Dynamic simulation of carbon stocks in tropical lowland savanna in East Nusa Tenggara, Indonesia

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Abstract

Tropical forest can stabilize CO_2 concentration in atmosphere by absorbing CO_2 through photosynthesis process and store it in forest biomass. Carbon stock information in forest biomass is required to facilitate carbon sink programme. This study aims to calculate carbon pools and carbon sequestration, and to simulate the dynamics of carbon stocks in the tropical lowland savanna by using the Carbon Accounting Simulation Software (CASS) programme. The study was located at Taman Wisata Alam Camplong (Camplong Nature Recreation Park), Camplong village, Kupang Regency, East Nusa Tenggara Province, Indonesia. Plots size of 20 m x 100 m were established in six study sites. The scenario for this research was divided into 3 scenarios i.e. Scenario 1 (Natural and traditional forest management) was applied for virgin dry forest and traditional agroforestry sites, Scenario 2 (Timber-based plantation forest management), and Scenario 3 (Non timber-based plantation forest management). The results show that the carbon concentration of Traditional agroforestry system (or Mamar forest) were up to 52% higher than virgin dry forest. Carbon stock of living vegetation and soil were increased with a decreasing of harvesting rotation and reached the highest level in Mamar forest (273.558 gC/m^2/year and 344.042 gC/m^2/year). Timber-based plantations with mixed species had the next higher value of carbon stock, and the non-timber-based plantation forest was the third. In the study sites, managing the dry forest for timber is compatible with maximizing carbon storage if appropriate harvesting practices are used.

Keywords: carbon pool, tropical lowland savanna, carbon storage, carbon accounting simulation software (CASS), carbon dynamics

Introduction

Global concern over rising atmospheric concentrations of carbon dioxide is stimulating the development and implementation of policies aimed at reducing net greenhouse gas emissions. One way of doing this is by enhancing carbon sinks. Natural forests are a major carbon sink. One option for reducing net emissions is to lessen damage to residual natural forests by selective logging, thereby retaining additional carbon in the biomass (Pinard & Putz, 1996). The main carbon pools in tropical forest ecosystems are the living plant biomass (phytomass) of trees and understorey vegetation, and the dead mass of ground litter, woody debris and soil organic matter (Gibbs, Brown, Niles, & Foley, 2007). Dry forests by nature have much less above-ground biomass per hectare than humid forests, and thus have proportionally less above-ground carbon stock on an area basis. An example case is dry forests in sub-Saharan Africa with between 20 to 75 tonnes carbon/ha compared to 200-210 tonnes carbon/ha in equatorial rainforest, (Gibbs et al., 2007, cited in Skutsch & Libasse, 2010).

Soil organic carbon (SOC) is the major component of soil organic matter and plays a key role in the terrestrial carbon cycle and thus has drawn great attention from the scientific community. It is a dynamic component of terrestrial systems, affecting carbon exchange between the terrestrial ecosystem and the atmosphere (Lal, 2004). Long-term experimental studies have confirmed that SOC is highly sensitive to land conversion from natural ecosystems, such as forest or grassland, to agricultural land, resulting in substantial SOC loss (Martin, 2010). Globally, land use change has resulted in a carbon release of 1.6±0.8 Pg C per year to the atmosphere during the period of the 1990s (Schimel, 2001) and global carbon release from SOC mineralization owing to agricultural activities was approximately 0.80 Pg C/year (Lal & Bruce, 1999).

