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

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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 photosynthesis. 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

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[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.

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[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

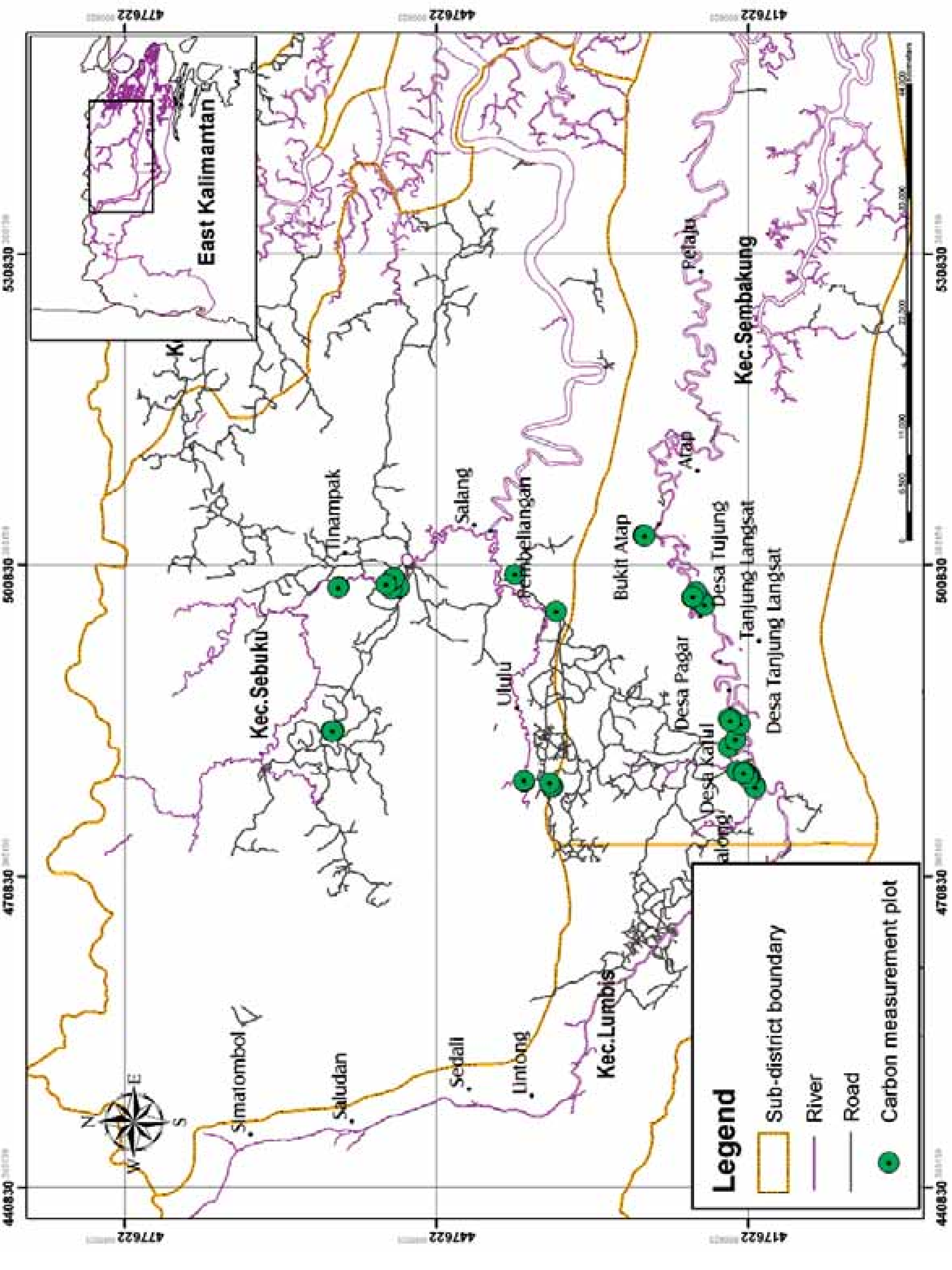

Figure 3.1 Map of plots where carbon was measured.

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:

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

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})

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[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}).

