan, 2002 and Smith *et al.* 2003). The main discussion on legal logging is on management issues highlighting the importance of sustainable

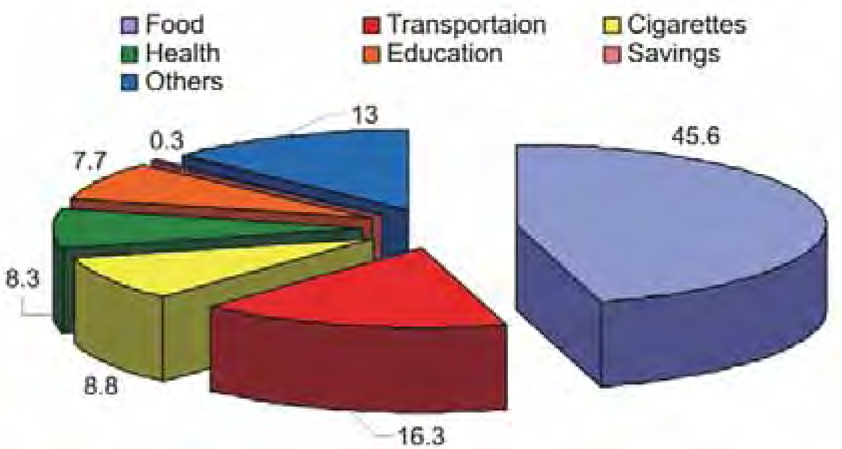


Figure 2.4. Household expenditure allocation in Sebuku and Sembakung

Table 2.18. Percentage of expenditure to income at household level.

	Sebuku %	Sembakung %	Total %
Percentage of food expenditure to income	14	17	15
Percentage of non-food expenditure to income	19	16	18
Percentage of total expenditure to income	33	33	33

methods for harvesting forest timber (Barr, 2002 and Sist *et al.*, 2003). The debate on illegal logging mostly addresses governance and policy issues, stressing the need of a better way to monitor illegal logging in order to recover the loss of local and national income that could be gained through taxes (Taconi, 2004). A careful study on household perspectives of logging and its economic contributions to household economy is required to develop alternative activities for income generation, as part of finding solution to maintain existing forest and reduce deforestation.

Conclusion

- The main farming systems in Sebuku and Sembakung sub-districts of Nunukan are fruit tree -based agroforestry systems, comprising 83% of farmers plots covering 71% of farming land and managed by 98% of respondents.
- Other farming systems found in the area are *jakaw* (fallow rotation systems with upland rice as crop), rain-fed paddy systems and smallholder plantation (oil-palm and monoculture pepper), in total managed by 29% of respondents.
- The return to land of agroforestry systems on average is Rp. 1,964,000 per ha, lower than rain-fed paddy systems. But given that agroforestry systems is the main system managed by farmers and 75% of agroforestry products are marketed, this systems is the main source of income from on-farm activities.
- Income per capita in Sebuku and Sembakung is Rp. 446,000 and Rp. 228,000, respectively per month and the average income per household is Rp. 2,299,000 and Rp. 1,288,000 respectively.
- In Sebuku, forest products contribute 56% of household income, in contrast to 7% in Sembakung. The additional income generated by forest products in Sebuku increased average household income by 78% and increase income per capita by 96%.

3. ABOVEGROUND CARBON STOCK ASSESMENT FOR VARIOUS LAND USE SYSTEMS IN NUNUKAN, EAST KALIMANTAN

Subekti Rahayu, Betha Lusiana and Meine van Noordwijk

Introduction

The role of terresterial ecosystems in the global carbon cycle has raised considerable interest among researchers and policy makers. Exchange between atmosphere and vegetation involves large two-way fluxes, with fixation of CO_2 into biomass through photosynthesis approximetaly balanced by the release of CO_2 through processes of decomposition and burning. It is estimated about 60 Pg[1] carbon is exchanged (in both directions) between terresterial ecosystems and the atmosphere every year, with a net terresterial uptake of 0.7 ± 1.0 Pg[1] C (Lasco, 2004). However, relative to the size of the atmospheric pool of CO_2, land use change and forest conversion are significant source of CO_2 contributing to around 1.7 ± 0.6 Pg C year (Watson *et al.* 2000). In geological history the process of CO_2 fixation has dominated over that of CO_2 release, contributing to the large reserves of 'fossil fuels'. At the current rate of global fuel consumption and economic growth, it is predicted that within 100 years global mean temperature will increase by 1.7 - 4.5ºC (Houghton *et al.*, 2001).

Forest conversion to agricultural land releases substantial quantitities of stored carbon to the atmosphere, but may have relatively little effect on current CO_2 absorption by terresterial ecosystems, unless the conversion process leads to degraded soils lacking green vegetation, or to jungles of concrete and asphalt without active photo-synthesis. Despite rates of photosynthesis that can be similar to that of forest, the carbon stocks stored in agricultural systems are much smaller, as the annual gains in fixed CO_2 tends to be rapidly released back into the atmosphere. This can occur on-site, through burning or decomposition of crop residues, or off-site after removal through harvesting. The main issue in land use change, however, is the change in stored carbon. Release to the atmosphere upon forest conversion can be rapid, with C stocks of up to 250 Mg C ha^{-1} lost in slash and burn clearing, while the re-accumulation in wood is relatively slow, of the order of 5 Mg C ha^{-1} $year^{-1}$.

Current efforts to mitigate the impact of climate change are through ways of increasing carbon sequestration (Sedjo and Salomon, 1988) and/or mitigating carbon emission (Lasco *et al.*, 2004). Mitigating C emission can be accomplished through: (a) conservation of existing C stocks by protecting forest reserves, controlling deforestation, the use of silviculture practices, reversing the drainage and degradation of peat lands with their large carbon stocks and improved management of soil organic mater stocks, (b) increase in carbon stocks by enhancing woody vegetation and (c) subtitution of fossil fuels-based products by renewable energy sources derived

[1] 1 Pg = 10^{15} g = 10^9 Mg = 1 Gt

directly or indirectly (wind, biomass, water flows) from solar radiation, tidal action or geothermal processes.

Increased carbon stocks (carbon sequestration) can be achieved by (a) natural increases in forest growth and biomass, (b) increasing tree stocks in existing forest either through increasing growth or decreasing harvest and (c) establishing fast growing tree plantation (Sedjo and Salomon, 1988). Carbon sequestered is stored in the form of woody biomass, thus the simple way to increase carbon stocks is to plant and manage trees (Lasco *et al.*, 2004).

Terrestial carbon stocks consist of above and below ground carbon. Above ground carbon stocks component includes biomass (stems, twigs, leaves, vines, epiphytes and understorey) and necromass (dead trunks, standing dead trees, litter in form of leaves, stem, twigs, flowers, fruits and fire residues). Below ground carbon stocks components are roots of live or dead plants, soil organisms and soil organic matter (Hairiah and Murdiyarso, *in press*). Harvesting tree products such as timber (for lumber, pulp and paper or charcoal production or for use as firewood), resin and fruits or leafy biomass as fodder, removes carbon stocks when considered at plot scale, but is not necessarily a loss when viewed at global scale. The same may apply to loss of soil organic matter by erosion. Some of the global carbon accounting systems include the carbon flows (especially those in wood) and their subsequent decomposition, but it is difficult to obtain consistency with such methods if they do not relate to assessments of existing stocks (mostly in urban areas). According to Canadell (2002), in the humid tropics maximum potential in carbon sequestration will be achieved by focussing on increasing aboveground biomass in woody vegetation rather than as soil carbon, given the smaller pool size of soil organic matter and short mean residence time. Peat soils are an obvious exception to this (van Noordwijk *et al.*, 1997; Paustian *et al.*, 1997).

This paper describes the study conducted in Nunukan, East Kalimantan to measure carbon stocks in various land use systems. The study is carried out under FORMACS (Forest Resources Management for Carbon Sequestration) project with the following objectives:

1. to estimate carbon stocks in representative land cover classes of the main land use practices in Kabupaten Nunukan
2. to identify land use systems that can best maintain carbon stocks.

Methods

Plot level C-stocks

Prior to measurement, a quick survey was conducted in Sebuku and Sembakung Distric to identify existing land-use systems and the land cover classes that are associated with a typical cycle of each land use system (see Chapter 2). This survey established the 'strata' that had to be considered in a stratified sampling scheme.

During December 2003 - March 2004, 54 plots were sampled (Appendix 1) including primary forest, logged-over forest (3, 10, 30 and 50 years after the 1st logging), upland rice, fallow (*jakaw*) (1, 2, 3, 4, 5, 7, 15 years after slash-and-burn clearing and agroforestry systems (9, 11-20 and 21- 30 years old)[2]. In each plot, the diameter and height of live and dead trees were measured in 30 x 10 m^2 plots with litter and understorey samples in subplots (for full protocol see Hairiah *et al.*, 2001). Soil carbon was not measured in this study, as there are no major areas of peat with high belowground carbon stocks, and the land-use change induced changes in soil carbon were therefore expected to be less than the existing spatial variation.

[2] Although result in chapter 2 shows the existence of smallholder plantations, these were not sampled. The reasons are: (1) oil palm plantation is still in its early phase and (2) only few plot of both systems exist in the sample

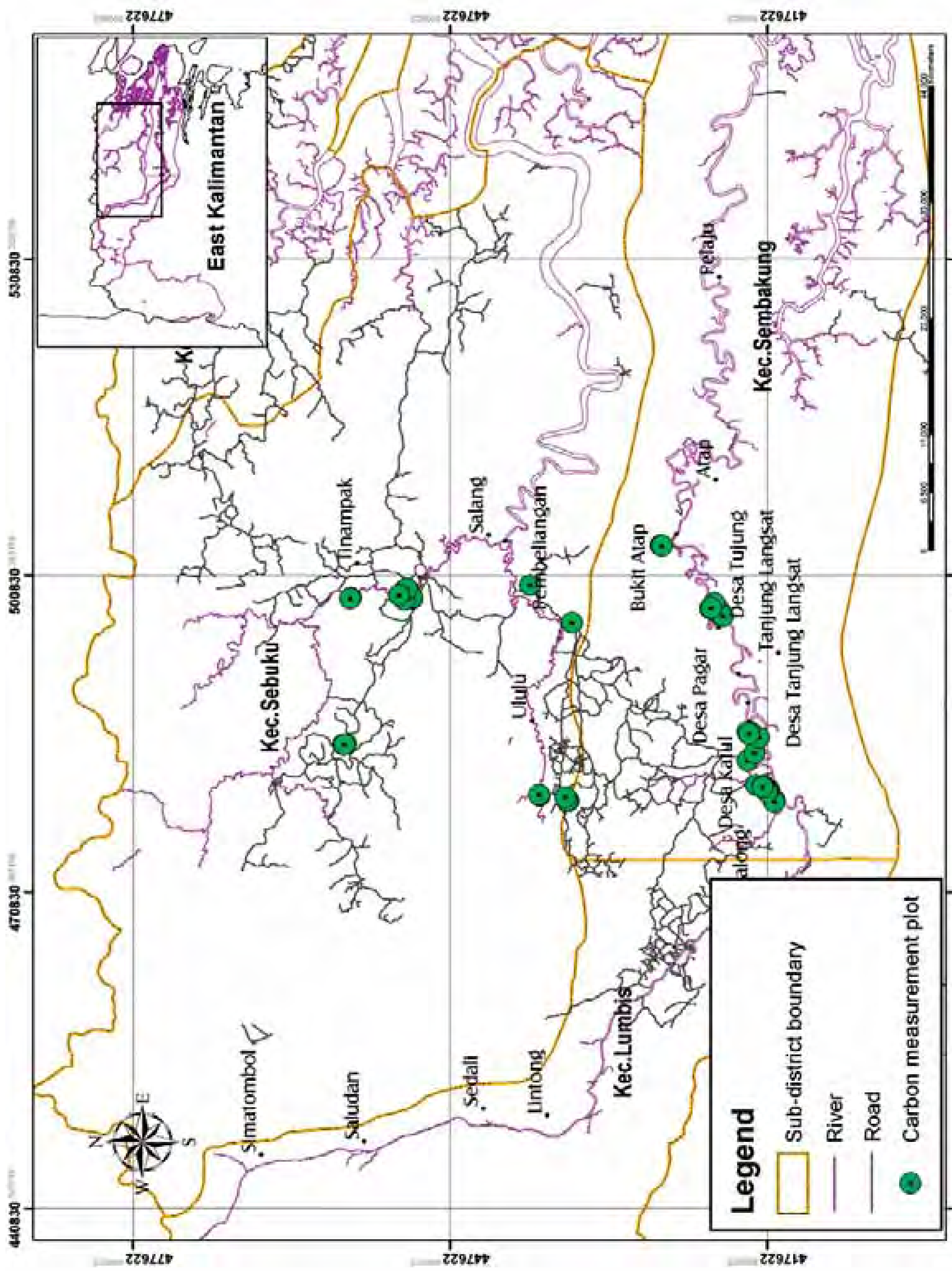


Figure 3.1 Map of plots where carbon was measured.

Trees

Carbon stock of a land-use system is influenced by its vegetation. A land use system consisting of tree species with high wood density will have a higher biomass carbon compared to that with a low wood density and similar tree diameter.

Tree biomass (in dry weight) was estimated using allometric equation on the basis of stem diameter (in cm) at 1.3 m above the ground[3]. Table 3.2 listed the allometric equations used in this study to estimate different vegetation. For wood density, values from literature review are used[4].

Total C content (carbon biomass) was estimated using the following equation:

Carbon biomass (Mg ha^{-1}) = Total biomass (Mg ha^{-1}) x 0.45, that assumes C content of biomass (in dry weight) is 0.45.

Time-averaged carbon stocks

To compare the carbon sequestration potential of a land-use system, it is necessary to assess the systems across their life cycle, between the minimum and maximum value that can be expected to be present in the landscape. If there is no active process of intensification or adoption of new practices, we can assume that all phases of the life cycle are represented spatially in accordance with their proportion in the total life cycle. The time-averaged carbon stock is defined as the integral over time of the carbon stocks in each phase of the systems cycle, divided by the duration of the 'cycle'. For rotational land use systems, time-averaged carbon stocks can be used for landscape assessments (Palm, 1995). In Nunukan, the *Jakaw-Rice* System is a rotational one. Assumning a time-independent rate of C sequestration during the fallow, the time averaged carbon stock is derived as:

$$C\ [\mathrm{Mg\ ha^{-1}}] = f_{crop}\, C_{crop} + f_{fallow}\, C_{fallow} = f_{crop}\, C_{crop} + f_{fallow}\, (T_{fallow}\, C_{incr,fallow}/2) \quad (1)$$

Where f_{crop} and f_{fallow} refer to the fraction of time that the system is cropped or fallowed, respectively, C_{crop} and C_{fallow} are the C stocks (Mg ha^{-1}] of the crop and fallow phase, T_{fallow} is the length of a single fallow cycle [year] and $C_{incr,fallow}$ is the rate of C sequestration [Mg ha^{-1} $year^{-1}$] during the fallow phase.

Table 3.2. List of allometric equations used to estimate biomass of various vegetations

Biomass Category	Allometric equation	Source
Branching trees	$B = 0.11\rho\ D^{2.62}$	Ketterings, 2001
Non-branching trees	$B = (\pi/40)\ \rho\ H\ D^2$	Hairiah, 2002
Necromass (dead trees)	$B = (\pi/40)\ \rho\ H\ D^2$	Hairiah, 2002
Coffee (pruned)	$B = 0.281\ D^{2.06}$	Arifin, 2001; Van Noordwijk, 2002
Banana	$B = 0.030\ D^{2.13}$	Arifin, 2001; Van Noordwijk, 2002
Paraserienthes falcataria	$B = 0.0272\ D^{2.831}$	Sugiarto, 2002; Van Noordwijk, 2002
Palm	$B = BA^*\ H^*\rho$	Hairiah, 2000

NOTE:
B = biomass (dry weight, kg $tree^{-1}$)
D = diameter (cm) at breast height (1.3 m)
H = tree height (cm)
BA = basal area (cm^2)
ρ = wood density (Mg m^{-3}, kg dm^{-3} or g cm^{-3})

[3] Australian Greenhouse Office (2002) recommended three methods for biomass modelling: (i) allometric equtions between diameter and/or height to above ground biomass, (ii) stem volume models and conversion to above-ground biomass using an expansion factor and (iii) Stand basal area to biomass relationships http://www .greenhouse.gov.au/land/bush_workbook_a3/index.html

[4] A database compiling wood density of 2800 tree species is currently available at http://www.worldagroforestry.org/ sea/Products/AFModels/treenwood/treenwood.htm

Results and Discussions

Tree diversity

Wood density composition

The wood density of trees can be categorized into four types: light, medium, heavy and very heavy (Pendidikan Indutri Kayu Atas, 1979). A summary of the wood density (derived from a literature database) for tree species found in the various land use systems in Nunukan is listed in Table 3.3. Primary forest has the highest median wood density and *jakaw* has the lowest value. In terms of the distribution of tree species density characteristics, *jakaw* and agroforestry are mostly dominated (more than 80%) by light and medium tree species.

In primary forest 42% of the trees are heavy and very heavy species, reflecting the prominence of late-successional species. Figure 3.1 shows the cumulative frequency of wood density in four land use systems in Nunukan.

Species composition

In the primary forest plots sampled, 40% of the vegetation consisted of commercially valuable tree species (Appendix 2A), such as keruing (*Dipterocarpus* sp.), meranti (*Shorea* sp.) and kayu kapur (*Dryobalanops* sp.). The rest of the vegetation is composed of Sapotaceae (*Palaquium* sp.), Anarcardiaceae (*Buchanania* sp., *Gluta* sp.), Ebenaceae (*Diospyros* sp.), Meliaceae (*Aglaia* sp.), Myriasticaceae (*Horsfieldia* sp.) and Lauraceae (*Beilschmiedia* sp.). In logged over forest aged less than 30 years, the Dipterocarpacea species have decreased to 30% of the remaining trees due to timber harvesting (Figure 3.2).

In the *jakaw* systems, forest is opened through slash and burn methods after which farmers planted food crops such as rice, maize and groundnut. When the food crop production has decreased and no longer provides sufficient return to labour (as yields decline and labour requirement for weeding go up), farmers leave the plot. After 1 year of fallow, the common vegetation found is wild banana. After 2 - 6 years, pioneer trees start to grow in the plot, such as sedaman (*Macaranga* sp.) from the Euphorbiaceae familly.

The abundance of species found in *jakaw* (fallow) and logged over forest 0 - 10 years are influenced by the establishment of pioneer vegetation on disturbed forest. Disturbed forest (either by fire or logging) will go through natural succession. During the first five years after disturbance vegetation will be dominated by shrubs ('semak') that require full light. For the next five years, it will be dominated by trees ('belukar') that requires full light to grow, such as *Macaranga* sp. and

Table 3.3. Wood density of trees in the various land use systems

Land Use Systems	Median Mid-range* Wood Density** ($Mg.m^{-3}$)	Distribution of species*** (%)			
		Light < 0.6 Mg m^{-3}	Medium 0.6 – 0.75	Heavy 0.75 – 0.9	Very Heavy > 0.9 Mg m^{-3}
Primary Forest	0.68	34.2	23.4	11.7	30.6
Logged-over Forest	0.61	25.9	41.3	17.6	15.2
Agroforestry	0.60	50.1	38.1	7.0	4.7
Jakaw	0.59	61.7	18.8	12.5	7.0

* Wood density value of a certain tree species resulted from literature review is expressed as a range of values. For example: Tengkawang (*Shorea stenoptera* Burck.) has wood density value of 0.31 - 0.57 Mg m^{-3}. Thus mid-range wood density value for Tengkawang is 0.42 Mg m^{-3}.

** Mg = 10^6 g = 1 ton. In this study, we use the unit of Mg m^{-3} instead of kg m^{-3}, for reason that it is in International unit and has a value equal to g cm^{-3} (while kg m^{-3} = 1000 g cm^{-3}).

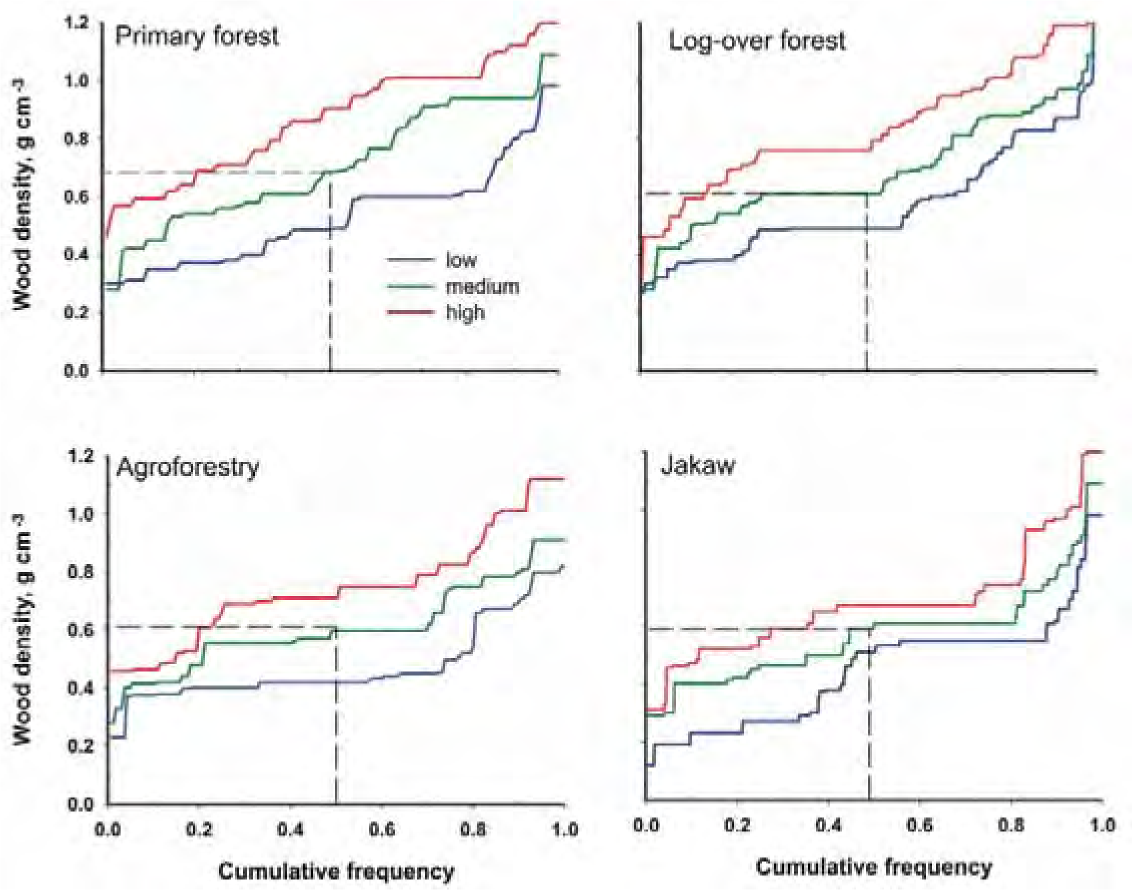


Figure 3.2. Cumulative frequency of wood density estimates for tree species found in: (a) the primary forest, (b) logged-over forest, (c) agroforestry and (d) *jakaw*.