The sources and sinks of carbon from land use and landcover change (LULCC) are significant in the global carbon budget (Houghton, 1999 as cited in Houghton et al., 2012). Most changes in land use affect the amount of carbon held in vegetation and soil. Land use results in either the release of carbon dioxide (Greenhouse gas) to the atmosphere, or the removal of carbon dioxide from the atmosphere. The greatest fluxes of carbon result from the conversion of forests to open lands (Houghton & Goodale, 2004). The human population densities in these areas tend to be much higher than those of humid forests (Campbell et al., 2008 as cited in Skutsch & Libasse, 2010), which means they are more subject to forces which cause degradation and they are likely to represent a considerable source of emissions, although the quantity of these emissions is not accurately recorded or known (Achard et al., 2002; Fearnside and Laurance, 2003 as cited in Skutsch & Libasse, 2010). Forest conversion to intensive agriculture leads to a reduction of ecosystem C stocks, mainly due to removal of aboveground biomass by harvesting of crops and loss of C as CO_2 through farm activity such as burning and decomposition of organic materials (Hairiah & Berlian, 2006). Loss of carbon (C) stocks from terrestrial ecosystems continues to be a significant contributor to the increasing concentrations of greenhouse gases in the atmosphere.

In the southeastern United States, southern Appalachian red spruce (*Picea rubens* Sarg.) and Fraser fir (*Abies fraseri* Pursh.) forests were historically heavily cut (Korstian, 1937 as cited in Moore, DeRose, Long, & van Miegroet, 2012) and, although productive (7.7 Mg biomass/ha/yr), these spruce-fir forests can either be C sinks or C sources depending on the management regime, the dynamics of snags or coarse woody debris (Korstian, 1937; Moore et al., 2007; Moore et al., 2008; Fahey et al., 2010 as cited in Moore et al., 2012) or natural disturbance regimes.

To reduce carbon emissions effectively we have to take into account all existing and potential land-based sources of emission. In this study, we examined the contribution of virgin dry forest, timber-based plantation forest, non timber-based plantation forest, and with traditional agroforestry systems (or Mamar forest) to change in carbon stock. To address the effects of the contribution of these land uses and land cover types on carbon storage in East Nusa Tenggara province, the Carbon Accounting Simulation Software (CASS), was applied to evaluate the temporal patterns of carbon storage on the dry forest of East Nusa Tenggara province during the past 200 years. The objectives of this study were: 1) to investigate the temporal patterns of carbon storage on the lowland forest of East Nusa Tenggara province, Indonesia; and 2) to identify the relative contribution of land use activities (i.e. timber-based plantation forest, non timber-based plantation forest, and traditional agroforestry systems) to the carbon storage changes.

Methodology

Study area description

The study was located at Taman Wisata Alam Camplong (Camplong Nature Recreation Park), Camplong village, Kupang Regency, East Nusa Tenggara Province, Indonesia. Geographically, Camplong is located at coordinates latitude 10^{0}01’19.7’’ – 10^{0}03’21.5’’ south and longitude 123^{0}55’01.3’’ – 123^{0}56’23.8’’ east (Figure 1). The study area of 3.3×10^{6} ha of East Nusa Tenggara province receives annual rainfall between 1,000 and 2,000 mm with 5 - 8 dry months (April to November) (<100 mm rainfall), and an area of about 1 × 106 ha area receives <1,000 mm annual rainfall with 8 - 10 dry months. The topography of the area includes about 1.7 × 106 ha mountainous terrain (>30% slope), and 1.5 × 106 ha is hilly (15 – 30 % slope) (Balitklimat, 2004). The altitude of the area is 92–465 m above sea level. Generally, Timor island dominated by Margalitis soil, its unstable soil that can easy to break in the dry season (BKSDA, 1996). The study area consists of 6 study sites with altitude ranging from 246 to 379 meter above mean sea level, and slope gradient between 1 and 9 degrees.