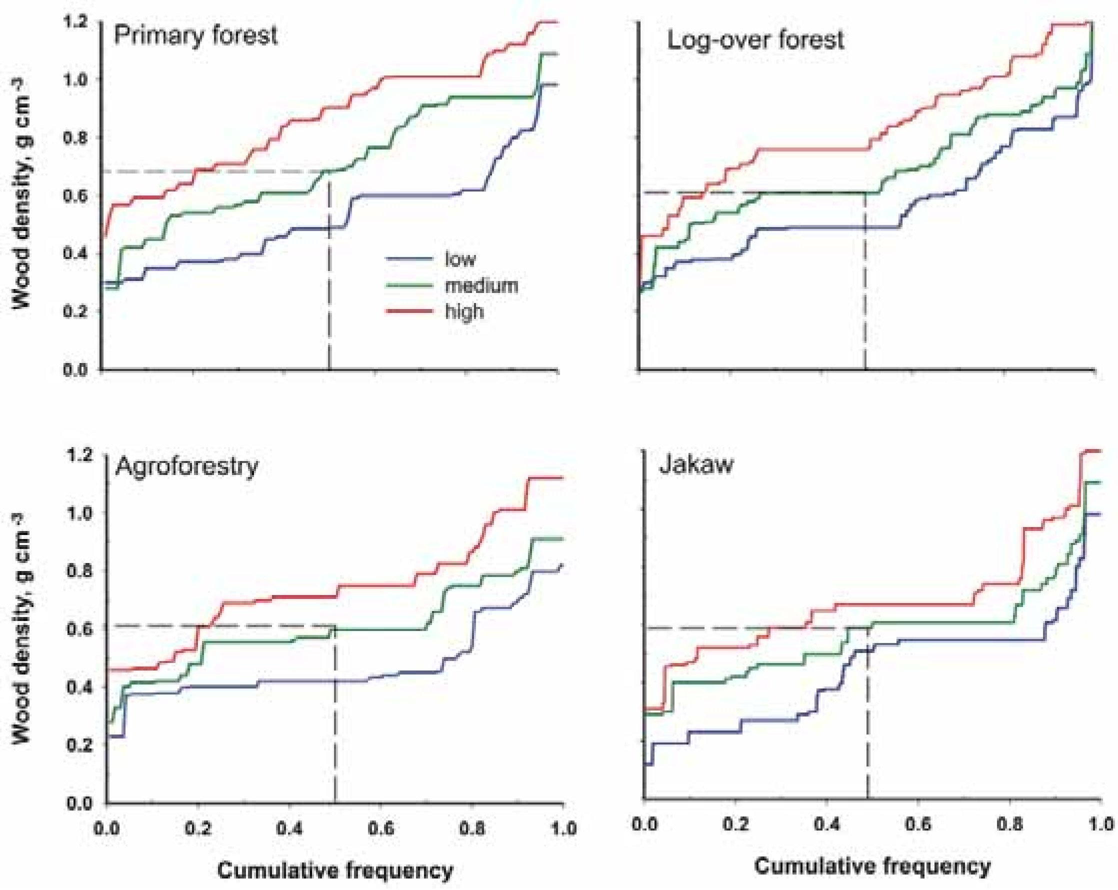

Figure 3.2. Cumulative frequency of wood density estimates for tree species found in: (a) the primary forest, (b) logged-over forest, (c) agroforestry and (d) *jakaw*.

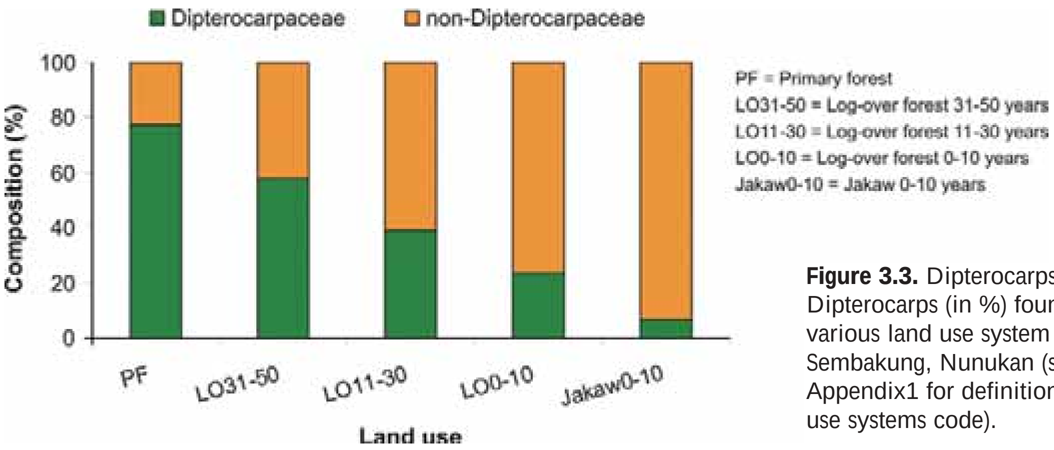

Figure 3.3. Dipterocarps and non-Dipterocarps (in %) found in various land use system of Sebuku-Sembakung, Nunukan (see Appendix1 for definition of land use systems code).