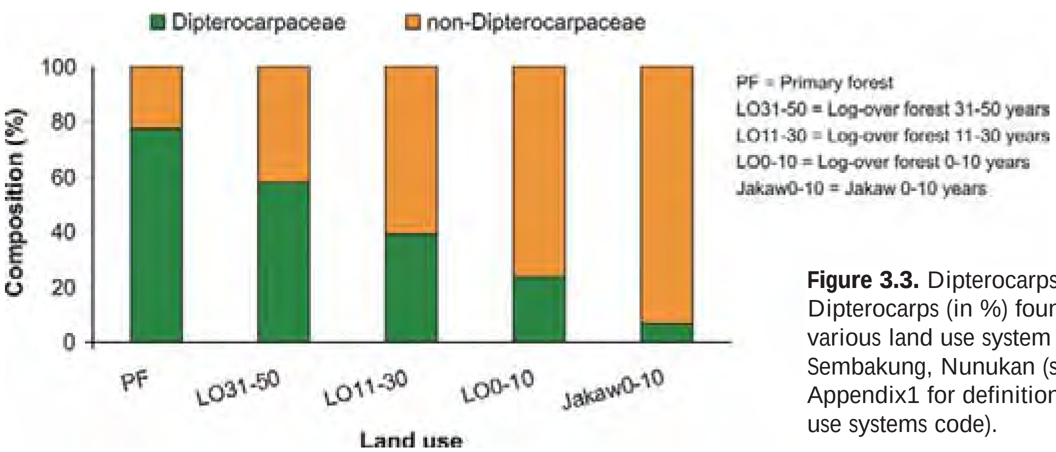


Figure 3.3. Dipterocarps and non-Dipterocarps (in %) found in various land use system of Sebuku-Sembakung, Nunukan (see Appendix1 for definition of land use systems code).

Mallotus sp.. When fallows reach more than ten years of age and in forests logged 11-50 years ago the total number of species may decline after full canopy closure and reduced opportunities for light-demanding understorey, but the number of late-successional species increases (Van Nieuwstadt, 2002).

Agroforestry systems that are commonly managed by farmers in Nunukan are fruit-tree based. In systems aged 0-10 years, besides fruit trees, low commercial trees that still remain after logging are commonly found such as terap (*Artocarpus* sp.) dan sedaman (*Macaranga* sp.). Under systems aged more

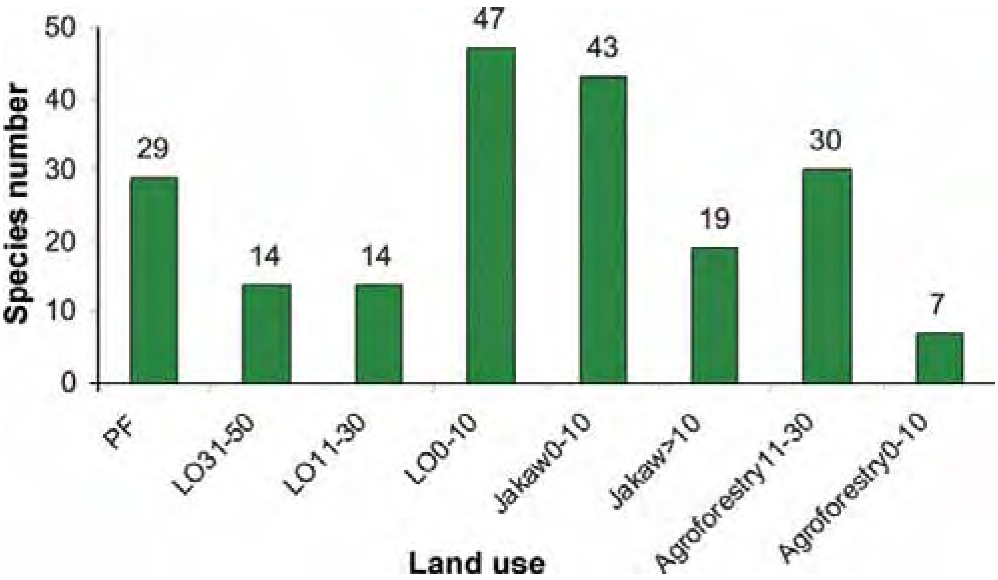


Figure 3.4. Number of woody species found in a 40*5 m^2 plot in various land use system of Sebuku-Sembakung, Nunukan (see Appendix 1 for definition of the land use systems code).

than 10 years, the fruit species are more abundant. Timber species also have established by this time. The fruit species commonly planted are durian (Durio zibethinus), mangga (*Mangifera indica*), langsat (*Lansium domesticum*), cempedak (*Artocarpus integer*), rambutan (*Nephelium lappaceum*) dan kelapa (*Cocos nucifera*). Many of the gardens also include coffee (*Coffea* sp.) and cacao (*Theobroma caccao*) as component. In this systems the number of species is almost equal to that of forest systems but has a different composition (Figure 3.4).

Size composition

The existence of trees with diameter more than 30 cm in a certain land use systems makes a large contribution to the total carbon stocks. In primary forest, 70% of the total carbon biomass comes from trees with diameter > 30 cm. In natural forest, trees with

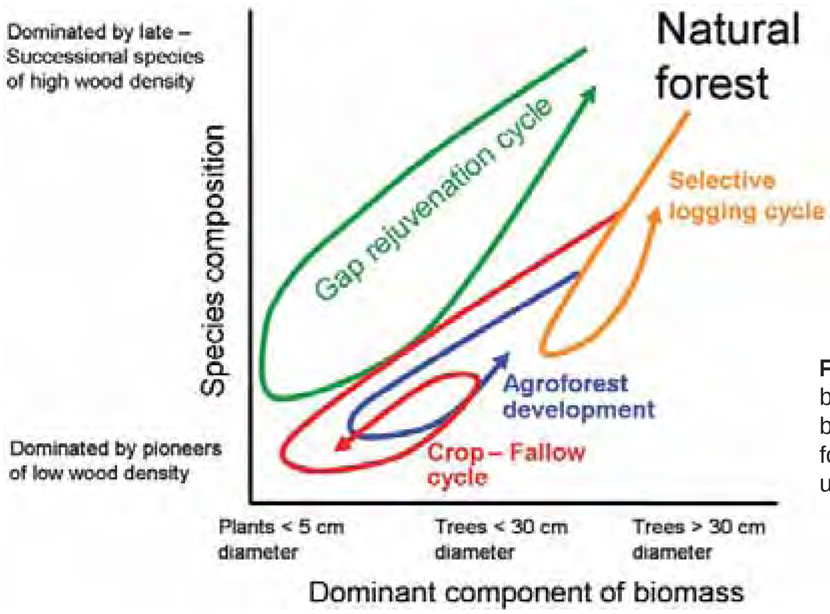


Figure 3.5. Schematic relationship between species composition and biomass composition of various forms of forest and derived land uses in Nunukan.

diameter 5-30 cm mainly occur where gaps were created in the past by big trees dieing and falling (Hairiah and Murdiyarso, *in press*).

In logged-over forest, the total carbon stocks contributed by trees with diameter >30 cm increased as the length of time after logging increased. For logged over forest aged 0-10, 11-30 and 31-50 years, the contribution of carbon stocks from trees with diameter > 30 cm are 75%, 78% dan 83% respectedly.

In agroforestry systems, trees with diameter >30 cm only contribute to 30% of total carbon for agroforestry aged 0 - 10 years and 15% for agroforestry age 11-30 years. This low contribution is due to the history of the systems itself. Agroforestry plots are established from logged over forest that mostly have light wood density species as remnant trees. Thus, they have a relatively low biomass.

In *jakaw* systems aged 0-10 years hardly any trees with diameter > 30 cm exist. In this system, farmers slash and burn all vegetation prior to planting upland rice. Occasionally, however, one or a few large trees are spared in the land clearing and cultivation phase, accounting for the few large trees in fallow vegetation. Apart from these, all vegetation starts to establish around the same time. In *jakaw* aged more than 10 years, trees with diameter > 30 cm contribute almost 80% of total carbon stocks, similar to that of logged-over forest aged 11 - 30 years. *Jakaw* is dominated by pioneer trees (of low wood density) that grow fast, thus within 15 years it already has many trees with diameter > 30 cm.

Carbon stocks

Total carbon biomass

The estimated aboveground carbon stocks of land use systems in Nunukan are estimated to range from 4.2 - 230 Mg ha^{-1} (Table 3.4). The aboveground carbon stock in in primary forest in Sebuku-Sembakung, Nunukan is well in the range of previous studies, with its 230 Mg ha^{-1}. The ASB studies in Sumatra derived estimates up to 300 Mg C ha^{-1} (Hairiah dan Murdiyarso, *in press*). Indonesian forest have been estimated to carbon stocks ranging from 161 - 300 Mg ha^{-1} (Murdiyarso *et al.*, 1995). Lasco (2002) reviewed various studies of forest carbon stocks in South East Asia. The carbon stocks of forests in tropical Asia are between 40 - 250 Mg ha^{-1} for vegetation and 50 - 120 Mg ha^{-1} for soil. For national green house gas inventory studies, IPCC recommends a default value of 138 Mg ha^{-1} of carbon (or 275 Mg ha^{-1} of biomass in dry weight) for humid forests in Asia (Lasco, 2002).

The carbon stocks in primary forest are the point of reference for this study. The measurements in logged-over-forest yielded values of 80 - 92% of this value, but without

Tabel 3.4. Mean aboveground carbon stocks of land use systems sampled in Nunukan

Land Use Systems	Carbon stock (Mg ha^{-1})	Percentage (%)
Primary forest	230.1	100
Logged-over-forest aged 0-10 years	206.8	90
Logged-over-forest aged 11-30 years	212.9	92
Logged-over-forest aged 31-50 years	184.2	80
Jakaw aged 0-10 years	19.4	8
Jakaw aged more than 10 years	58.0	25
Agroforestry aged 0-10 years	37.7	16
Agroforestry aged 11-30 years	72.6	31
Imperata	4.2	2
Upland Rice	4.8	2

clear pattern of carbon stocks measured with the length of time since logging. A number of factors influence this:

- original composition of forest sampled: the attractiveness of a forest depends on the number of commercially extractable species, as well as location; the type of forests logged earlier may have differed from the ones logged later
- changes in logging practice with time, caused by (i) response to markets (with a larger share of the trees becoming 'economically attractive' for logging), (ii) technical harvesting practices and (iii) government regulation and monitoring of compliance to the rules.

In the absence of a further analysis of these factors, the mean of the various logged plots is used as an indicative of the 'logged forest' condition, without a time component for recovery. According to Lasco (2002), right after logging carbon stocks in primary forest can decline by about 50%. In tropical forest Asia, the decline is expected to range from 22%-67%, while other estimates for Indonesia indicated 38% - 75%. However, logging damage can be significantly reduced by practicing reduced-impact logging (including the use of directional felling techniques and well-planned skid trails).

In agroforesty systems around the study site, the estimated carbon stocks are 37.7 Mg ha^{-1} for systems that have been managed 0 - 10 years and 72.6 Mg ha^{-1} for systems 11 - 30 years of age, which are 16% and 32% of the primary forest values, respectively. *Jakaw* systems has slightly lower carbon stocks, 19 Mg ha^{-1} (8% of primary forest) for systems that had been fallowed 0 - 10 years and 58 Mg ha^{-1} (25%) for systems fallowed more than 10 years. The higher carbon stocks in agroforestry systems is to be expected as this system still has remnants forest trees, where as farmers slash and burn the vegetation in *jakaw*.

Imperata grassland and upland rice sytems stored 4 Mg ha^{-1} dan 4.8 Mg ha^{-1} of carbon. Most of the carbon stored by upland rice will be released during or after harvest. Carbon emission may also occur during weeding and soil tillage (Hairiah dan Murdiyarso, *in press*).

Carbon stocks components

Trees are the largest component of aboveground biomass. Result form study site shows that tree biomass from primary forest, logged-over-forest and agroforestry systems aged 11 - 30 years contribute to 90% of the total carbon (Figure 3.6). Only 10% of the total carbon is derived from necromass and understorey. Similar conditions were also found in a secondary forest and groforestry coffee area of Sumberjaya, Lampung where understorey and necromass contributed to only 8% of total carbon stock (van Noordwijk *et al*., 2002).

Between the various land use systems in Nunukan, *jakaw* systems that have been fallowed less than 10 years have the lowest fraction of their total biomass in the form of trees, but it still is 68%. The rest is derived from necromass (2.5%), understorey (7%) and litter (21.5%). Agroforestry systems aged 0 - 10 years have 86%, 0.4%, 5% and 17.6% of their total carbon stock in the form of tree biomass, necromass, understorey and litter, respectively. *Jakaw* plots have higher necromass (both relatively and absolutely) resulting from slash and burn activities practiced by farmers. As the agroforestry systems become more mature, the relative tree biomass component increases by 7%. In imperata grassland, carbon stocks is derived only from grass (and shrub).

Figure 3.6 shows the distribution of carbon stock components for each land use systems. The complete listing of estimated total carbon stocks and then its components from each sampling plot are recorded in Table 1.

Time-averaged carbon stocks

Time-averaged carbon stocks reflect the dynamics of carbon that is present in a certain land use systems over its life span. It depends on the rate of carbon accumulation, the minimum and maximum value of carbon stored by the systems, the length of time required to reach its maximum value and the rotation period (Palm *et al*, 1999).

For natural forest, it is assumed that the samples directly represent the 'time-averaged' carbon stock, reflecting the fine-scale mosaic of the patch regeneration cycle.

The expected pattern of logged-over forest over time is a direct decrease (due to biomass removal), followed by an induced-tree mortality phase with declining C stocks and a recovery of the vegetation (the dotted line in the upper panel of Fig. 3.6). The data derived from the field not really match the expected pattaren. The unexpected pattern especially noticeable in the plots logged 30-50 years ago. In the absence of an interpretable time pattern, the spatial average over the various logged-over forest plots is used as an estimate of the 'time-averaged' C stock.

For the agroforestry and the *Jakaw*-Rice land use systems a plot of total carbon stock versus time does match the expected increase (Fig. 3.7). A linear increase with a very small intercept characterizes the *Jakaw* data, while

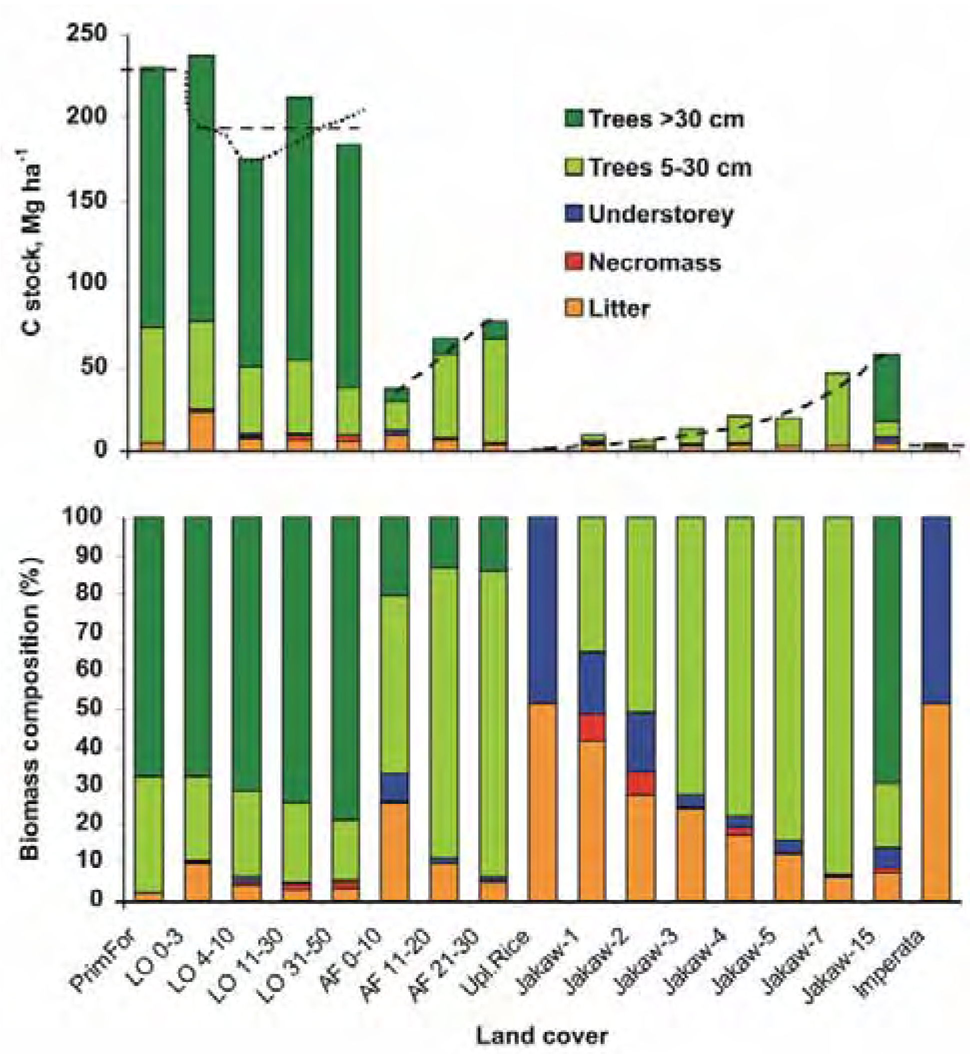


Figure 3.6. Aboveground carbon stocks and their relative composition in Nunukan (upper panel absolute values in Mg ha^{-1}, lower panel expressed as %)

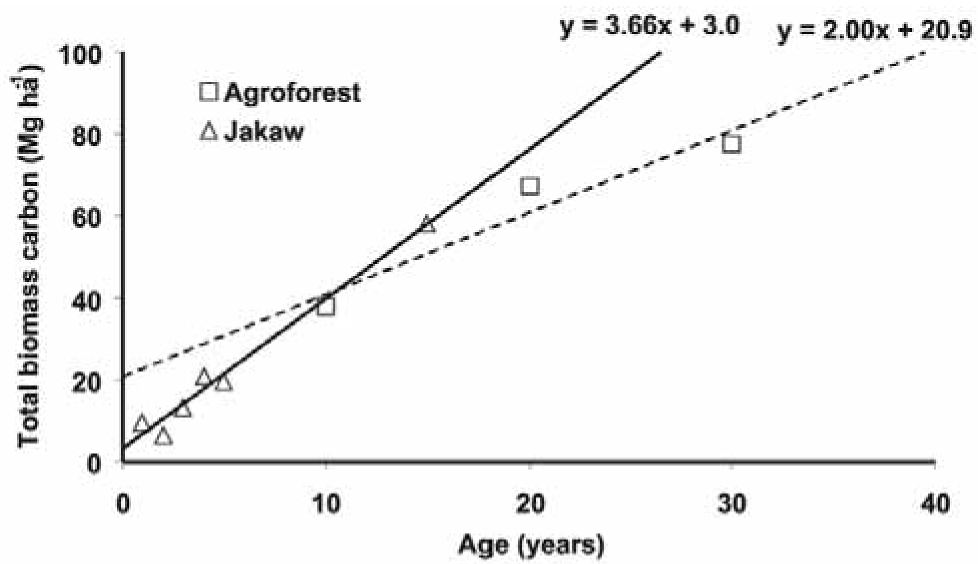


Figure 3.7. Rate of carbon sequestration in agroforestry and *jakaw* systems in Nunukan

the agroforestry systems data indicate a substantially higher intercept (remnant forest trees), as well as lower rate of increase.

The estimated rate of carbon sequestration for *jakaw*: 3.66 Mg ha^{-1} year^{-1} and for agrofrestry systems: 2.00 Mg ha^{-1} year^{-1} (Figure 3.7) are comparable to the fallow systems observed in Sumberjaya, Lampung with a rate of 3.44 Mg ha^{-1} year^{-1} (van Noordwijk *et al*, 2002). On the basis of this linear increase of total aboveground carbon stock with time, the time-averaged carbon stock as a function of rotation length for the *Jakaw*-Rice system can be derived using potrayed in Figure 3.7.