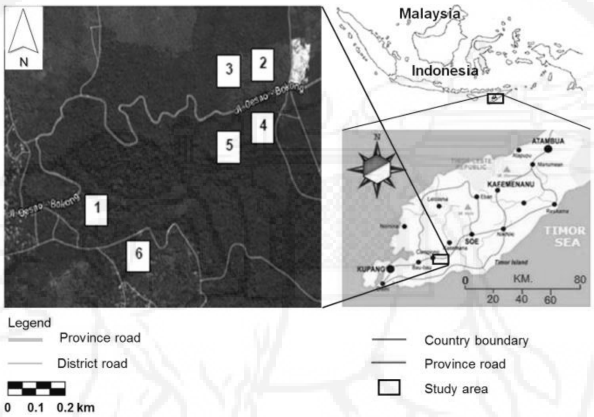

Figure 1 Locations of the study area and study sites

The vegetation in the Camplong Nature Recreation Park is representative of a lowland dry forest ecosystem. The natural ecosystem in this area can be classified into two (2) types, monsoonal forests and savanna. In the monsoonal forest, most of the trees are deciduous, shedding all their leaves over the dry season. A savanna (or savannah) is a grassland ecosystem characterised by the trees being sufficiently widely spaced giving an open canopy. The open canopy allows sufficient light to reach the ground to support an unbroken herbaceous layer consisting primarily of grasses (McPherson, 1997).

Study Plot

To determine the potential of species tree, we setup a research plot with a size of 20 m x 100 m, three replications were placed at each study site. For all plots, the number list was recorded, diameter at breast height (DBH) of tree species was measured by using diameter tape. The diameter at breast high of all trees was converted into biomass using an allometric equation. The equation used in this study specifically developed for dry vegetation, i.e. $Y = 0.139D^{2.32}$ (Brown, 1997). Where, Y refers to aboveground biomass (kg) and D refers to tree diameter (cm). The total biomass in each plot was calculated from the summed biomass of all trees in the plots. After that, we determine the ratio of biomass and species composition of vegetation. This data is used for the simulation of carbon. At the site 1 we get species with ratio of 19 %, 18 %, 7 %, 7 % and 49 % for *Dysoxylum gaudichaudianum*, *Senna siamea*, *Prunus arborea*, *Annona squamosa* and others species, respectively. Site 2 dominated by commercial timber tree species with the ratio of 39 %, 31 %, 10 %, 3 % and 17 % that for *Tectona grandis*, *Senna siamea*, *Delonix regia*, *Acacia leucophloea* and others species, respectively. Site 3, we get dominated by non commercial timber with the ratio of 58 %, 14 %, 14 %, 4 % and 10 % that for *Melaleuca cajuputi*, *Cassia fistula* L, *Senna siamea*, *Prunus arborea* and others species, respectively and at the site 4, we obtain the ratio 11 %, 9 %, 8 %, 6 %, 66 % for *Gossampinus malabarica*, *Gmelina arborea*, *Melaleuca cajuputi*, *Anacardium occdentale* and others species, respectively (Table 1). In this case, others species represent some trees that present small amounts in the study plots.

Table 1 Percentage of plant species in each study site

Site 1 (Virgin dry forest)		
Local Name	Scientific Name	%
Keolnasa	Dysoxylum gaudichaudianum	19
Johar	*Senna siamea*	18
Kabung	*Prunus arborea*	7
Anonak	*Annona squamosa*	7
Others species		49

Site 2 (Timber-based plantation forest)		
Local Name	Scientific Name	%
Jati	*Tectona grandis*	39
Johar	*Senna siamea*	31
Flamboyan	*Delonix regia*	10
Kabesak	*Acacia leucophloea*	3
Others species		17

Site 3 (Non timber-based plantation forest)		
Local Name	Scientific Name	%
Kayu putih	*Melaleuca cajuputi*	58
Nikis	*Cassia fistula L*	14
Johar	*Senna siamea*	14
Kabung	*Prunus arborea*	4
Others species		10

Site 4 (Traditional agroforestry or Mamar forest)		
Local Name	Scientific Name	%
Kapok hutan	*Gossampinus malabarica*	11
Gmelilna	*Gmelina arborea*	9
Kayu Putih	*Melaleuca cajuputi*	8
Jambu Mente	*Anacardium occdentale*	6
Others species		66

Simulation scenarios

We contrasted 3 different scenarios to explore the long-term effects of different forest management on carbon pools (Table 2). Scenario 1 (Natural and traditional forest management) was applied for virgin dry forest and traditional agroforestry sites (Site 1 and Site 4, repectively), we assumed there was no timber harvesting activity. Virgin dry forest was used as a null model for comparison purposes, since we simulated an expected behavior in the absence of any specific processes. We hypothesized that virgin dry forest, by virtue of their longstanding protection status, would be older than forests in surrounding landscapes, and forest C stocks and stock changes are affected by natural disturbances.