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

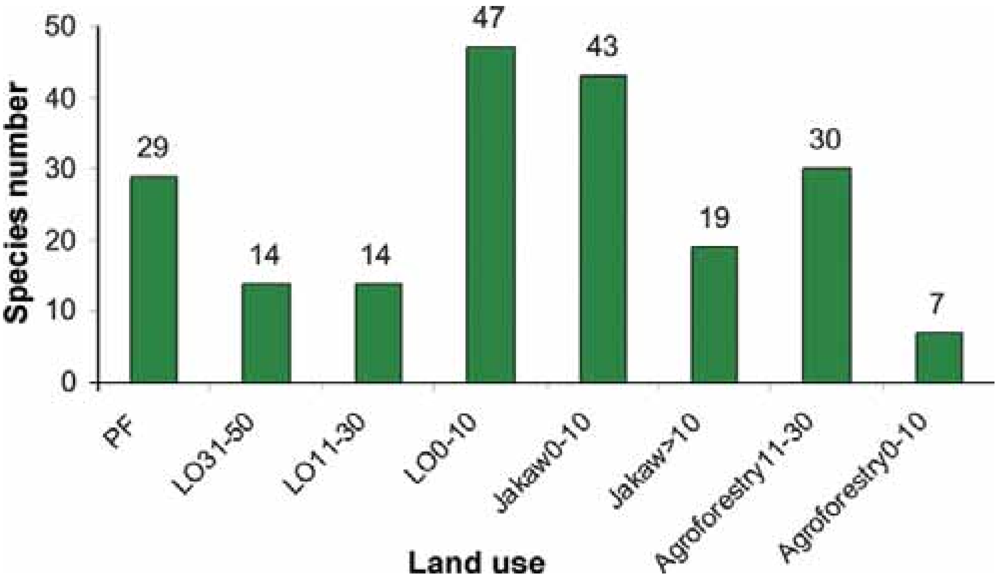

Figure 3.4. Number of woody species found in a 40*5 m^2 plot in various land use system of Sebuku-Sembakung, Nunukan (see Appendix 1 for definition of the land use systems code).

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

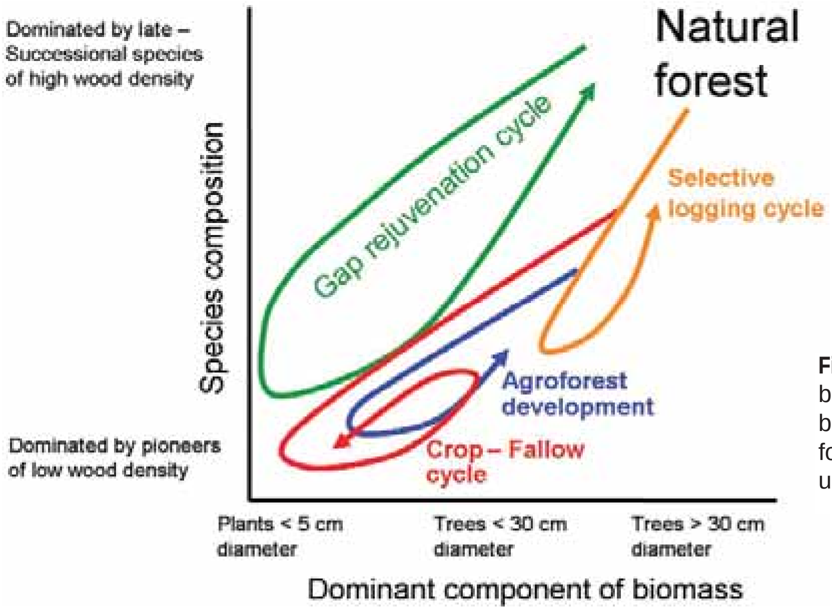

Figure 3.5. Schematic relationship between species composition and biomass composition of various forms of forest and derived land uses in Nunukan.