For the agroforestry system, two situations can be distinguished: (i) the system is rejuvenated at gap level ('sisipan') and older forest trees are selectively maintained. In this case the time-averaged C stock depends on the mean 'successional age' of the system; and (ii) the agroforestry sytems isrenewed at field level by clear felling and starts to build up from a near zero value in each cycle. The existing agroforests in Nunukan are mostly of the 'sisipan' type. More intensive tree crop production systems tend to be of the rotational type.

The impacts of land use change can be directly derived from a comparison of the time-averaged carbon stocks: a transition from natural forest to logging (at the historical intensities) costs 12% of the original carbon stock, a further shift of logged-over forest to agroforest costs a further 58% of the original carbon stock, while a change of logged forest to the *Jakaw*-Rice system costs 76 % of the original carbon stock, and degradation of the *Jakaw*-Rice to annually burned Imperata grasslands cost 10%. Vice versa, reclamation of Imperata grasslands to (rotational) agroforest can be expected to lead to a gain of 15-20% of the original forest carbon, while a modofication from the relatively mature *Jakaw* systems to agroforest can lead to a gain of about 25% of the original forest carbon stock.

Conclusions

- The natural forest of Kabupaten Nunukan has carbon stocks of abour 230 Mg ha^{-1} and is in line with existing estimates for forests of Sumatra and elsewhere in Kalimantan. The impact of historical logging practices on the carbon stocks have been relatively small (a 12% reduction in existing stocks), but it is possible that the

Table 3.4 Time-averaged carbon stock values for the four major land cover/land use systems of the uplands of Kabupaten Nunukan; for the agroforestry system two variants are described with different tree rejuvenation strategies (rotational or based on gap rejuvenation ('sisipan')); the currently dominant variants of the various land use systems are indicated in bold.

	Cycle length [years]	Time-averaged C stock [Mg ha^{-1}]	Relative to forest
Natural forest (remaining)		230.1	100.0
Logged forest (at historical logging intensity)		202.7	88.1
Agroforest	15	25.5	11.1
(rotational)	25	35.5	15.4
(sisipan)			
mean age	25	**70.9**	**30.8**
mean age	40	100.9	43.8
Jakaw-rice	4	7.1	3.1
1 year crop	6	10.6	4.6
X-1 year fallow	8	14.2	6.2
	10	17.8	7.7
	15	**26.9**	**11.7**
	20	36.0	15.7
Imperata (yearly fire)		4.2	1.8

original C stock of natural forest was higher and the losses due to logging have been higher if we assume that the best forests have been logged first and the remnant forest is not representative of the original condition.

- There are two main systems practiced by farmers in Sebuku-Sembakung area: (i) *Jakaw*-Rice systems, where farmers slash and burn logged-over-forest plots and plant upland rice for 1 or more years of cropping before farmers leave the land to a fallow egrowth phase and (ii) agroforestry systems, where farmers plant fruit trees in between remnant trees left from logging activities.
- Plot level measurement found that estimated carbon stocks of agroforestry systems is higher than that of the *jakaw* systems, with values between 19 and 58 Mg ha^{-1} for fallowed-*jakaw* of 0 - 10 years and more than 10 years and 38 and 73 Mg ha^{-1} for agroforestry systems managed 0 - 10 years and 11 - 30 years, respectively. The estimated carbon stocks of agrofrestry fruit-tree based systems found in the study area seems to be low compare to other agrofrestry systems in other areas, such as coffee based systems in Lampung and rubber agroforestry systems in Jambi. This could be due to the type of trees that exist in the tree-fruit based systems are of low wood density type (mostly are remnants trees of low commercial value).
- The annual rates of C sequestration after clear felling or in agroforests that represent relatively young succesional stages is of the order of 2 - 4 Mg C ha^{-1} year^{-1}, lower than the 5-7 Mg C ha^{-1} year^{-1} that are possible in well managed tree plantations. For an appraisal of the land use system level, however, the annual rates of C

sequestration do not need to be considered, as a comparison of 'time-averaged' C stocks allows a direct comparison.

- Conversion of forest to agricultural land for an upland rice - fallow growth cycle will reduce carbon stocks by more than 85%, depending on the length of the fallow cycle. The agroforest land use options where intensively managed trees provide income is an 'intermediate' land use system, which can be expected to function at about 31% of the original forest carbon stocks.
- The data suggest that well-managed forms of logging that avoid forest degradation may provide the best opportunity for maintaining high C stocks in the Nunukan landscape, while providing income to the local community. In practice, however, logging may be the start of a process of further degradation. To mitigate the loss of carbon stocks, a sustainable way of managing land in the more intensively managed agricultural domain is necessary. Agroforestry and other tree-based systems allow the generation of income with carbon stocks of 20-40% of the original forest, depending on the management regime chosen.
- Overall, management of logging activcities should be the highest priority in efforts to reduce the on going loss of carbon stocks, while enhancement of the agroforest land use form can provide a partial mitigating effect on the overall rate of carbon loss. For a further discussion of such options, however, the C stock data need to be combined with data on profitability, employment opportunity and returns to labour, as is discussed in Chapter 5.

4. LAND USE CHANGE IN NUNUKAN: ESTIMATING LANDSCAPE LEVEL CARBON-STOCKS THROUGH LAND COVER TYPES AND VEGETATION DENSITY

Atiek Widayati, Andree Ekadinata and Ronny Syam

Introduction

Background

Forests harbour large carbon stocks. Undoubtedly, Kalimantan as one of the largest islands in Indonesia and with vast areas of forest left but a rapid rate of decline in forest cover as well as forest quality, has become a major focus in discussions on the dynamics of forest cover and the impacts on carbon stocks and carbon sequestration.

The FORMACS project of CARE Indonesia in Kabupaten Nunukan was established to test community based forest management as an approach to enhance local livelihoods and reduce negative current trends of forest cover change. Carbon-stock monitoring is needed to evaluate the effectiveness of the project approach towards the goals and to establish a baseline of the rate of change before the project became fully effective.

Remote sensing approaches are an effective way to monitor landscape changes over time. By integrating the changes in vegetation cover with carbon stocks measurements at plot level, changes in carbon stocks at a landscape level can be estimated. Two methods used for such studies: (i) approaches that relate quantitative pixel-level information to carbon stocks as a basis for spatial extrapolation, and (ii) approaches that first classify the land cover according to land use units and then convert to carbon stocks on the basis of properties of the land use units.

Both methods have strengths and weaknesses, and mixed approaches are possible. This study applied both approaches and assessed the level of uncertainty in both.

Objectives

The objectives of this study are:

- Analyze land cover changes from 1996 to 2003 for Kabupaten Nunukan by comparing two independent remotely-sensed-derived land cover maps for the respective years.
- Produce vegetation density maps through the analysis of a Normalised-Difference Vegetation Index (NDVI) of the remotely sensed data.
- Relate the observation points of carbon-stock measurement to the NDVI at pixel level as a basis for spatial extrapolation to the whole landscape.
- Relate mean carbon stock estimates per land cover class to the changes in land cover for an alternative assessment of landscape level carbon stocks
- Assess the strengths and weaknesses of both approaches on the basis of the ncertainty in the underlying relationships,

to advise on the method to be used in future work.

Study Site

Kabupaten Nunukan is located at the northeastern-most part of East Kalimantan province, covering six subdistricts (kecamatan), i.e Krayan, Lumbis, Sebuku, Sembakung, Nunukan and Sebatik (Figure 1.1). Most of Kabupaten Nunukan consists of the Sembakung and Sebuku river basins (each with an 'upland' and 'lowland/coastal' Kecamatan Lumbis-Sembakung and Sebuku-Nunukan, respectively). The western most subdistrict, Krayan, drains to Malinau district and is not accessible from the two main rivers of Nunukan (Figure 4.1). It has a different dynamic of forest cover change. For the more detailed discussion of carbon stocks we will focus on the Sembakung and Sebuku river basins.

Data

Image data used

Multitemporal Landsat images were used to produce land cover maps of Kabupaten Nunu-kan. Acquisition date of each image is shown in table 4.1. Satellite image coverage over Kabupaten Nunukan area is shown in figure 4.2.

Spatial and spectral characters

Spatial resolution of Landsat images is 30 m with 7 spectral channels, ranging from 0.45-0.69 m in the visible spectrum and 0.76-2.35 m in the infrared spectrum. Each band represents different characteristics of wavelengths used to capture features on the earth surface (Table 4.2.).

Table 4.1 Image acquisition dates

Image path/row	Series 1: Landsat 5/ETM	Series 1: Landsat 7/ETM
117/057	December 29th, 1996	January 23rd , 2003
118/057	July 13th, 1996	May 22nd, 2003
118/058	August 17th, 1997	May 22nd, 2003

Table 4.2 Landsat image spectral characteristics (Lillesand and Kiefer, 1994)

Channels	Wavelength (µm)	Characteristics and possible application
1	0.45-0.52	Provides increased penetration of water bodies Supports analyses of land use, soil, and vegetation characteristics
2	0.53-0.6	Corresponds to the green reflectance of healthy vegetation Sensitive in the region between the blue and red chlorophyll absorption bands.
3	0.63-0.69	Sensitive to red chlorophyll absorption of healthy green vegetation, therefore it is important bands for vegetation discrimination. Useful for soil-boundary and geological boundary mapping
4	0.76-0.9	Responsive to the amount of vegetation biomass Useful for identification of vegetation types, Emphasizes soil-crop and land-water contrasts
5	1.55-1.75	Sensitive to turgidity - the amount of water in plants. Discriminate between clouds, snow, and ice Able to remove the effects of thin clouds and smoke
6	10.4-12.5	Measures the amount of infrared radiant flux (heat) emitted from surfaces. Used in locating geothermal activity,
7	2.08-2.35	Discriminate between geological rock formations. Effective in identifying zones of hydrothermal alteration in rocks.

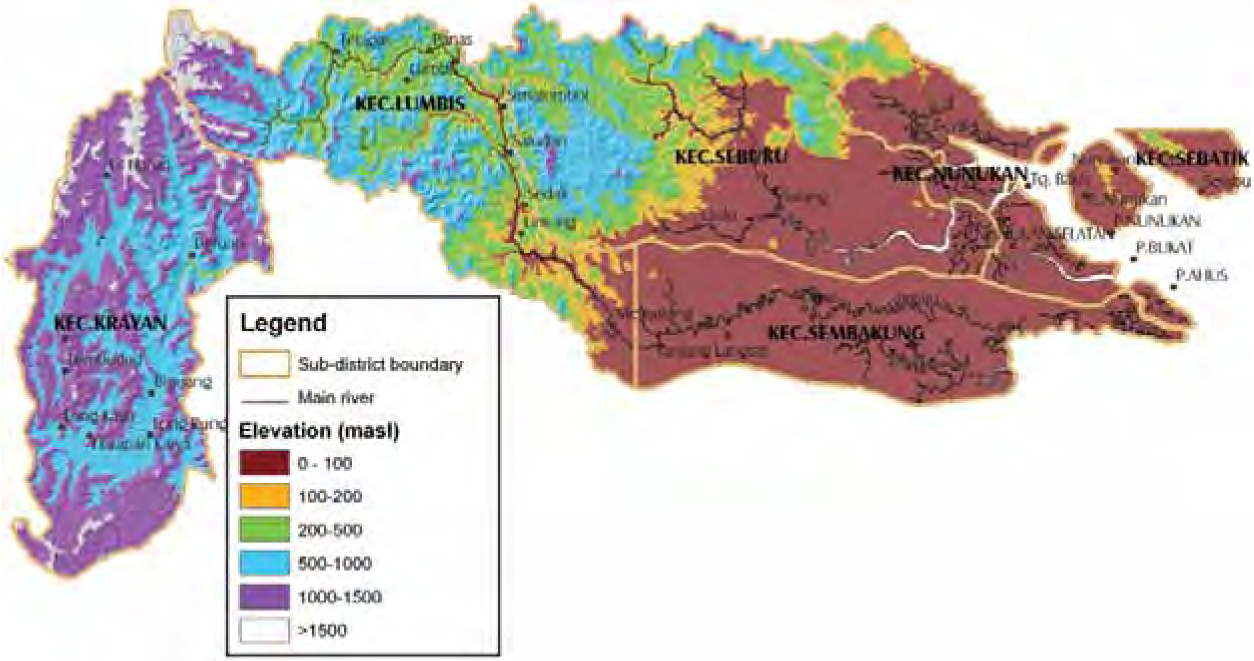


Figure 4.1 Elevation map of Kabupaten Nunukan, East Kalimantan

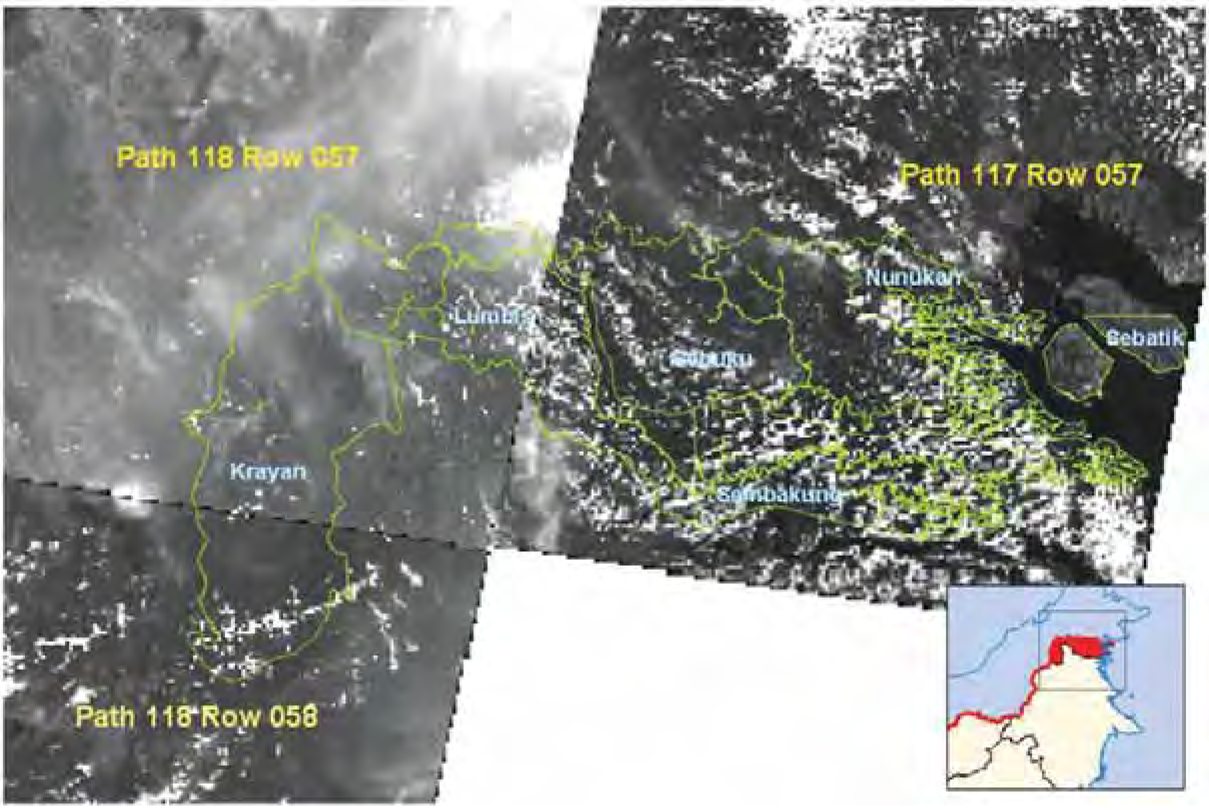


Figure 4.2 Landsat images coverage

Auxiliary Geospatial data (Maps)

Auxiliary geospatial data was required to support the analyses conducted in Kabupaten Nunukan. Four main types of information needed are topography, administrative divisions, geology and land system. Table 4.3 shows the list of maps used in this study.

Methods

Land cover classification and land cover change

Land cover change analysis was conducted on Landsat images using post classification comparison methods where information of changes is derived from multitemporal land cover maps. The flowchart of land cover classification and change detection is shown in figure 4.3.

Image corrections

Radiometric correction

Raw, remotely sensed data captured by a satellite, provide information about object's reflectance at the surface of the earth, which are scaled to a range of number called Digital Counts (DC) or Digital Numbers (DN). Along with the scaling process, some distortion is caused by atmospheric scattering, variation in viewing angle, scene illumination, and instrument response characteristic (Lillesand and Kiefer, 1994 and Chavez, 1996). Practically, the objective of a radiometric correction is to remove the radiometric noises mentioned above.

Geometric correction

Satellite images usually contain geometric distortion caused by several factor ranging from variations in altitude, satellite attitude, and velocity of the sensor platforms, to factors such as panoramic distortion, earth curvature, atmospheric refraction, relief displacement and non-linearities in the sweep of a sensor's IFOV (Instantaneous Field of View) (Lillesand and Kiefer, 1994). To correct the distortion, a geometric correction has to be conducted. Assuming that geometric distortion on images used in this research are non-systematic distortions, geometric correction was carried out by establishing mathematical relationship between pixels in the image and the corresponding coordinates of those pixels on the ground. The mathematical relationship was established based on a set of Ground Control Point (GCP) derived from the topographic map.

Land cover classification

Land cover classification was conducted using supervised classification methods. In supervised classification, training areas are used to define spectral patterns/signature for a specific land cover feature. The signature will then be used by a set of classifiers to identify similar patterns of characteristics over all the area of interest. The result will be an image categorized into a number of land cover types.

Table 4.3 List of maps used in Nunukan study.

No	Title	Scale	Source
1	Topographic map	1:50,000	Dit Top Angkatan Darat
2	Nunukan Spatial Planning Map	-	BAPPEDA Nunukan
3	Geology map	1:250,000	Pusat Penelitian dan Pengembangan Geologi
4	Land System Map	1:250,000	Transmigration Department

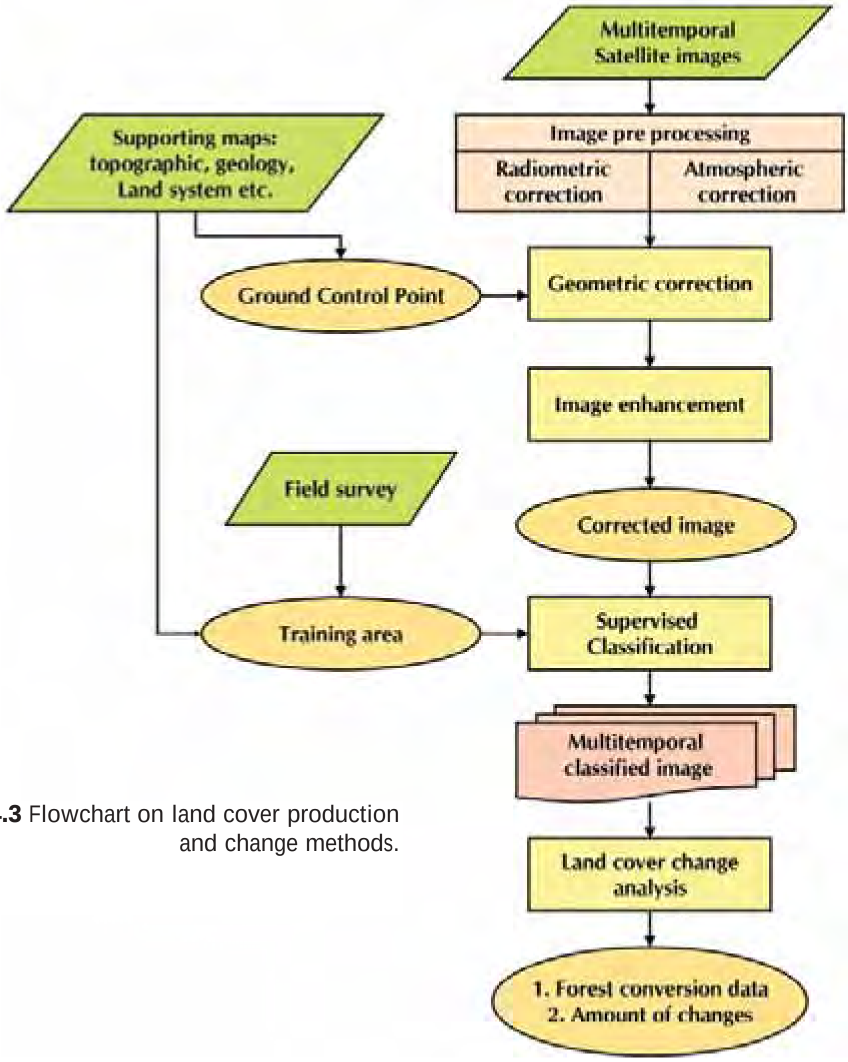


Figure 4.3 Flowchart on land cover production and change methods.

Training samples

Training samples for image classification were obtained during field verification. Global Positioning System (GPS) was used to record the position of training samples. A total of 14 land cover classes were identified during field data collection. The classes are shown in table 4.4.

Classification procedures

Classification process to produce land cover map of Nunukan followed a hierarchical classification structure as shown in figure 4.5. The structure divided the classification process into 3 levels where each level utilized a different source of information combining training sample's spectral signature from

Table 4.4. Land cover classes

No	Land cover Class
1	Mangrove
2	Primary forest
3	Industrial timber plantation
4	Logged-over forest
5	Secondary forest
6	Old mixed garden (agroforest)
7	Young mixed garden (agroforest)
8	Young oil palm plantation
9	Shrub land
10	Cleared land
11	Settlement
12	Fish ponds
13	Water body

Figure 4.4. Land cover types in Nunukan; shrub land (upper left), young oil palm plantation (upper right), fishpond (lower left) and secondary forest (lower right). (*Foto: PT Hatfindo Prima*)

satellite image and supporting information derived from thematic maps.