In Scenario 2 (Timber-based plantation forest management), it was only applied on timber-based plantation forest (Site 2) with logging rotation 40 years and 80 years. They result in 3.95 % harvesting disturbance of stem (Table 2). The Scenario 3 (Non timber-based plantation forest management) was applied on non timber-based plantation forest (Site 3) with logging rotation 40 years and 80 years. Based on the Table 2, non timber-based plantation forest with logging rotation 40 years and 80 years resulting in damage to the stem around 28.28 % disturbance by harvesting of stem. These two scenarios were examined over a 200 years. According to Williams, Collatz, Masek, and Goward (2012), disturbed forests, if not converted to another land cover type, have the potential to regrow, recover, or even surpass pre-disturbance carbon stocks over decades to several hundred years. Because it is unclear how fast the forests would recover from selective logging (Eaton & Lawrence, 2009), secondary tropical dry forest can attain a biomass similar to mature forest after 50 years of regrowth following cultivation (Brown & Lugo, 1982; Brown & Lugo, 1990 as cited in Eaton & Lawrence, 2009). In the Yucata´n, however, recovery from shifting cultivation may take 55-95 years (Read & Lawrence, 2003 as cited in Eaton & Lawrence, 2009).

Although in reality, site treatments such as prescribed burning or scarification may have been undertaken following harvesting, for simplicity these have been ignored in the simulations. All residual dead organic matter associated with harvest slash was assumed to be additional litter input to the decomposing forest floor (Jiang, Apps, Peng, Zhang, & Liu, 2002). The minus value of leaf biomass shows that biomass potential is higher in the two plantation forest and mamar forest in comparison with virgin dry forest (Table 2).

Table 2 Main parameters used for simulating the dynamics of carnon stock in different forest managements and disturbances using CASS programme

Parameters	Timber-based plantation forest		Non timber-based plantation forest		Traditional agroforestry (mamar forest)	Sources
	40 yrs	80 yrs	40 yrs	80 yrs	10 yrs	
Leaf[a] (%)	-253.59	-253.59	-63.56	-63.56	-160.40	Present study
Stem[a] (%)	3.95	3.95	28.28	28.28	43.81	Present study
Leaf litter ($gC/m^2/yr$)	0.65	0.65	1.108	1.108	-5.59	Present study
Stem litter ($gC/m^2/yr$)	9.26	9.26	15.23	15.23	80.13	Present study
Humus ($gC/m^2/yr$)	3.04	3.04	3.04	3.04	3.04	Stephenson, 1941
Rate of succession (m^2/yr)	1.95	1.95	1.95	1.95	1.95	Chapman & Chapman, 1990
Litter[b]	0.10	0.10	0.10	0.10	0.10	Roxburgh , 2004
Atmosphere[b]	0.10	0.10	0.10	0.10	0.10	Roxburgh , 2004
Fuelwood[b]	0.10	0.10	0.10	0.10	0.10	Roxburgh , 2004
Long-term storage[b]	0.70	0.70	0.70	0.70	0.70	Roxburgh , 2004

Note: [a]Percentage of pool removed, [b]Partitioning of lost carbon

Carbon accounting simulation software (CASS)