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

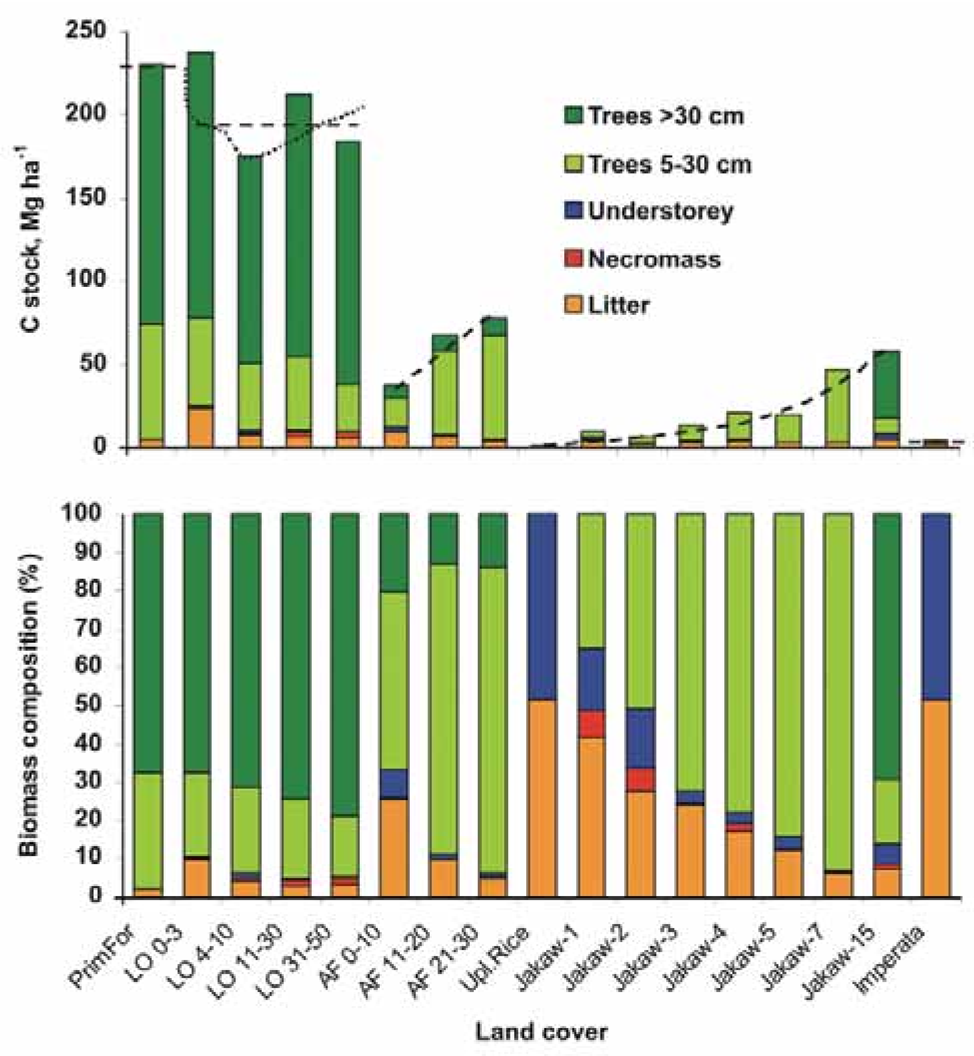

Figure 3.6. Aboveground carbon stocks and their relative composition in Nunukan (upper panel absolute values in Mg ha^{-1}, lower panel expressed as %)

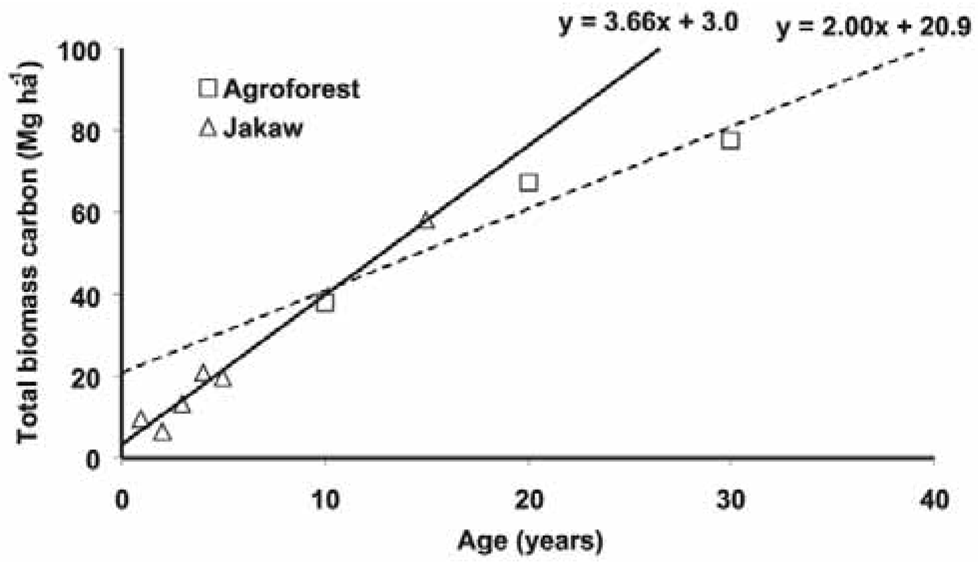

Figure 3.7. Rate of carbon sequestration in agroforestry and *jakaw* systems in Nunukan

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.