The first level of the hierarchy aimed to classify land cover classes based only on spectral characters derived from training samples. Two of the classes, however, were lumped and needed to be separated on the second and third level using other information. On the second level the two components of the class "mangrove and primary forest" were separated using thematic information from land system, geological and topographic maps. In the broad group of "secondary forest" a number of distinctions were made: Industrial plantations were identified using industrial concession maps of Kabupaten Nunukan, while old mixed garden was identified using its association with settlement, road and river. Logged-over forest was classified using thematic information from forest concession map of Kabupaten Nunukan and the presence of logging tracks, which are clearly seen in Landsat images. A remnant category of 'secondary forest' was retained. Level 3 of the hierarchy split the logged over forest category into classes, using additional information derived from monitoring sample plots in Kabupaten Nunukan.

Land cover change detection

Land cover change was detected by using the post classification comparison method (Sunar, 1998). The 1996 and 2003 classified images of Kabupaten Nunukan were overlaid and compared to be able to quantify the changes.

Vegetation density mapping

In satellite images, the spectral response is primarily sensitive to vegetation density (leaf

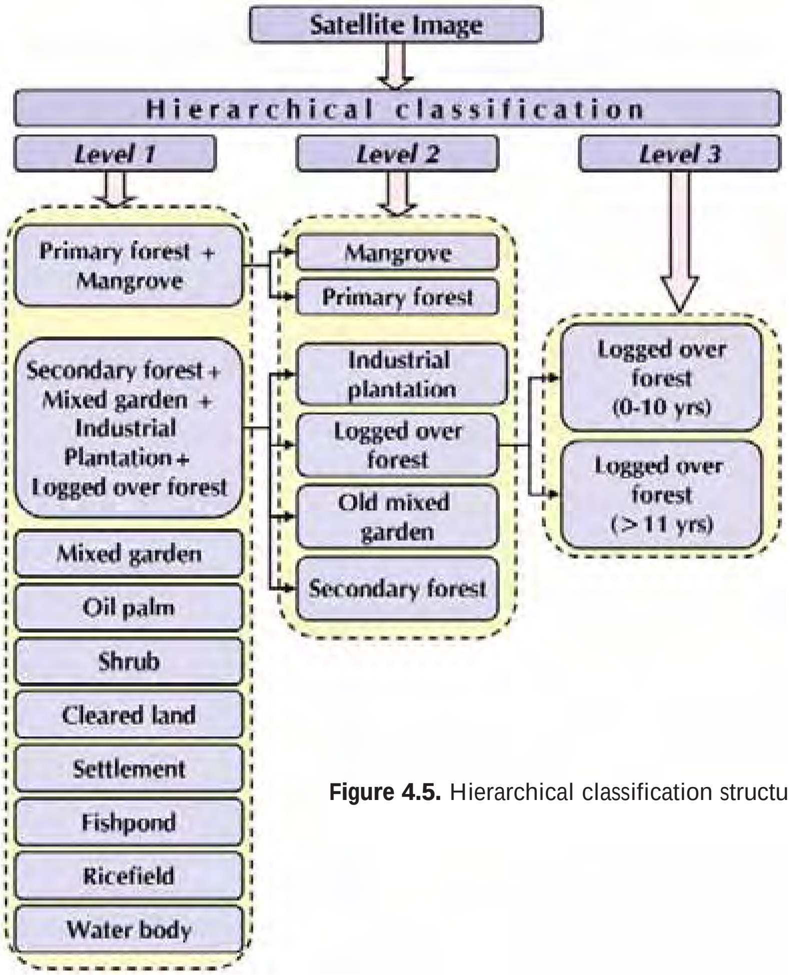


Figure 4.5. Hierarchical classification structure

area index), as well as canopy shading and leaf moisture. As a vegetation develops from open land through various successional stages, visible reflectance decreases in the visible spectrum due to the increased of leaf area and absorption as well as through shadowing both by and within the canopy. The maximum leaf area index is, however, reached much earlier in succession than the maximum tree basal area and tree biomass. On the same circumstances, near infrared reflectance increases due to reflectance from the canopy, transmission throughout the canopy and reflectance of the soil. (Coops, 1996).
The dynamics of visible-infra red spectral response against vegetation density can be well represented by a 'vegetation index' (Huete, 1998). This simple mathematical combination of the Red band and NIR band has been found to be a sensitive indicator of the presence and condition of green vegetation (Lillesand and Kiefer, 1994). While there are several versions of such vegetation indices, the one that was used in this study is the *Normalized Differences Vegetation Index* (NDVI).

NDVI calculation

The NDVI basically measures the slope of the line between the origin of red-NIR space and the red-NIR value of the image pixel. NDVI is calculated using the formula:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

where NIR=value of near infra red channels; red=value of visible-red channel

The range of NDVI values are -1 to 1. Value of -1 to 0 is usually assumed as non-vegetation.

For this study, NDVI is presented as percentage with the lowest original value (-1) presented as 0 and the highest (1) as 100.

Estimation of land cover under the cloud cover

High cloud cover in the images (up to 40 %) leaves the resulting land cover map with a "No data" value, which made it difficult to obtain land cover areas accurately and which especially created large gaps in the land cover change analysis (as clouds covered different areas in the subsequent images) as needed for landscape level carbon-stock estimation. An approach with GIS techniques was tried to estimate the fraction and area of land cover under the cloud-covered area using Landcover information from the cloud-free area in combination with the other layers of Landsystem and especially Elevation. The flow diagram of the method is presented in Figure 4.6.

Landscape C-stock estimation

Two methods were used for estimating total carbon stocks on the basis of the spatial data. Method one used the land cover information obtained as well as estimated from the procedures above and multiplied the area in each class with the typical aboveground carbon stock density [Mg C ha^{-1}] obtained from Chapter 2 (Rahayu *et al.*, this volume; with a number of additions from the literature for land cover types not sampled locally). Method two established a relationship between pixel level carbon stock and pixel level NDVI as a basis for spatial extrapolation.

Method 1: extrapolation based on land cover map

The two-time snapshot landscape level carbon stock was basically done by re attributing the land cover map of the particular year with corresponding plot-level carbon stock. The expected output was a carbon-stock estimation based on land cover.

The stepwise procedure was:

1. Re-interpretation of the land cover types in the map to the land cover type defined from plot measurement, to find the corresponding definition.
2. Re-attribute the land cover type with the carbon density[1] per land cover type from the plot measurements (table 4.5).
3. Area calculation of each land cover type, to achieve carbon budget for the the Sembakung and Sebuku river basins in Nunukan, for 1996 and for 2003.

Method 2: extrapolation of plots C-stock through vegetation density

To date, there is no method to measure tons of carbon on the ground in landscape level. Correlation between NDVI and ground based data has yielded information about standing biomass and is typically the approach to estimate carbon (Brown, 1996). Studies have been done to estimate biomass or other tree/vegetation biophysical characters using spectral characteristics or transformations of remotely-sensed data. Empirical approaches have found strong relationship between spectral transformations and basal area and (log) tree density (Coops, 1996). Relationship of spectral characters and biomass will reach saturation as canopy closes. Gemmel & Goodenough (1992) in Coops (1996), said that stand basal area continues

[1] Throughout this paper, carbon density is used to describe carbon stocks at plot level, while carbon stocls refer to carbon at landscape level

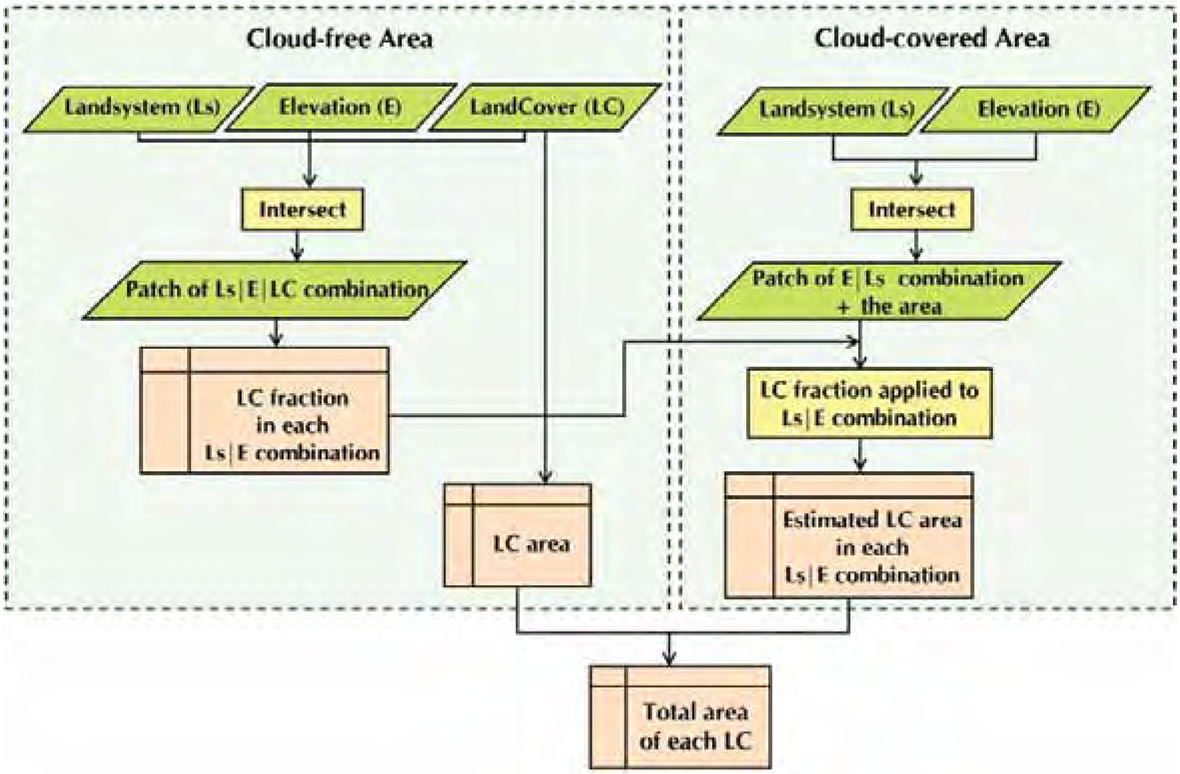


Figure 4.6. Estimation of land cover types under cloud-covered areas

Table 4.5. Re-classification result of carbon stock estimation process (Rahayu *et al.*, this volume)

No.	Land cover type from image classification	Corresponding land cover type at plot measurement	Carbon density (Mg ha^{-1})
1	Primary forest	Primary forest	230.1
2	Logged over forest	Logged over forest	201.3
3	Shrub	Jakaw 0-10 yrs (logged, padi + secondary growth)	19.4
4	Secondary forest	Jakaw > 10 yrs (logged, padi + secondary grwoth)	58
5	Young mixed garden	Agroforestry 0-10 tahun	37.7
6	Old mixed garden	Agroforestry 11-30 tahun	72.6
7	-	Imperata	4.2
8	Industrial plantation	Acacia (Lasco *et al.*, 1999)	88.1
9	Mangrove	Mangrove (Lasco *et al.*, 2000)	176.8
10	Young plantation	Oil palm (Tomich *et al.*, 1998)	91
11	Ricefield	-	
12	Fishpond	-	
13	Cleared land	-	
14	No data	-	
15	Settlement	-	
16	Water body	-	

to increase as the stand grows older but the remotely sensed signal is not affected by this increase because it is most effective to the degree of crown closure which reaches 100% at an early age. As for LAI, relationship between NDVI and LAI is curvilinear and reaches plateau at an LAI of ~6 for coniferous forest (Spanner, Pierce *et al.*, 1996, in Brown, 1996).

The emphasis of this method was to find a relationship between plot level C-stock with the parameter(s) of remotely-sensed data, which is in this case NDVI representing vegetation density. Plot level data on aboveground C stocks are based on four components: tree biomass, understorey vegetation, necromass and litter. NDVI essentially measures the greenness level of vegetation, i.e the leaf components of tree biomass and understorey vegetation. The large fraction of the area with cloud cover and thus absence of NDVI data, restricted the use of method 2 to the cloud-free areas.

The stepwise procedure was:

1. Obtain NDVI values at the positions of the sample plots.
2. Analyze the statistical regression of plot level C stock on NDVI of the associated pixel.
3. Apply the selected regression equation to estimate C stocks in all cloud-free pixels and summarize the results for the the Sembakung and Sebuku river basins in Nunukan, for 1996 and for 2003.

Results and Discussions

Land cover

Land cover 1996

Image classification result of Landsat TM 1996/1997 (figure 4.7) shows that forest was still a dominant land cover type in Kabupaten Nunukan at that time. Classes of primary and secondary forest comprise a total area of almost 9000 km^2 or more than 55% of total area of Kabupaten Nunukan. The total area should be considered as an underestimation as several areas is classified as "no data" due to cloud cover on the satellite image. Mangrove covered more than 5% of the total study area, near the coastline and of Nunukan and Sembakung Sub-districts. The area of "No data" covered almost 28% of total Nunukan's area in the 1996/7 image (table 4.6).

Land cover 2003

Figure 4.8 shows the classification result of Landsat ETM 2003. Cloud cover on the 2003 image was almost 42%, higher than the one in 1996. Primary and secondary forest decreased to about 44% of the district although they are still the dominant land cover types in the area, while shrub increases to 320 km^2 or almost 2% of Nunukan.

Land cover estimation for cloud covered areas

The result of land cover estimation of cloud-covered area using land system and elevation map in 1996 and 2003 is shown in table 4.8, respectively, for the Sembakung and Sebuku river basins, covering approximately 1.1 million ha out of the 1.6 million ha of Kabupaten Nunukan. With cloud-covered removal, in 1996, the area estimation of primary forest increased from 55.6% to 84%; for 2003, the estimated primary forest increased from 28.9% to about 64%.

Land cover changes

Land cover change in the Sembakung and Sebuku river basins in Nunukan over the 1996-2003 period first of all indicates forest conversion. Primary forest decreased from 915,183 ha in 1996 to 697,695 ha in 2003, which means about 24 % of the remaining primary forest disappeared in 7 years (figure 4.9); the equivalent yearly relative conversion

Table 4.6. Area summary of 1996 classified image

CLASS_NAME	Sum km²	%
Water	1263.68	7.9182
Logged over forest	107.35	0.6727
Primary forest	8566.97	53.6809
Secondary forest	396.34	2.4835
Young mixed garden	65.57	0.4108
Old mixed garden	91.50	0.5734
Mangrove	803.37	5.0339
No data	4449.08	27.8781
Settlement	1.20	0.0075
Ricefield	9.05	0.0567
Shrub	124.14	0.7779
Fishponds	7.58	0.0475
Cleared area	73.23	0.4589
Total	**15959.06**	**1**

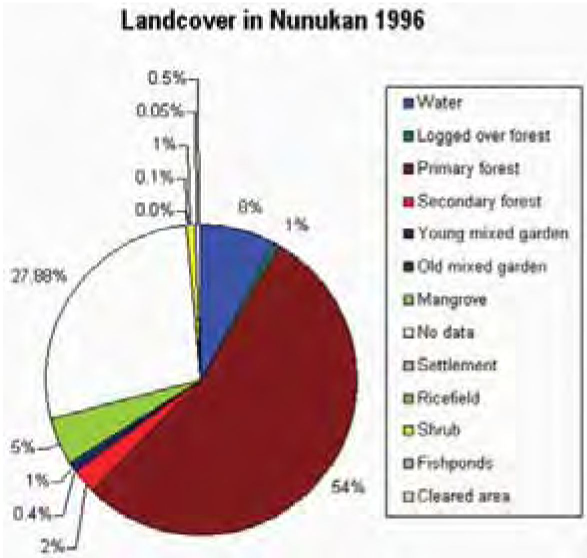
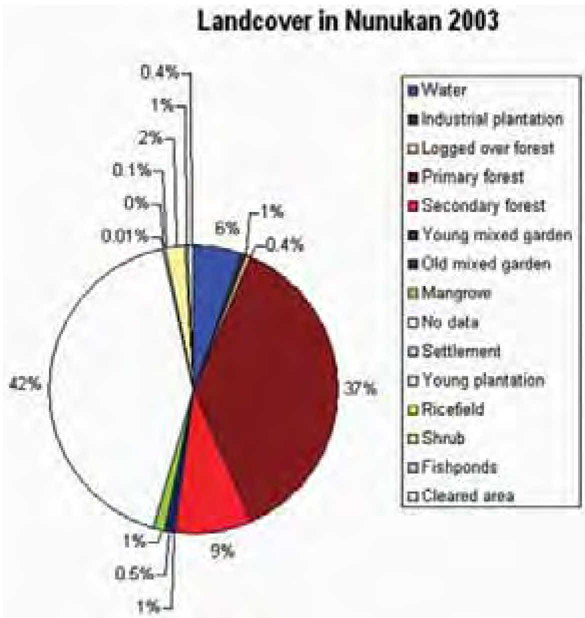


Table 4.7. Area summary of 2003 classified image

CLASS_NAME	Sum km²	%
Water	890.6463	5.58
Industrial plantation	88.9245	0.56
Logged over forest	65.9511	0.41
Primary forest	5865.5493	36.76
Secondary forest	1364.0382	8.55
Young mixed garden	119.3238	0.75
Old mixed garden	73.1916	0.46
Mangrove	228.5811	1.43
No data	6718.2588	42.10
Settlement	1.674	0.01
Young plantation	48.8646	0.31
Ricefield	20.6442	0.13
Shrub	321.3576	2.01
Fishponds	80.1468	0.50
Cleared area	70.2036	0.44
Total	**15957.36**	**100**



rate is 3.85%. A map (figure 4.10) of forest conversion maps suggests that most of the conversion took place close to the main rivers. The mangrove zone was quite stable, covering 6% of the Sembakung and Sebuku river basins along the coastline. The main land cover class that replaced primary forest was the generic 'secondary forest' class, with relatively small increments for industrial timber plantations, shrub and fishponds.

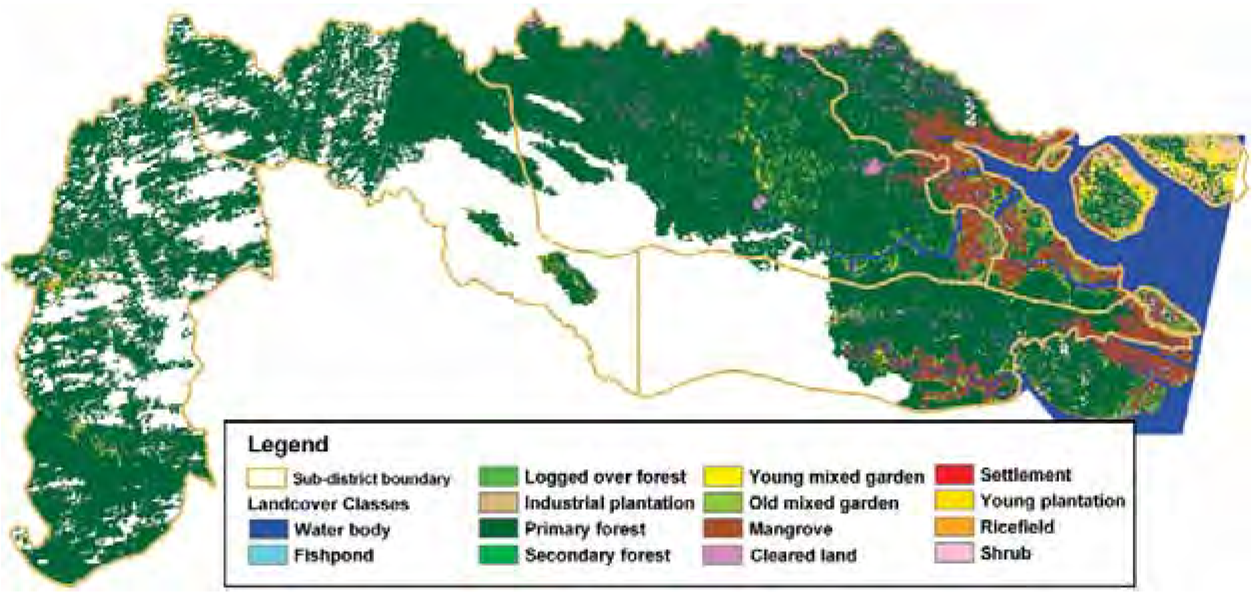


Figure 4.7. Classified image of Landsat 1996/1997

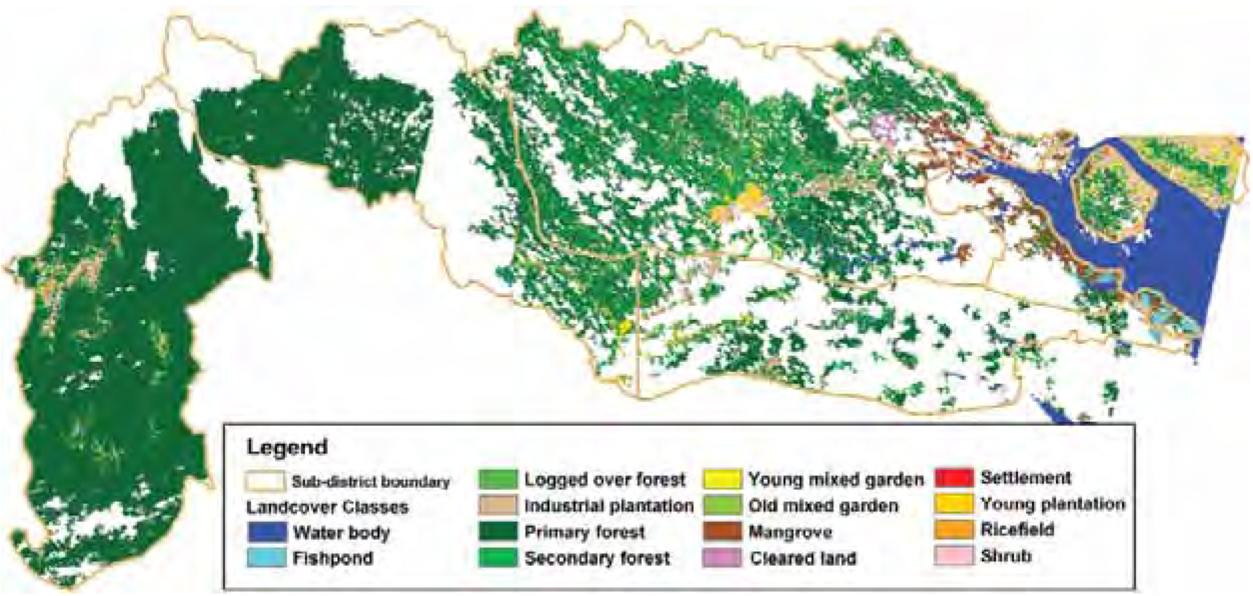


Figure 4.8. Classified image of Landsat 2003

Table 4.8A. Land cover 1996 of Nunukan after cloud removal

Land cover classes	Before cloud removal ha	Before cloud removal %	After cloud removal ha	After cloud removal %
Water body	25641.06	2.35	25886.41	2.38
Logged over forest	8802.26	0.81	8904.11	0.82
Primary forest	606337.99	55.65	915183.03	83.99
Secondary forest	29379.53	2.70	31521.27	2.89
Young mixed garden	6519.73	0.60	7085.34	0.65
Old mixed garden	8248.01	0.76	8978.87	0.82
Mangrove	70190.31	6.44	71532.09	6.56
Settlement	114.13	0.01	114.48	0.01
Shrub	11202.54	1.03	12896.81	1.18
Fishpond	184.97	0.02	185.49	0.02
Cleared land	5977.22	0.55	6615.71	0.61
No data	317041.63	29.10	735.78	0.07
Total	1089639.40	**100**	1089639.40	**100**