The philosophy underlying the CASS model is that carbon in terrestrial ecosystems can be partitioned into a number of separate pools. At the coarsest level there are four major pools (1) carbon present in living vegetation, (2) carbon in dead vegetation (Litter), (3) carbon in the soil (from soil surface to 1 m depth), and (4) CO_2 in the atmosphere. Although, the CO_2 in the atmosphere is not explicitly included in the model. Sub-pools can be defined within each of these major pools. The number of sub-pools varies considerably among different carbon models. For example, the ‘Century’ model is commonly used in studies of climate change, and it has two living pools, four litter pools and six soil pools. The CASS model contains three living pools (leaves, stems and roots), three litter pools (leaf litter, stem litter and root litter) and two soil pools (Labile fraction and stable fraction) (Roxburgh, 2004). However, the negative value of percentage of leaf pool removed that resulted from the comparison between virgin forest to timber-based plantation, non timber-based plantation, and traditional agroforestry.

Basically productivity refers to increases in the total amount of biomass of living photosynthetic organisms (Phytomass) in an ecosystem. While gross primary production (GPP) is the total amount of energy produced by vegetation, and some of the energy is used for cellular respiration i.e. for the growth and development of the plant. Thereafter the left over is called net primary production (NPP) and that represents the total available energy in an ecosystem the form of dry plant biomass.

For Figure 2, we firstly start with atmospheric carbon dioxide being fixed into solid form by photosynthesis at a rate determined by the Net Primary Productivity (NPP) specified for each ecosystem type, which are measured in unit of $gC/m^2/yr$. Some of this fixed carbon is incorporated into leaf biomass, some into stem biomass, and some into root biomass. The parameters a_l, a_s and a_r are proportions which define this partitioning, and sum to 1 (Roxburgh, 2004).

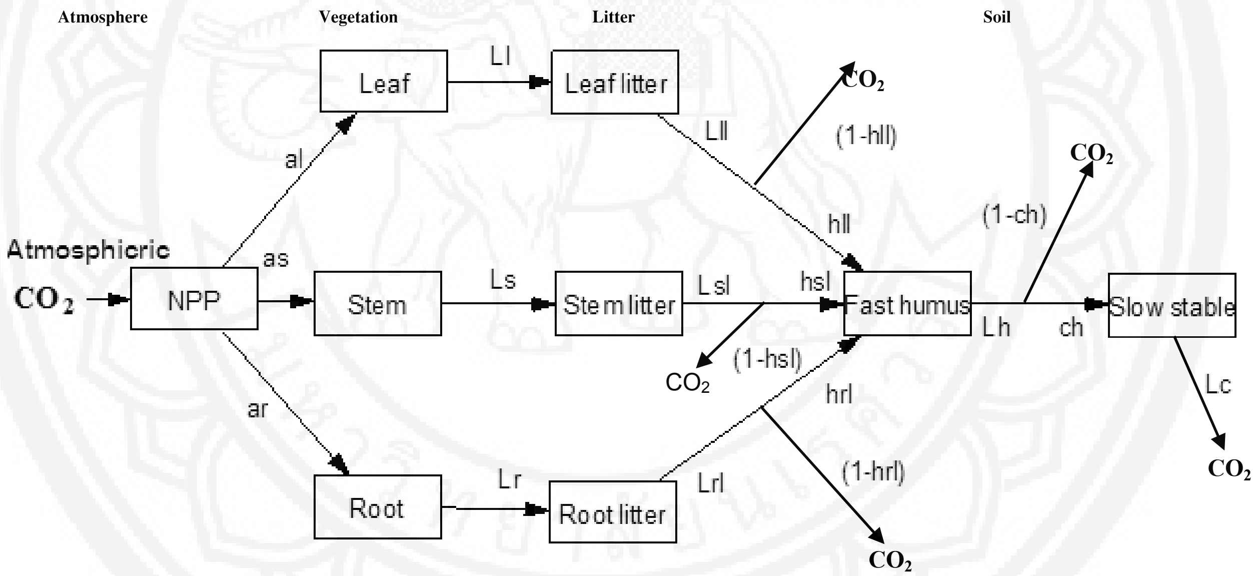

Figure 2 The overall structure of the model, which is sitimulated in CASS programme, where NPP = Net Primary Productivity, al; as; ar = partitioning of NPP into biomass, Ll; Ls; Lr; Lll; Lsl; Lrl; Lh; Lc = lifetimes of the carbon in the various pools, hll; hsl; hrl; ch = the rate at which carbon is being returned to the atmosphere, Fast humus is the labile fraction of soil organic matter, Slow stable = Recalcitrant organic carbon or stable fraction of soil organic matter (Roxburgh, 2004)