Table 4.8B. Land cover 2003 of Nunukan after cloud removal

Land cover Classes	Before cloud removal ha	Before cloud removal %	After cloud removal ha	After cloud removal %
Water	9950.47	0.91	10322.32	0.95
Logged over forest	8982.65	0.82	9244.66	0.85
Industrial plantation	6323.42	0.58	21172.53	1.94
Primary forest	314297.95	28.86	697695.81	64.07
Secondary forest	121823.99	11.19	184554.40	16.95
Young mixed garden	9936.01	0.91	13706.55	1.26
Old mixed garden	5239.42	0.48	5970.62	0.55
Mangrove	22339.35	2.05	67341.96	6.18
Settlement	155.10	0.01	323.71	0.03
Young plantation	4954.62	0.46	9037.78	0.83
Ricefield	942.36	0.09	2361.90	0.22
Shrub	25999.39	2.39	34299.43	3.15
Fishpond	7353.06	0.68	22115.31	2.03
Cleared land	6410.43	0.59	8918.61	0.82
No data	544216.06	49.98	1858.68	0.17
Total	1088924.27	1	1088924.27	

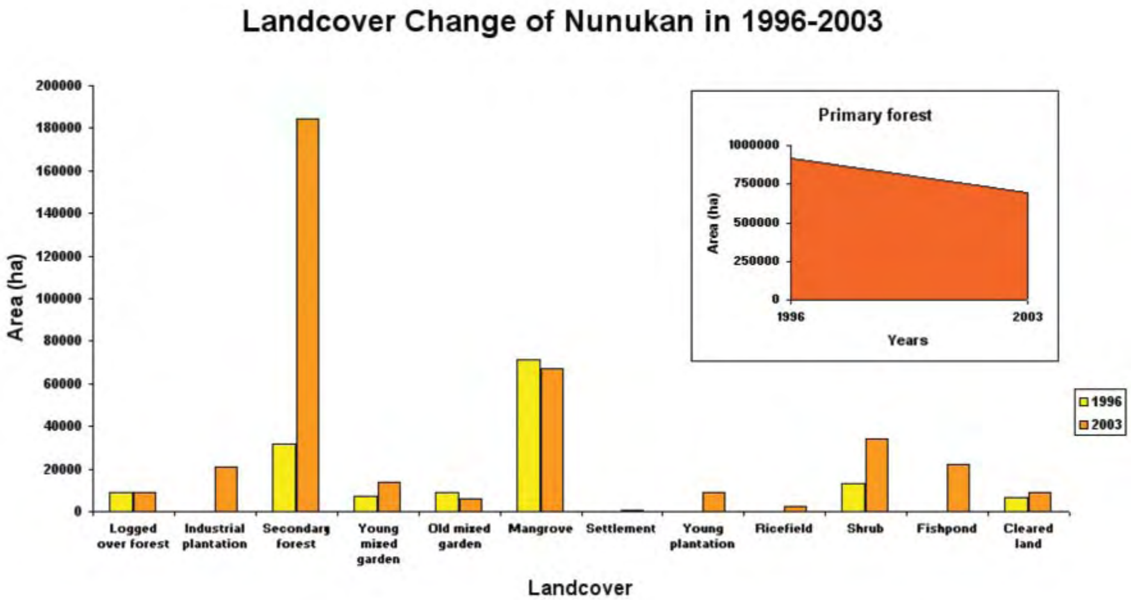


Figure 4.9. Land cover change of Sembakung and Sebuku river basins in Nunukan in 1996-2003

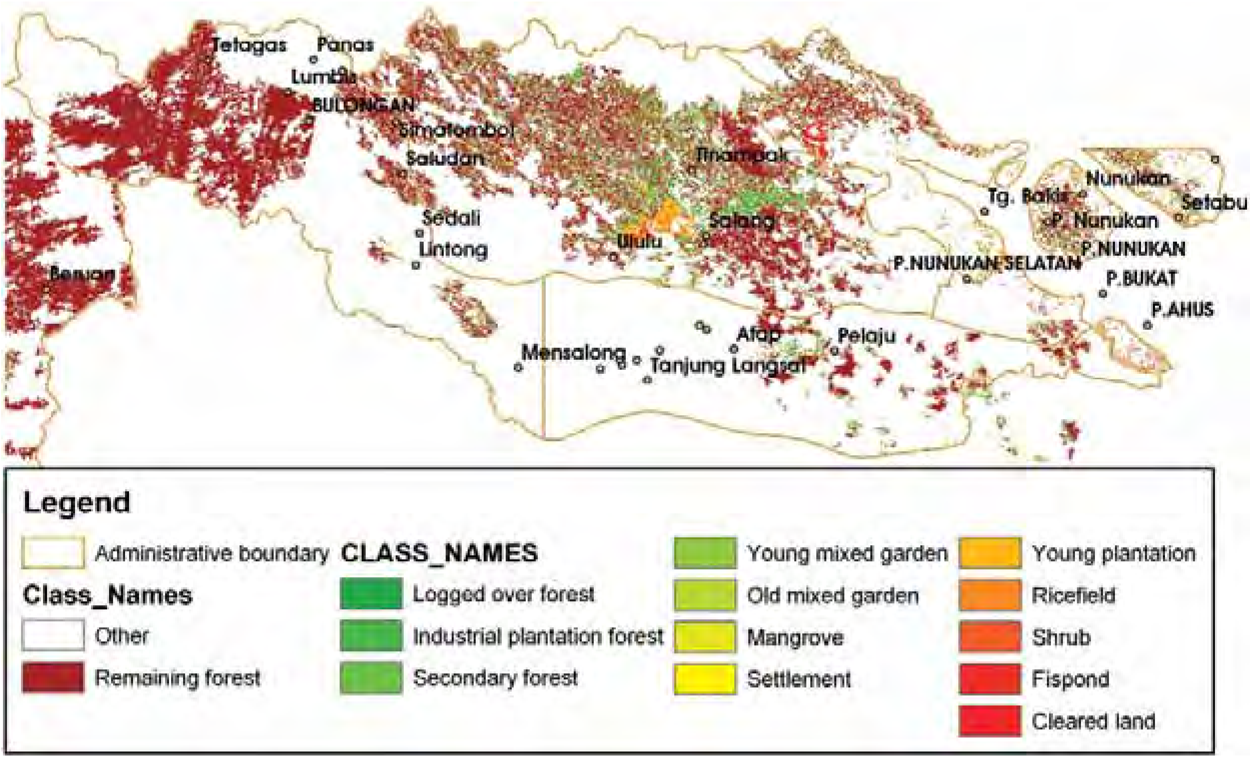


Figure 4.10. Forest change map of Sembakung and Sebuku river basins in Nunukan

Vegetation density

From the NDVI calculation, two NDVI maps are obtained and are shown in Figure 4.11. NDVI varied between 50 and 99, with only very few pixels with NDVI of less than 50 (non-vegetated).

The uneven cloud cover areas of 1996 and 2003 make it difficult to compare the distribution precisely, but large areas in Sebuku with NDVI values in the 70-99 range in 1996 shifted to the 60-70 range in 2003.

Images were not calibrated to various atmospheric and seasonal factors (the east image and west image were from different seasons) and therefore, the range of NDVI resulted was affected.

Difference in season caused a discrepancy in the NDVI calculation, due to different water content of the vegetation, although land cover did not change. Another factor was haze, which caused imperfect NDVI calculation (lower NDVI resulted). This case is clearly seen in west Lumbis with low NDVI (40-50), while most of those areas are still forest.

Landscape C-stock estimation

Land-cover-derived carbon stock estimation

The carbon density map (Figure 4.12) derived from the land cover classes and the typical C densities (Table 4.5) indicates a substantial decrease over the 1996-2003 period, especially along the rivers in the central part of Kecamatan Sebuku.

The total carbon budget estimated from land cover was obtained from the total areas of each land cover types, which include the ones estimated under the cloud cover. In the Sembakung and Sebuku river basins in Nunukan the total carbon stock was approximately 228 Tg[2] in 1996 and 189 Tg in 2003, which means a 17% decrease in seven

[2] 1 Tg= 10^{12} g

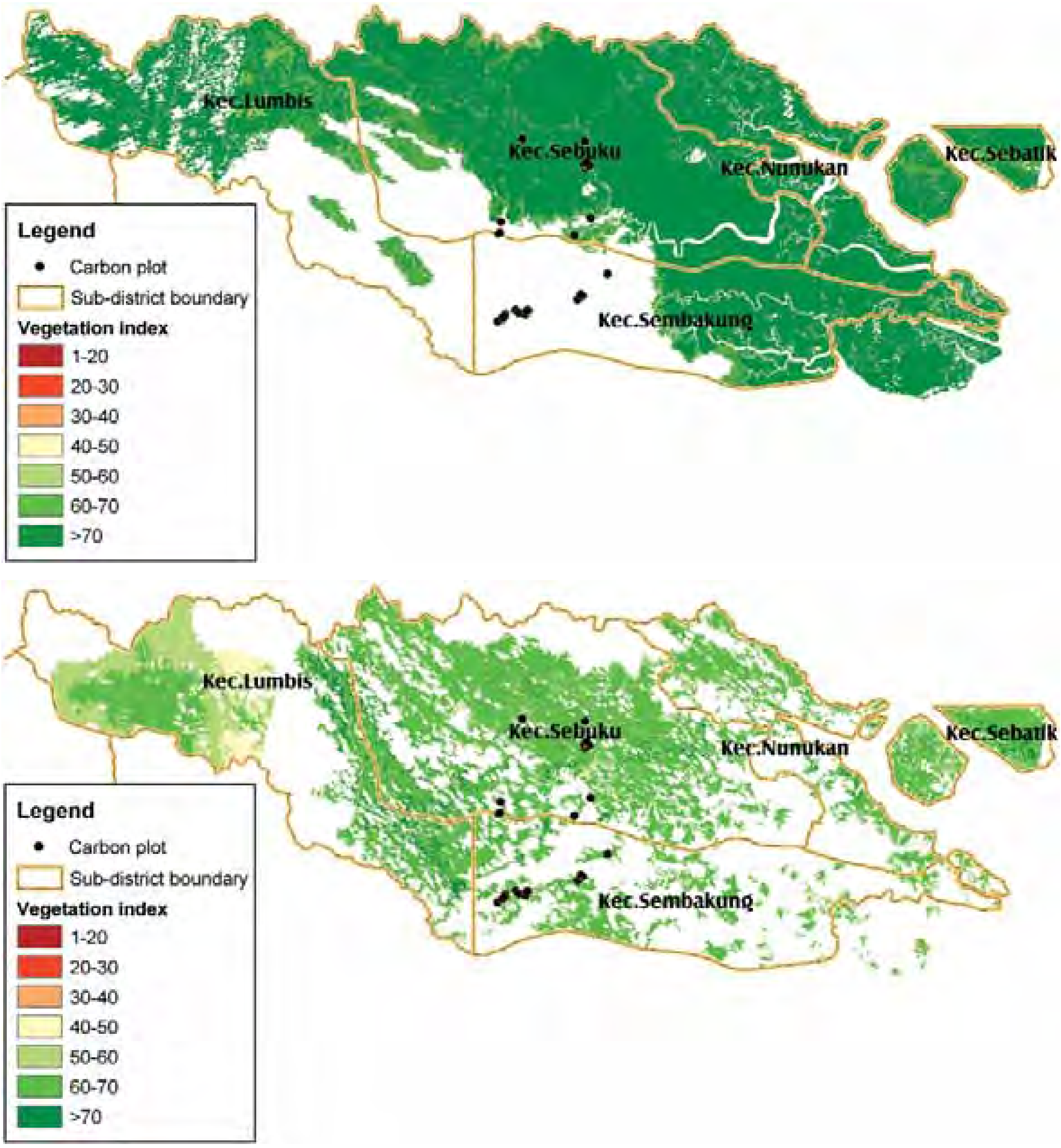


Figure 4.11. Vegetation density (NDVI) in of Sembakung and Sebuku river basins in Nunukan in 1996/7 (upper panel) and 2003 (lower panel) and the distribution of carbon-stock measurement plots.

years. Mean carbon stock density decreased from 209 to 174 Mg ha^{-1}, mostly due to the conversion of 217,000 ha of primary forest to other uses. The loss of C stock (17%) is less than the loss of primary forest (24%).

The geographic distribution of forest conversion, and thus carbon-stock decrease, is hard to be precisely described due to the cloud cover, but in general it can be seen that Kecamatan Sebuku has been experiencing forest loss substantially into *jakaw*, logging and new plantations. In Kabupaten Nunukan, the coastal areas are more or less stable with the existence of mangrove. However, the northern part also shows forest degradation and opening to other uses. These conversions explain the subdistrict's contribution to the decrease of carbon stock.

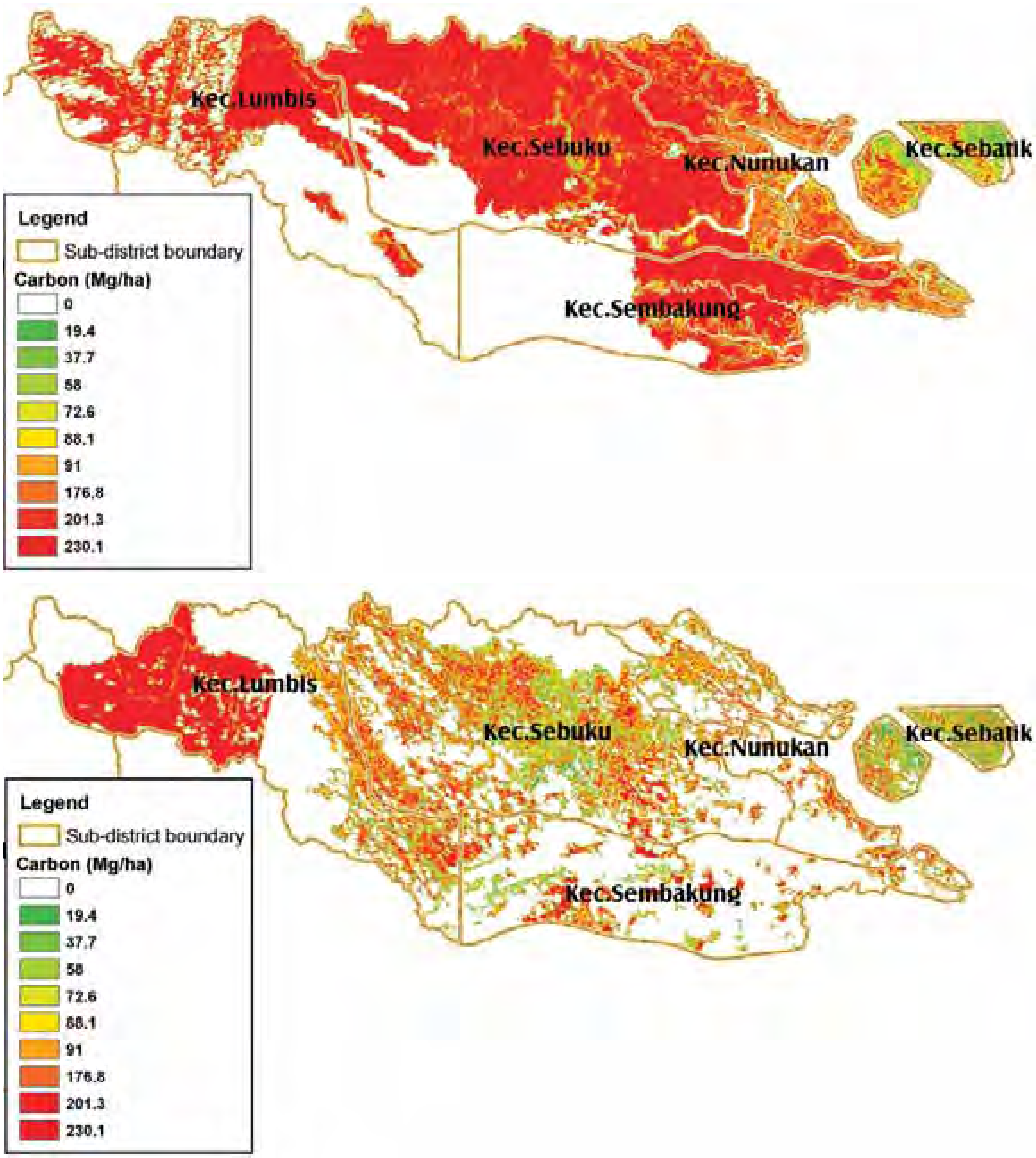


Figure 4.12. Distribution of land cover-derived carbon density in of Sembakung and Sebuku river basins in Nunukan in 1996/7 (upper panel) and 2003 (lower panel).

Vegetation density-derived carbon-stock estimation

Reference carbon density from plot measurements

Only 26 plots in cloud-free areas of the Landsat image could be used for the regression of NDVI on aboveground carbon stock (Appendix 1). The plots with the highest NDVI were agroforest and *Jakaw* left for fallow for > 6 years (NDVI >=69). These high values are expected and come from relatively dense canopy cover from the growing trees in the plot. Logged over forest also had high NDVI (67-69). *Jakaw* plots with a short fallow period corresponded to a wide range of NDVI values (45 - 67). Unfortunately, all the forest plots are located under the cloud-covered areas, and no NDVI values of those plots can be obtained. Relationship between plot carbon density and NDVI values are presented in Figure 4.13.

The relationship between NDVI and carbon stock was distinctly curvilinear and a logarithmic transformation of the C stock data was needed to meet the assumption for standard regression analysis of uniform variability. While carbon density keeps increasing with increments of woody biomass and growth of trees, NDVI values show saturation at the values of 70 as leaf area index reach a maximum. For the data set as a whole only 54% of the variation in the logarithm of measured carbon density can be attributed to variation of NDVI values. As the data suggest two phases on the relationship, a restriction of the NDVI range to values above 60 was attempted. This restriction improves the evenness of variation, but reduces the percentage of total variance accounted for. For further calculations the regression equation used was:

Carbon density [Mg ha^{-1}] = 0.0019*e $^{0.1462*NDVI}$

As the exponential equation relates to the logarithm of measured C stock, its use for predicting C stock can be expected to underestimate the mean value. In fact the mean of the 'predicted' value for the calibration points was only 52.8% of the measured values (and 59.7% if the restriction to NDVI > 60 was used). Applying this equation to estimate landscape level carbon will result in underestimation of carbon stock. Although the regression was derived for the NDVI values of 2003, it was applied as such to the 1996/1997 data, ignoring possible differences in NDVI due to season and haziness of the images (Figure 4.14).

Direct comparison with method I is possible only for the cloud free areas, or approximately 738,000 ha for 1996 and 522,000 ha for 2003. For these areas, NDVI-derived carbon stocks suggest a dramatic decrease from 1996 to 2003. In 1996, the average estimated carbon-density was 222 Mg ha^{-1}, while in 2003 it was only 27 Mg ha^{-1} (Table 4.9).

Table 4.9. Comparison of C stock estimates for 1996 and 2003 based on two methods

Year	Land-cover derived average carbon density [Mg ha^{-1}]	NDVI-derived average carbon-density [Mg ha^{-1}]
1996	210	222
2003	166	27

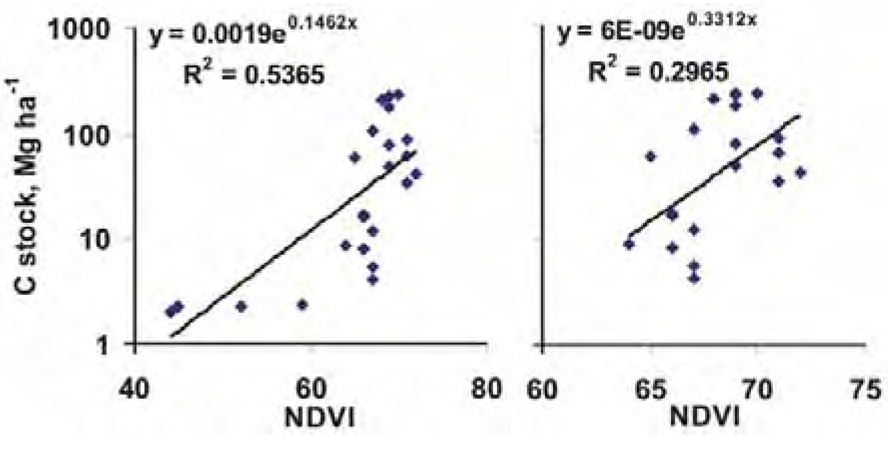


Figure 4.13. Relationship between NDVI and aboveground carbon-stock (logarithmic scale); left panel for the whole data set, right panel restricting the values to NDVI > 60

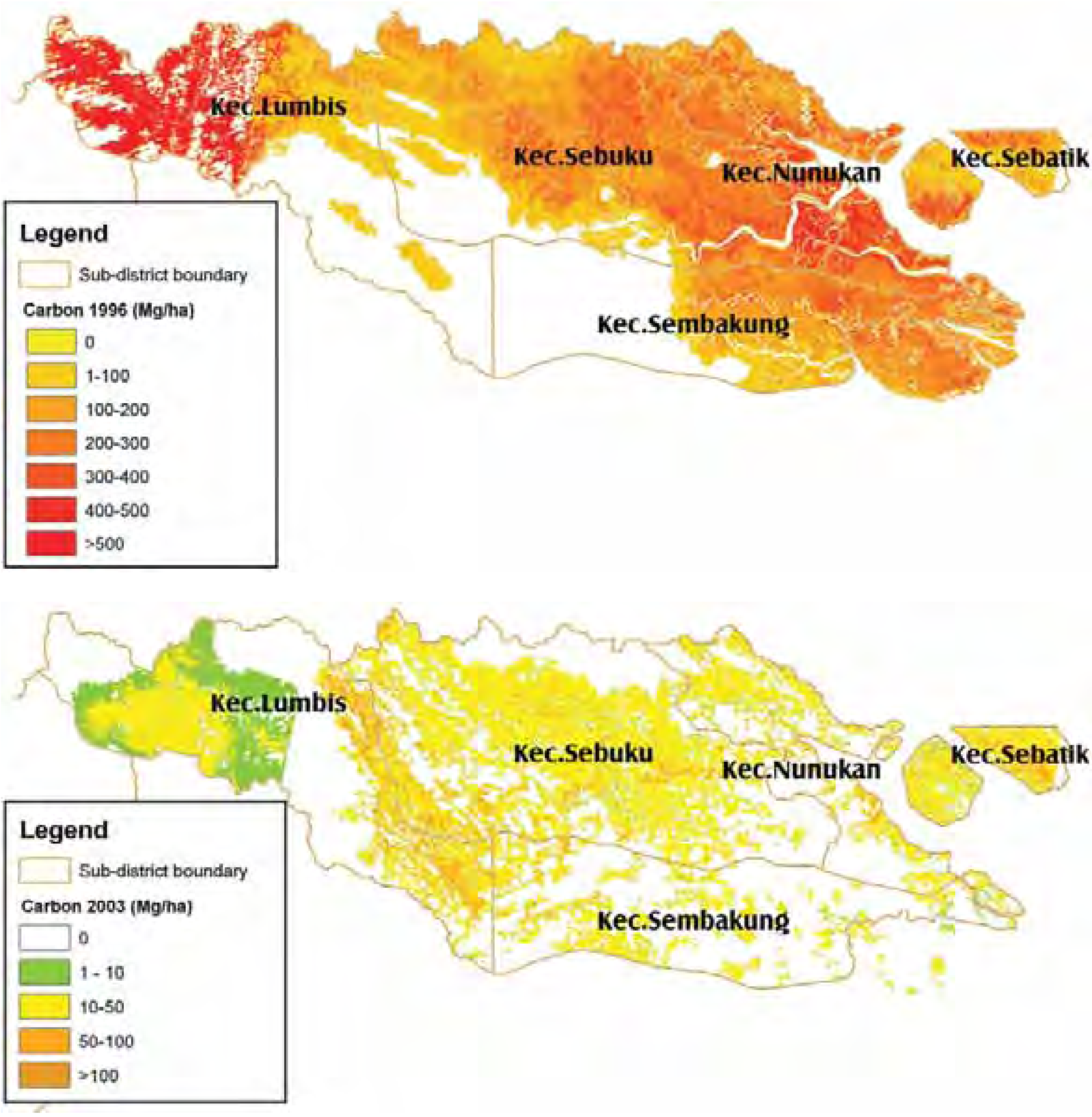


Figure 4.14. NDVI-derived carbon density of the Sembakung and Sebuku river basins in Nunukan in 1996 (upper panel) and in 2003 (lower panel)

Comparing carbon-stock estimates from land cover maps and from vegetation density

For 1996 the results of the mean C density in the cloud-free area show only a slight discrepancy between two methods, while for 2003 a big difference was found. A number of factors may contribute to this difference:

- For NDVI-derived carbon-stock estimation, the results are generally an underestimation, due to the low correlation between NDVI and measured carbon density, and the high variability of carbon density for the high values of NDVI (> 70%), in which carbon density varies from 50 to 250 Mg ha^{-1}. The non-linear aspect of the NDVI-C-stock regression line leads to a bias in the C stock results, as discussed before.
- For the land cover-derived carbon stock, accuracy of the land cover maps still need to be done using ground truth check (with

sample points that have not been used for defining the interpretation key). Verification of the resulted carbon density might also be conducted using independent C-stock measurements.

- The NDVI values for 1996 were considerably higher than those for 2003 due to a difference in season (water content of the vegetation) and general image quality (haziness), also for the forest land cover types that must have been in the same category in 1996 as they were in 2003. Yet, the NDVI regression line was established on 2003 data only and in fact most pixels in the 1996 data series were outside of the calibration domain, requiring extrapolation (with a weakly defined regression line). The similarity in results for 1996 may thus be based on a coincidence, with two types of error canceling each other, rather than on genuine agreement between the methods.

Conclusions

The main conclusions of this study are:

1. Land cover change from 1996 to 2003 in Kabupaten Nunukan has been substantial, with an estimated 3.85% $year^{-1}$ of conversion to other land cover types of the remaining primary forest.
2. Maps of vegetation density based on the Normalised-Difference Vegetation Index (NDVI) suggest an even more drastic change between the two observation times, but a number of technical difficulties with the method (differences in season and haziness of the images) are at least partially responsible for this difference.
3. Carbon-stock estimates based on NDVI at pixel level and a regression line of carbon stock on NDVI differ essentially from those based on spatial extrapolation of the land cover type of sample points to the whole landscape.
4. Using corrections for cloud-covered parts of the landscape, mean carbon stock density in the Sembakung and Sebuku river basins in Nunukan (i.e. the whole district minus the western most subdistrict) decreased between 1996 and 2003 from 211 to 175 Mg ha^{-1}, mostly due to the conversion of 217,000 ha of primary forest to other uses. The loss of C stock (17%) is less than the loss of primary forest (24%), as the resultant land cover types still retain part of the carbon stocks.
5. The main uncertainties in the overall estimates based on land cover types derive from the uncertain nature (and probably large internal variability) of the 'secondary forest' category in the land cover classification, as well as from the possibility of changes with time in typical carbon stock density within the main land cover types (esp. for categories such as 'logged-over' forest or agroforest), linked to changes in the intensity of land use within each of the categories.
6. Although a direct derivation of C stock from the remotely sensed images has theoretical advantages over estimation based on land cover classes, the nature of the relationship between leaf-area based indices such as NDVI and the largely wood-based C stock, make the method very vulnerable in practical application as well as subject to a bias that will require further statistical techniques to be overcome.

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

Desi Ariyadhi Suyamto and Meine van Noordwijk

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.

[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

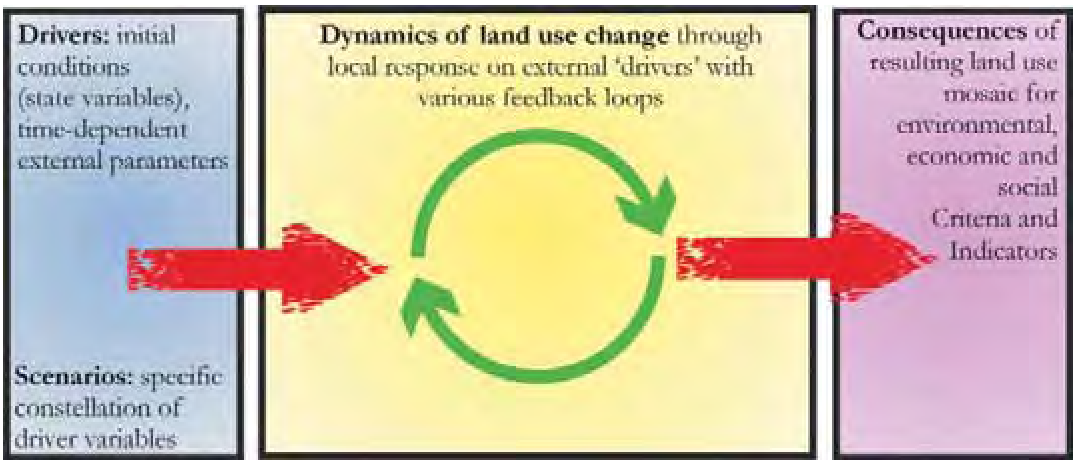


Figure 5.1. Generic structure of a model that translates 'driver' or exogenous variables to the time bound responses in a landscape, which has consequences ('externalities' in as far as they are not part of the feedback loops in the dynamic section) for criteria and indicators of system performance;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

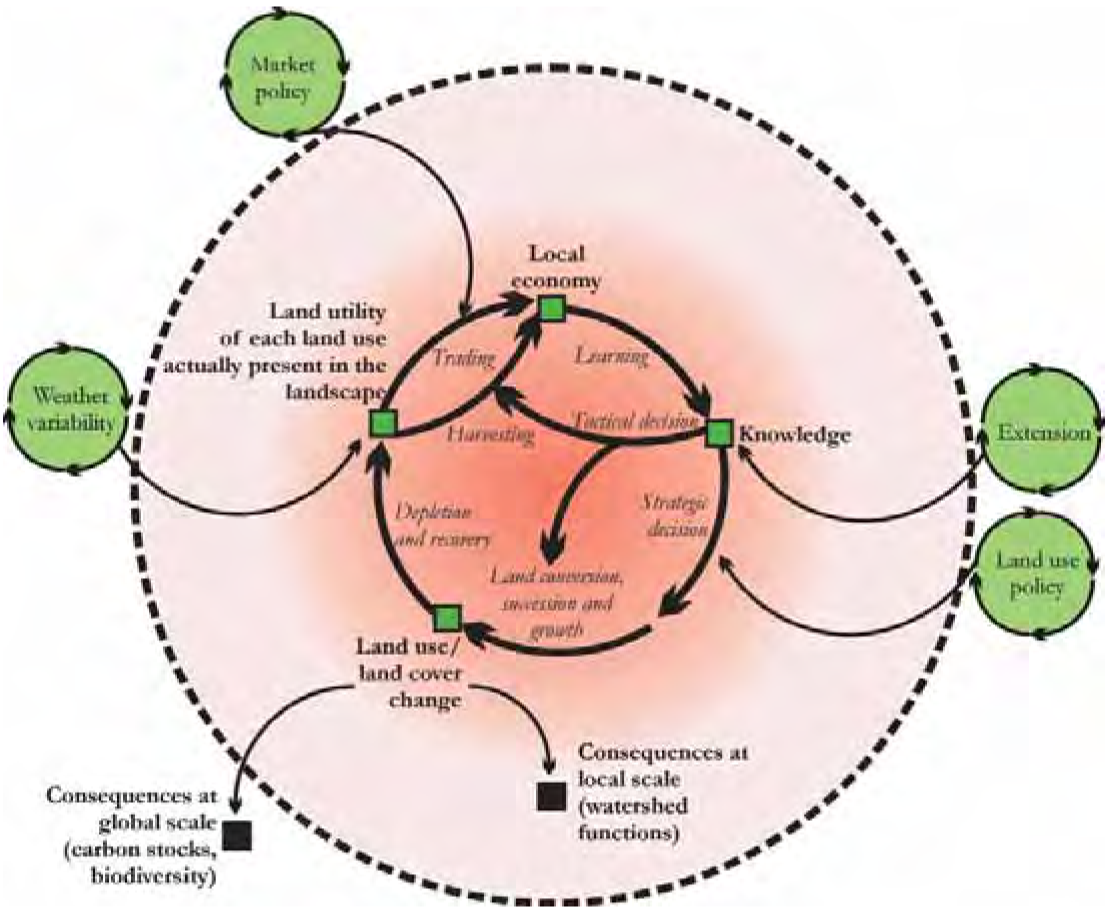


Figure 5.2. Key relationships considered in the main dynamic loop of the FALLOW model (land utility, local economy and land use decision) that determine the spatial pattern of land cover, and the modules that translate this pattern into consequences for environmental service functions such as C storage. 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

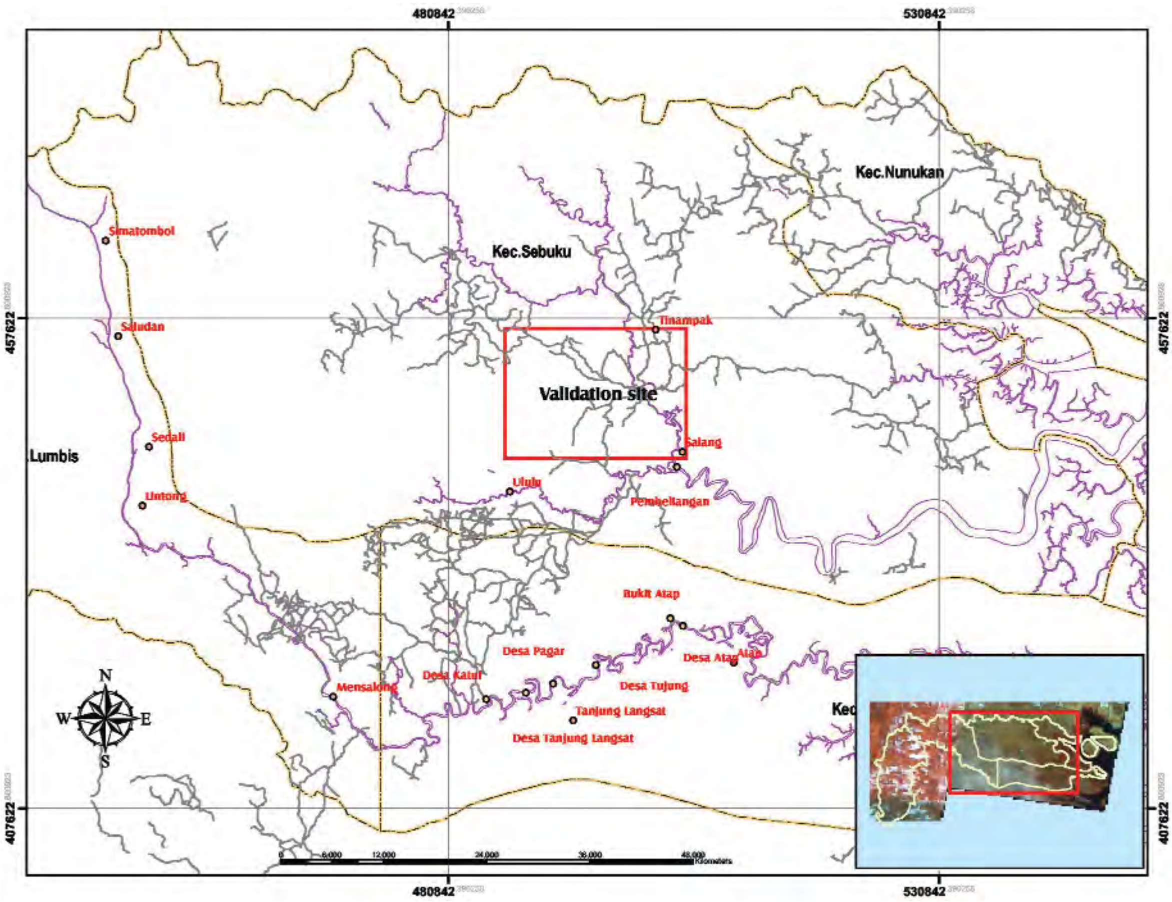


Figure 5.3. Validation site for modelling exercise within the study area of Sebuku-Sembakung, Nunukan. The site covers the area of 24,656 ha in Sebuku.

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

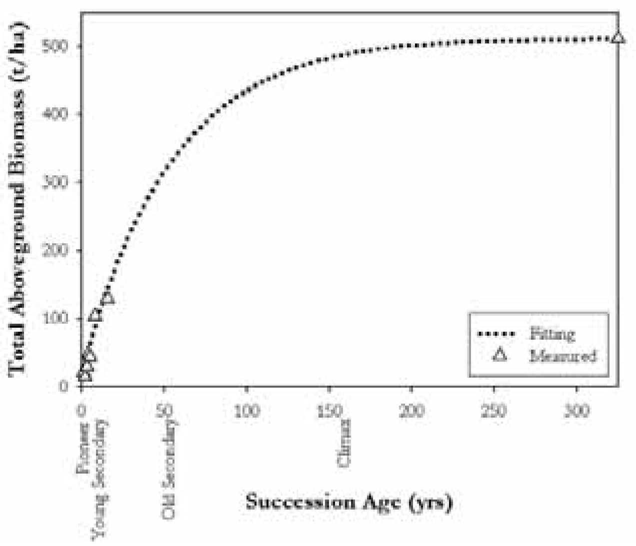


Figure 5.4. Total aboveground biomass as a function of age to derive parameters related to vegetation succession in natural forests.

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, β= 0.006, γ= 1.220, η= 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, β=1, γ=1.6, η=-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, β=0.001, γ=2.27, η=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.

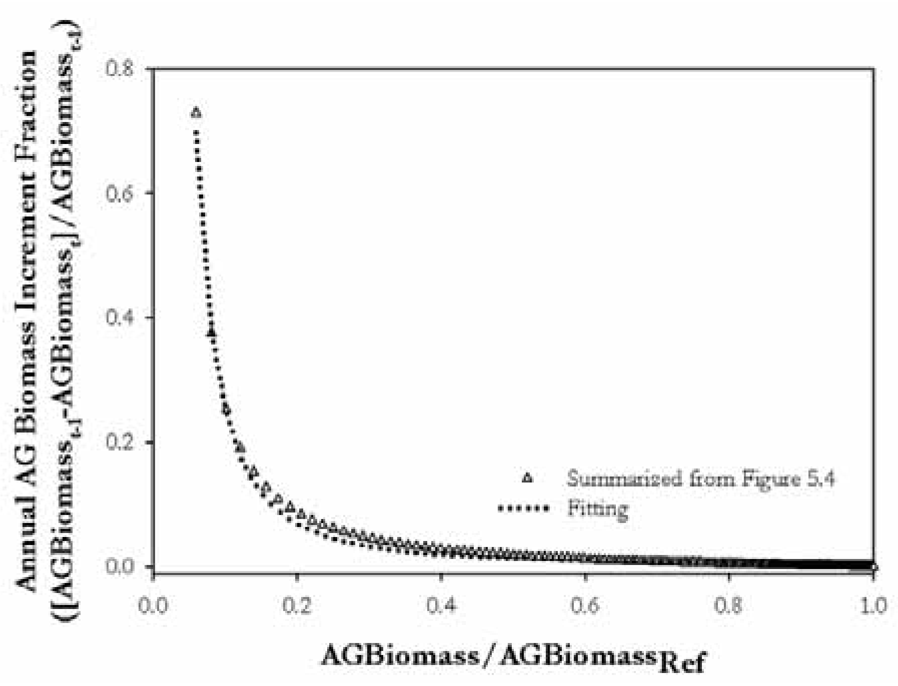


Figure 5.5. Annual increment of aboveground biomass in natural and logged-over forests was estimated from its current state relative to maximum aboveground biomass in primary forests (510.8 t/ha, see Table 5.2).

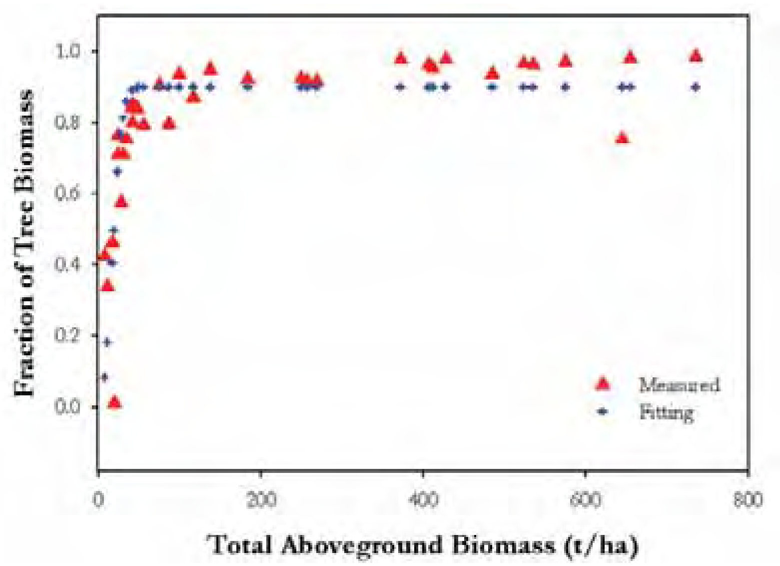


Figure 5.6. Curve fitting to estimate the tree components of forests' total biomass.

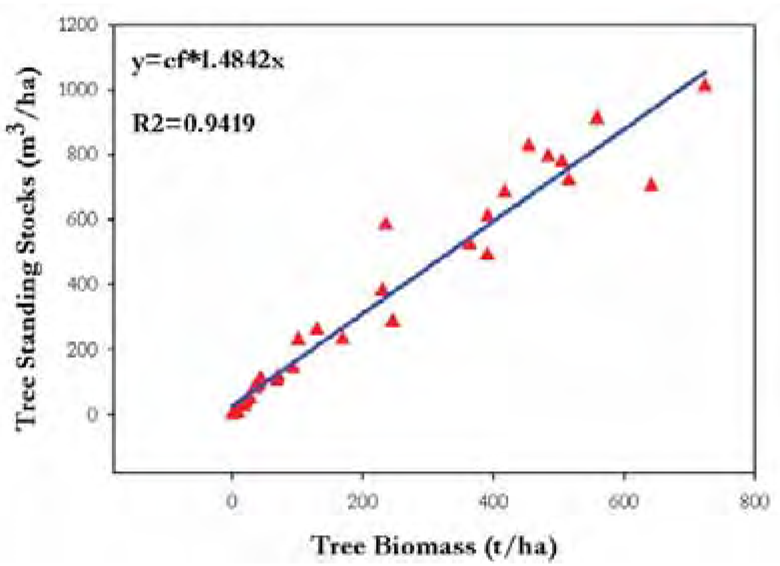


Figure 5.7. Tree standing stocks (harvestable wood) in forests as a function of tree biomass.

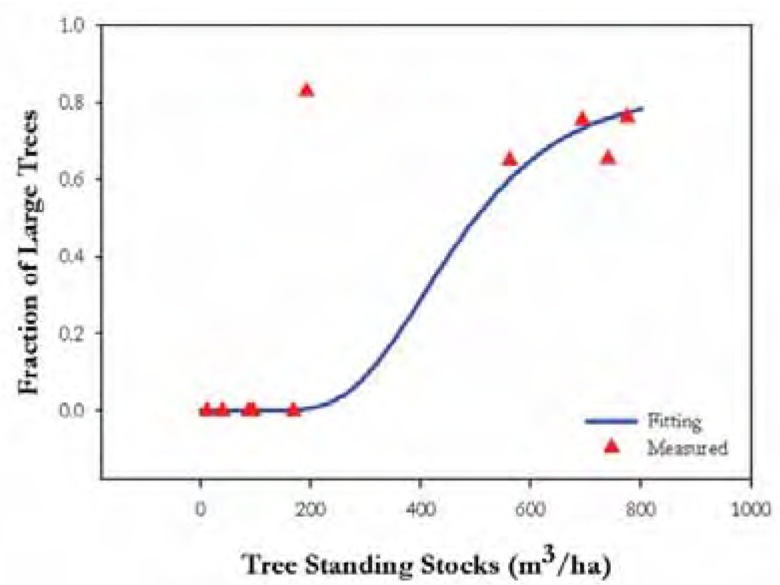


Figure 5.8. Fraction of harvestable trees (large tree) that exist in the forest as a function of standing stock.

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, β=0.005, γ=1.05, η=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, β=0.2, γ=0.95, η=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.

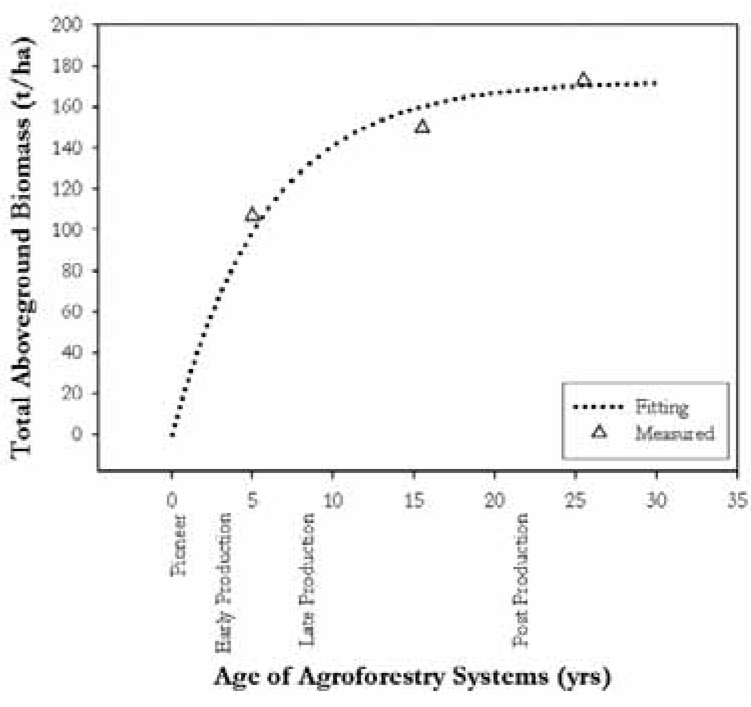


Figure 5.9. Total aboveground biomass as a function of age in agroforestry systems.

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

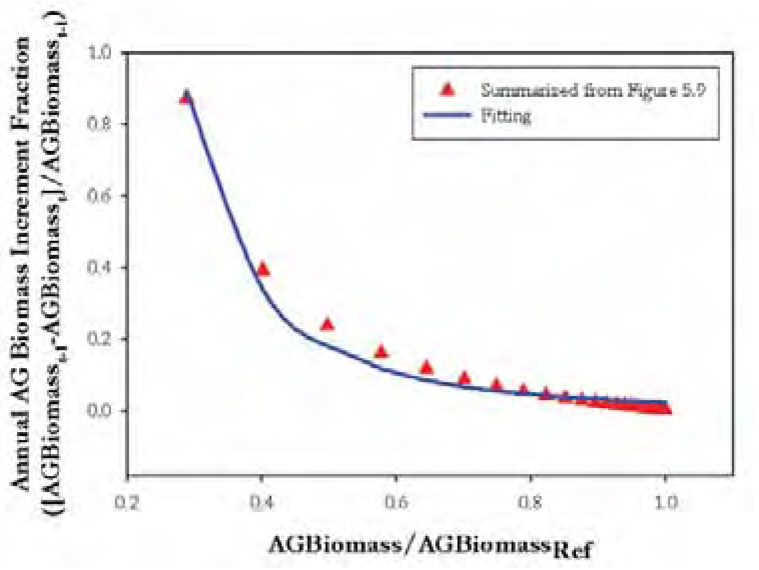


Figure 5.10. Annual increment of aboveground biomass in agroforestry system was estimated from its current state relative to maximum aboveground biomass in the oldest agroforesty system (171.7 t/ha, see Table 5.3).

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

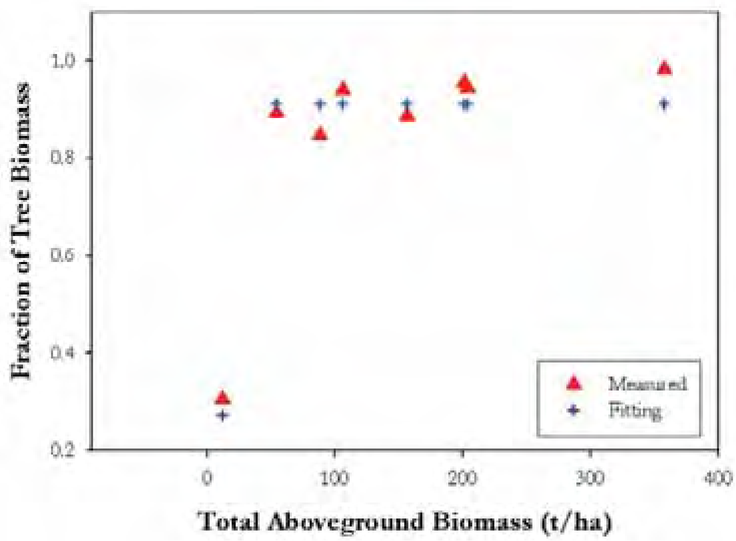


Figure 5.11. Curve fitting to estimate the tree components of agroforestry systems' total biomass.

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

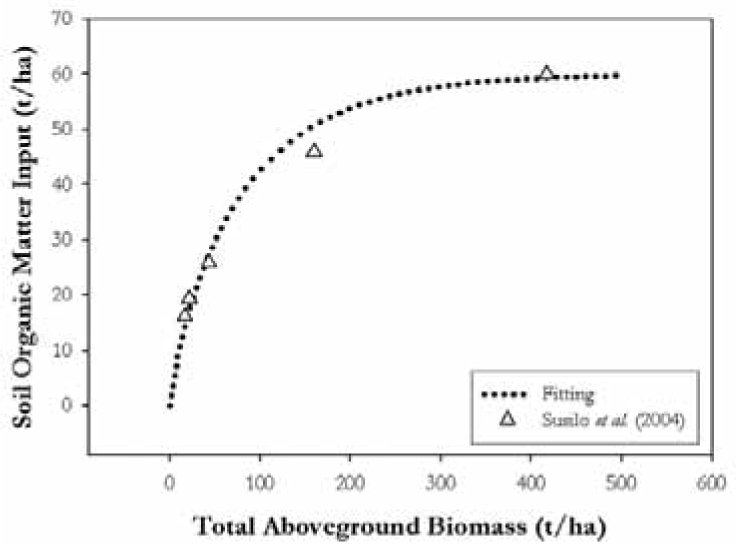


Figure 5.12. Relational curve between total aboveground biomass and soil organic matter input. This pattern was summarized from belowground biomass assessment in various land use systems in Jambi, Sumatera by Susilo, *et al*. (2004).

Soil fertility and agriculture productivity

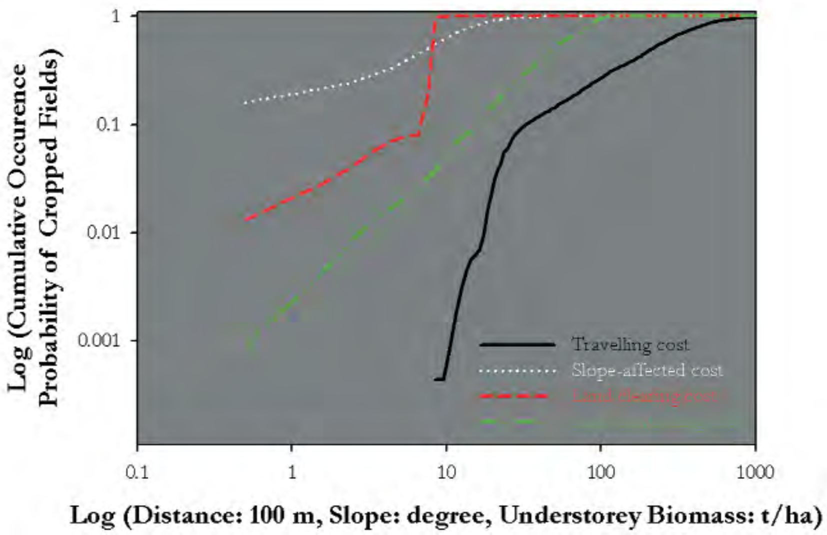
Assumptions underlying the estimate of annual organic matter input to the soil in various land cover types in Jambi, Sumatera (Susilo *et al*, 2004) are used to estimate soil organic matter input from aboveground biomass (Figure 5.12). Belowground stocks were initialised using this relational curve, 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

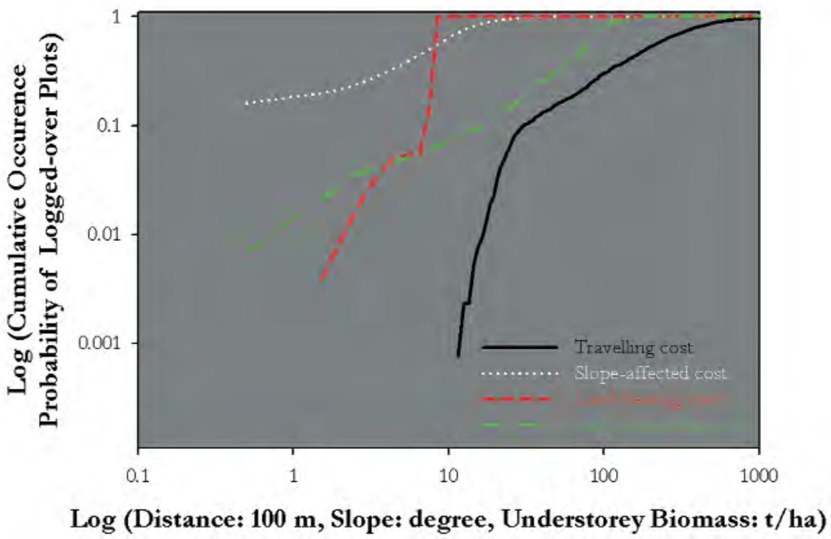
Not all parameters to initialize people's perception on livelihoods' benefits were derived directly from the socio-economic survey data. Some of the parameters were estimated by combining available information with secondary data (summarized in Table 5.8). Expected return to labour on food-crop agriculture 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.

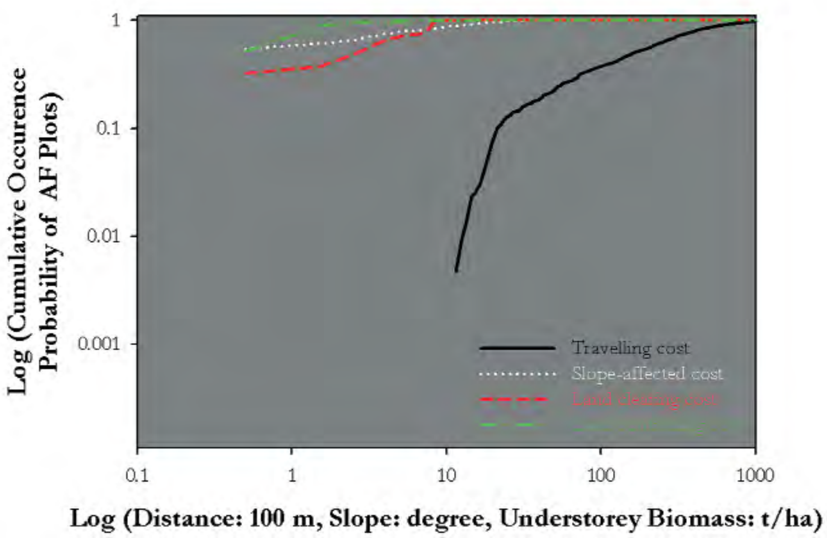
Livelihood	Expected Return To Labour (IDR/person.day)	Expected Return to Land (IDR/ha)
Food-crop Agriculture	18,380	1,348,194
Agroforestry (mix-fruit garden)	41,127	4,574,014
NTFP (gaharu)	3,968	N.A.
Logging	34,673	61,311,413
Off Farm	13,292	



(a) Agriculture



(b) Logging



(c) Agroforestry

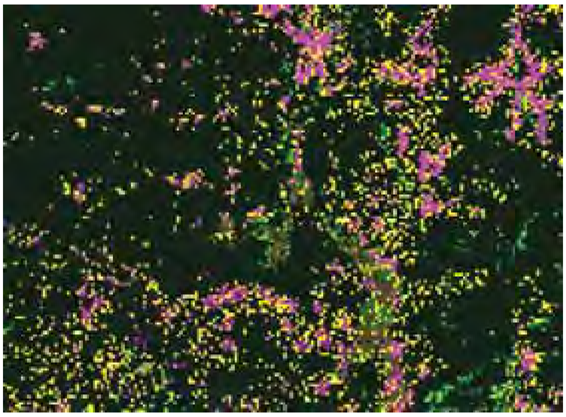
Figure 5.13. Spatial properties, determining people's deliberation in land expansion. Calculation procedure adopted from Costanza (1989) was used to calculate the strength of each spatial determinant, which is reflected by exponentially weighted average over all determinants' values: (a) in agriculture 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

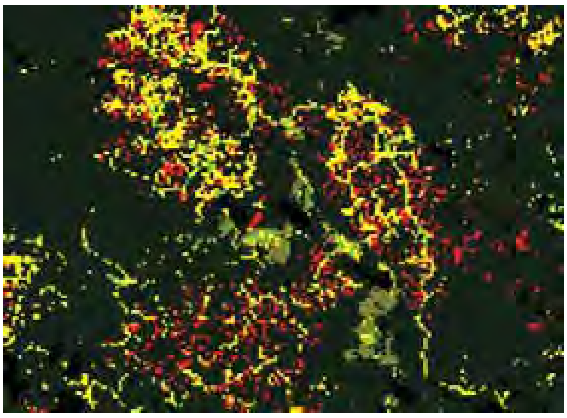
Validation was conducted to measure similarity of landscape pattern in 2003 between simulation result and the reference (landcover map, derived from Landsat TM – see chapter 4). The model was validated at three different levels: (1) at detailed nominal level, by measuring similarity of landcover

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

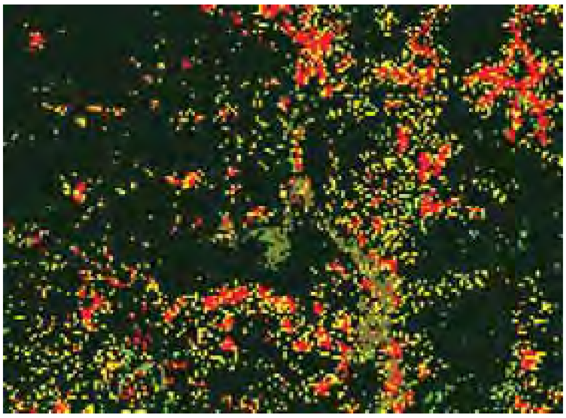


Simulated land cover

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).

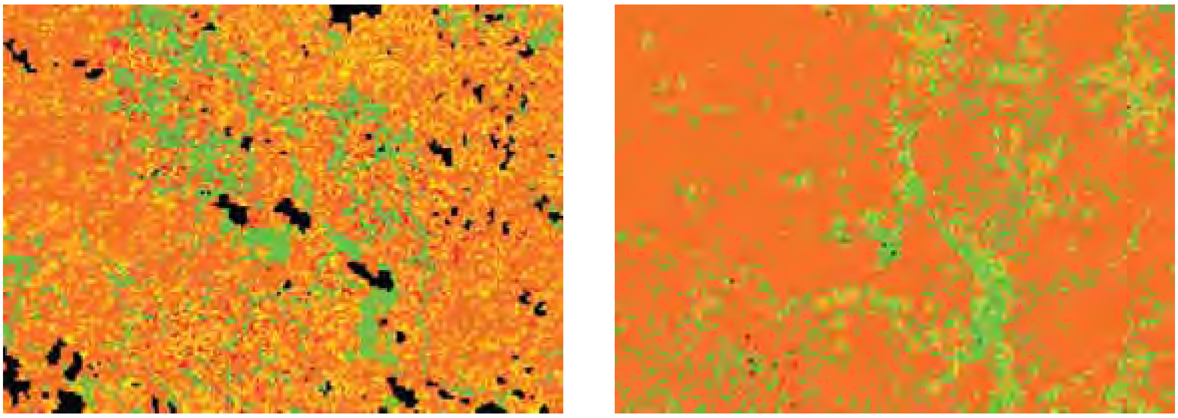


Actual land use (aggregate land cover). Black areas are missing data due to cloud cover.



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).

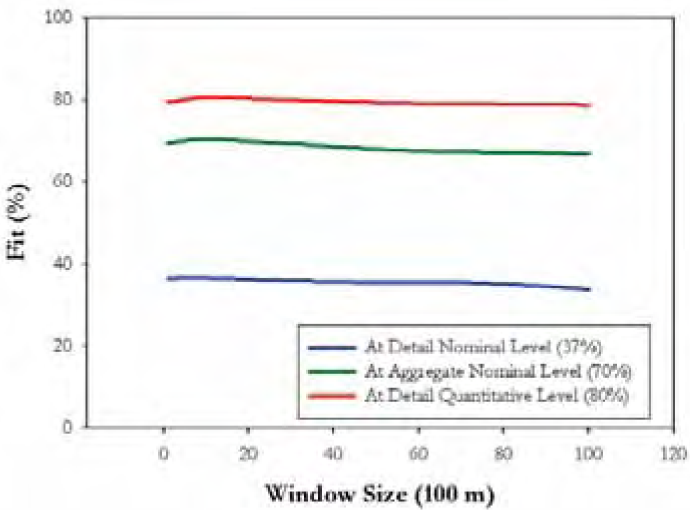


Figure 5.17. Fit between simulated and actual maps, measured at multiple resolution, ranging from 100 m to 10 km sampling windows' sizes (the procedure was adopted from Costanza, 1989). At detail nominal level (land cover comparison), overall fit was 37%. At aggregate nominal level (land use comparison), 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-

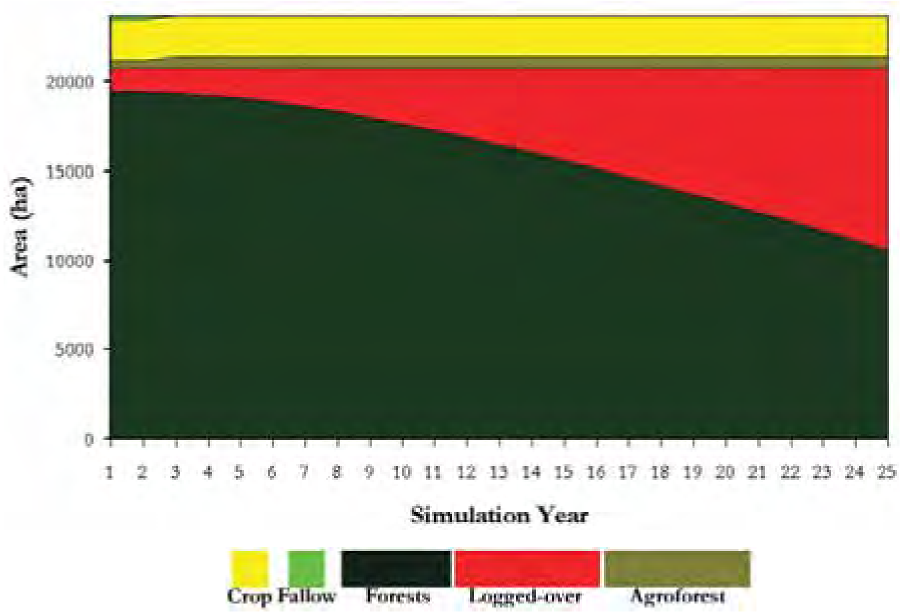


Figure 5.18. Simulated landscape dynamics in Sebuku from 2003 to the next 25 years using the current parameters setting, where logging is perceived as the most lucrative livelihood, depleting forests' carbon stocks.

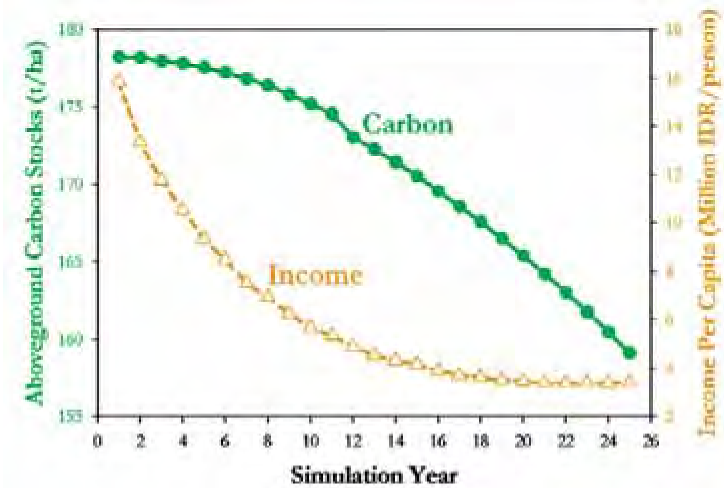


Figure 5.19. Using the current parameters setting, possible trend of landscape dynamics in Sebuku area for 25-year simulation period (initialised using land cover map 2003), resulted declining curves on both benefit indicators: income per capita (million IDR/person) and above ground carbon stocks (t/ha).

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

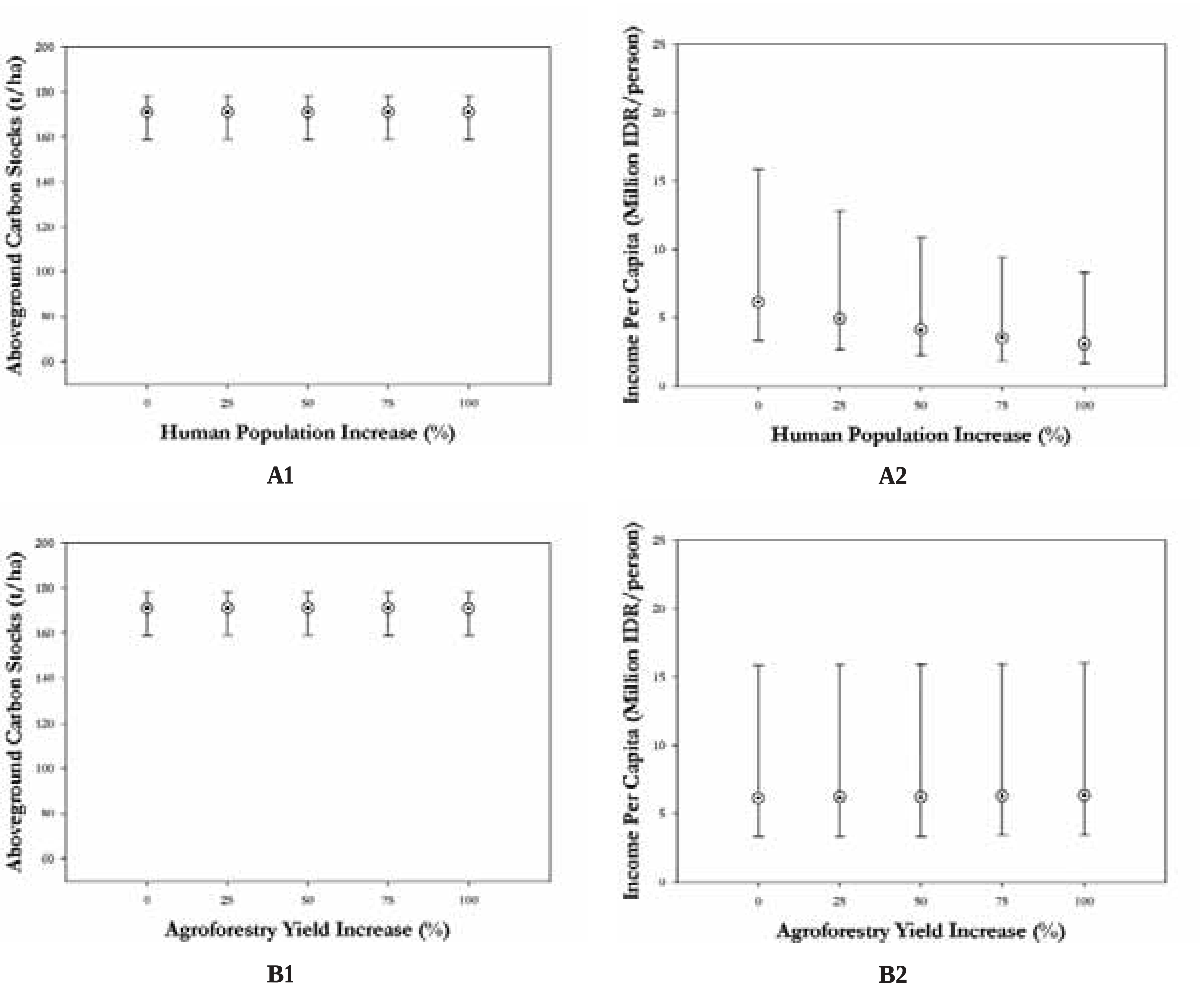


Figure 5.20. As simulated by the model, increase on human population reduced livelihood's benefit (A2), while carbon stocks remained the same as current trend (A1). Efforts to improve agroforestry profitability by increasing the yield and through better market development did not correspond to adoptability 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).

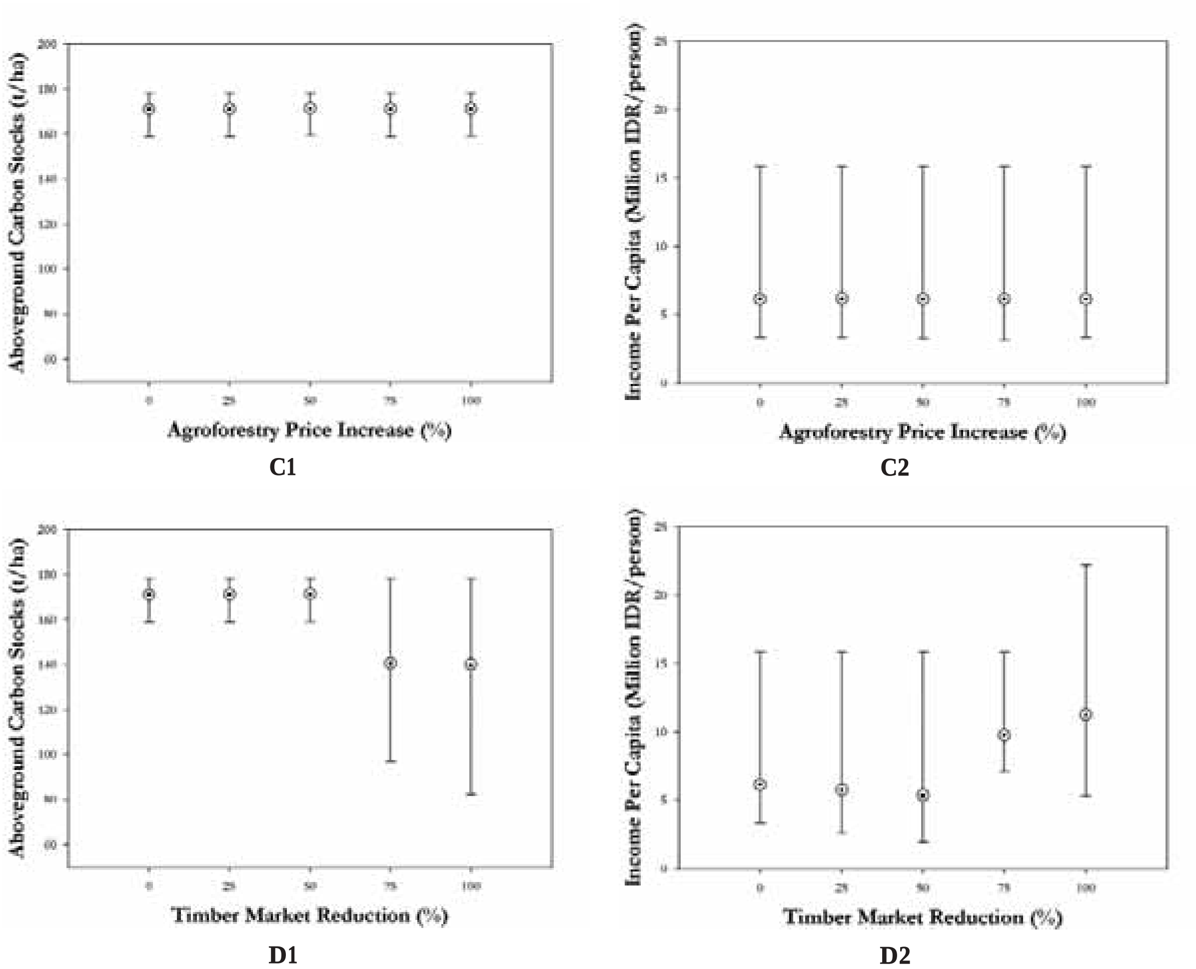


Figure 5.20. As simulated by the model, increase on human population reduced livelihood's benefit (A2), while carbon stocks remained the same as current trend (A1). Efforts to improve agroforestry profitability by increasing the yield and through better market development did not correspond to adoptability 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

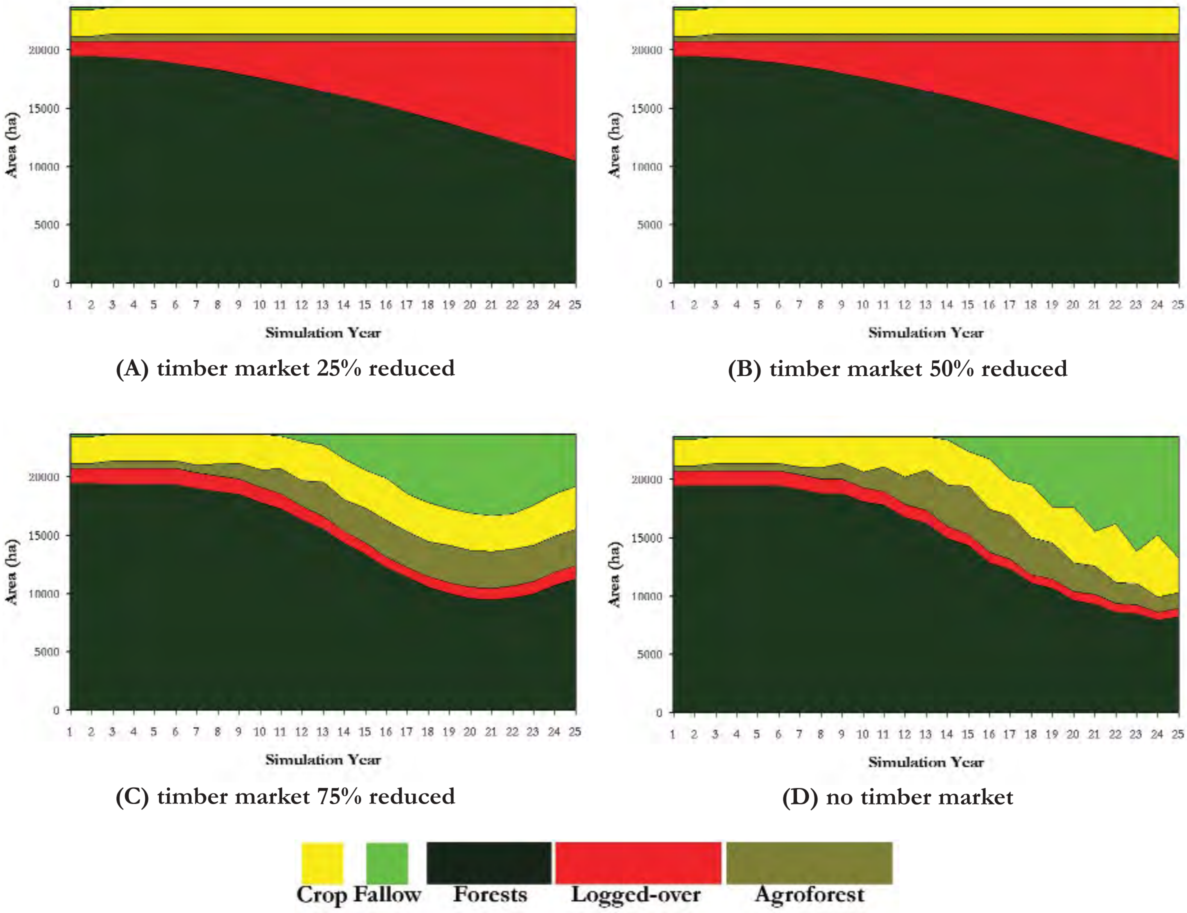


Figure 5.21. People still expected logging to give good earning for them, although timber market was reduced by 25%-50% from the current setting (A and B). When timber market reduction was increased by 75%-100%, people adopted agriculture and agroforestry to compensate benefit lost from logging activities.

Combined effect when agroforestry was improved and timber market was reduced

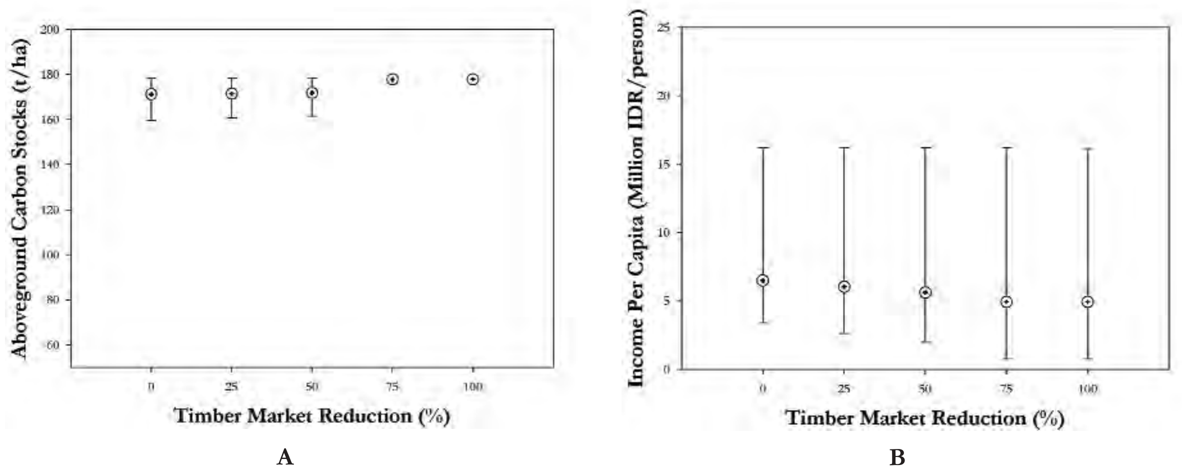


Figure 5.22. At current human population (4,046 inhabitants), when agroforestry was improved by 100% increasing its yield and its price from current setting, it could maintain carbon stocks when timber market was reduced at least by 75% (A), at the same income reduction risk as the current trend (B).

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

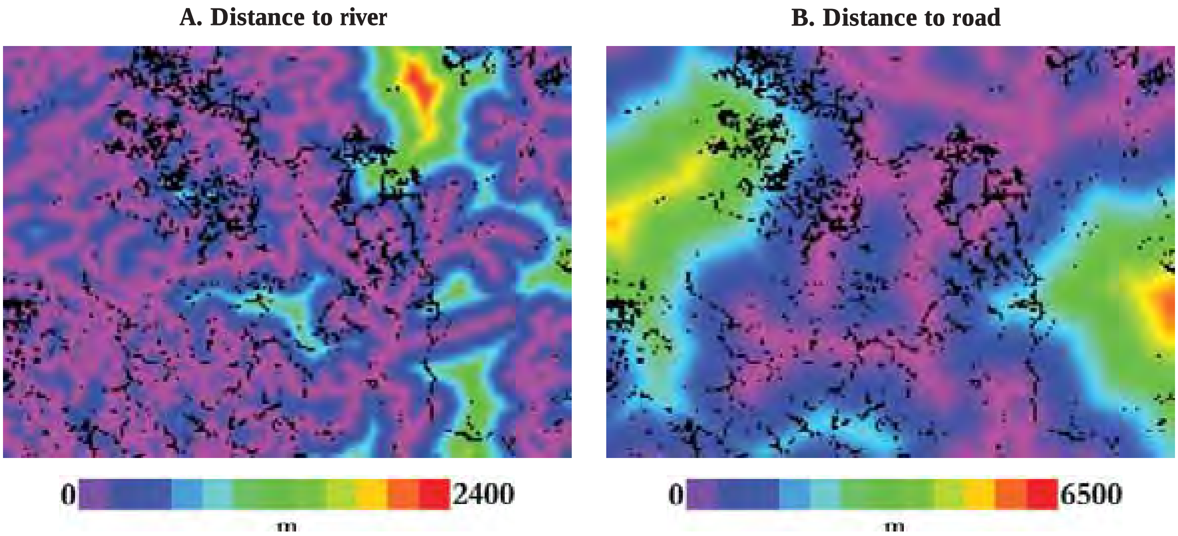


Figure 5.23. Cropped fields in Sebuku as observed by Landsat TM in 2003 (black pixels), overlaid with distance to river map (A) and distance to road map (B). Spatial patterns of cropped fields didn't follow the patterns of either river or road.

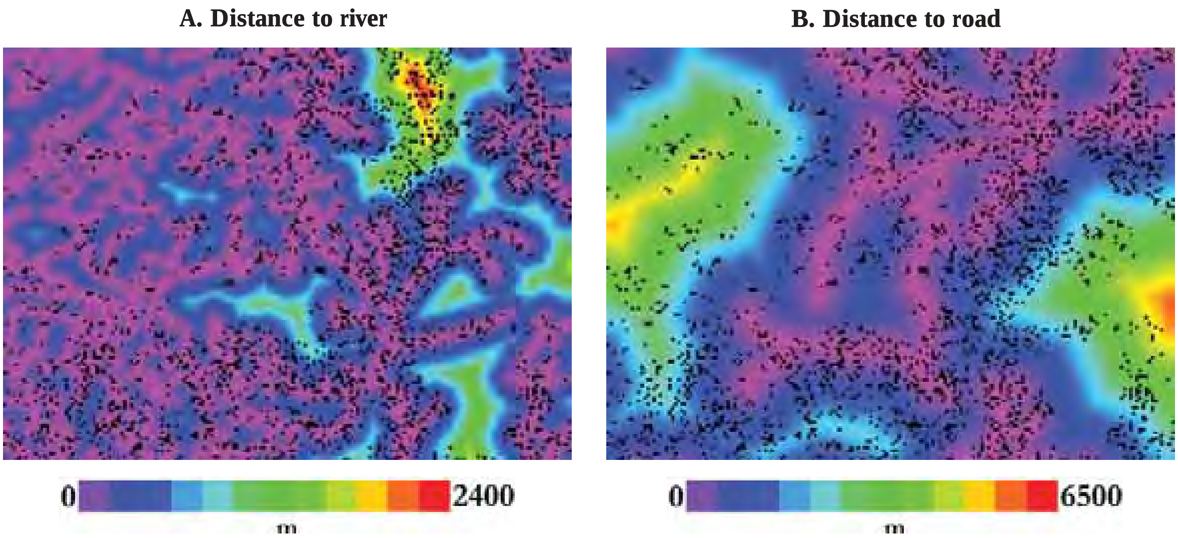


Figure 5.24. Simulated cropped fields in Sebuku in 2003 (black pixels), overlaid with distance to river map (A) and distance to road map (B). Spatial patterns of simulated cropped fields were agglomerated surrounding river or road.

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



The report describes a RaCSA (Rapid Carbon Stock Appraisal) that is build on four elements: 1. Socio-economic survey at household level aimed at understanding current land use paterns and the alternatives available. 2. Carbon stocks measurement at plot level in representative land use categories. 3. Analysis of current land use and recent land cover change using remote sensing analysis. 4. Landscape simulation modelling to explore how scenario changes the drivers of land use and how land use change are likely to affect both livelihood opportunities and landscape level carbon stocks.

The main conclusion for the Nunukan district in East Kalimantan that there are no ready 'alternatives to illegal logging' yet that can provide income substitution; only with a substantial increase in the profitability of agroforestry options will that land use become competitive. Restrictions on logging that conserve carbon stocks are bound to reduce income for the short term and a substantial compensation payment may be needed.

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