Results

Carbon storage potential

Table 3 summarizes the carbon storage distribution in each pools calculated by Carbon Accounting Simulation Software (CASS) programme. Totally, most of the carbon is allocated in living stem (43 %) and humus (34 %). High carbon storage on the stem is influenced by vegetation at the study site (timber-based plantation forest), which largely consist of trees with high wood density value. According to Oey Djoen Seng (1951) as cited in Soewarsono (1990), wood density value of *Tectona grandis* and *Senna siamea* are 0.7 and 0.8, respectively. This value of wood density is quite high when compared with other wood (less than 0.7). In case of high humus on the timber-based plantation forest with the 80-year harvesting rotation, its more due to the high contribution of litter carbon (164.56 gC/m^2). Contribution of litter carbon on soil carbon to other sites only around 118.66-148.50 gC/m^2.

Table 3 Carbon storage distribution in each pools calculated by using CASS programme

Study site	Living carbon (gC/m^2)			Litter carbon (gC/m^2)			Soil (gC/m^2)	
	Leaf	Stem	Root	Leaf	Stem	Root	Humus	Stable Soil
1	269.1	4853.1	448.3	134.6	220.4	89.6	3459.4	706.4
2	270.0	4856.1	450	135.0	220.5	90.0	3644.5	1538.2
3	326.2	4783.9	449.9	186.6	217.1	90.0	3689.7	1176.0
4	270.0	4280.4	450.0	135.0	193.1	90.0	3304.2	1183.5
5	270.0	4756.1	450.0	135.0	215.8	90.0	3450.9	1369.3
6	306.1	2264.1	449.9	168.3	97.7	90.0	2835.4	961.0

1 = virgin dry forest, 2 = Timber-based plantation forest 40 years, 3 = Timber-based plantation forest 80 years, 4 = Non timber-based plantation forest 40 years, 5 = Non timber-based plantation forest 80 years, 6 = Traditional agroforestry (mamar forest)

Virgin dry forest

Estimation of the carbol pools from the virgin dry forest is presented in Figure 4. It shows that in general there is tendency where the amount of carbol pools from the virgin dry forest is increasing with the year. To analyze the carbon stocks, we distinguished between three different carbon pools: carbon stored in the living, carbon in the litter, and carbon stored in the soil. According to the simulation, the virgin dry forest stored 42 % carbon in the living, 3 % in the litter, and 55 % in the soil. Total carbon increased with the time of simulation, where living carbon, litter carbon and total carbon get the highest change at second 40 years (53.05 gC/m^2/year, 4.548 gC/m^2/year and 87.02 gC/m^2/year, respectively) and soil carbon get the highest change at the third 40 years (36.20 gC/m^2/year).

Net biome production (NBP) denotes the net production of organic matter in a region containing a range of ecosystems (Biome) and includes, in addition to heterotrophic respiration, other processes leading to loss of living and dead organic matter (harvest, forest clearance, and fire, etc.) (Schulze & Heimann, 1998). The result showed the value of NBP in the virgin dry forest increased during the first 80 years, during this phase the highest value of NBP reach about 101.58 gC/m^2/year (78 years) with an average increase of 1.06 gC/m^2/year and after 80 year of simulation the NBP get slow decreased until 11.45 gC/m^2/year (200 years) with an average of 0.75 gC/m^2/year (Figure 3).

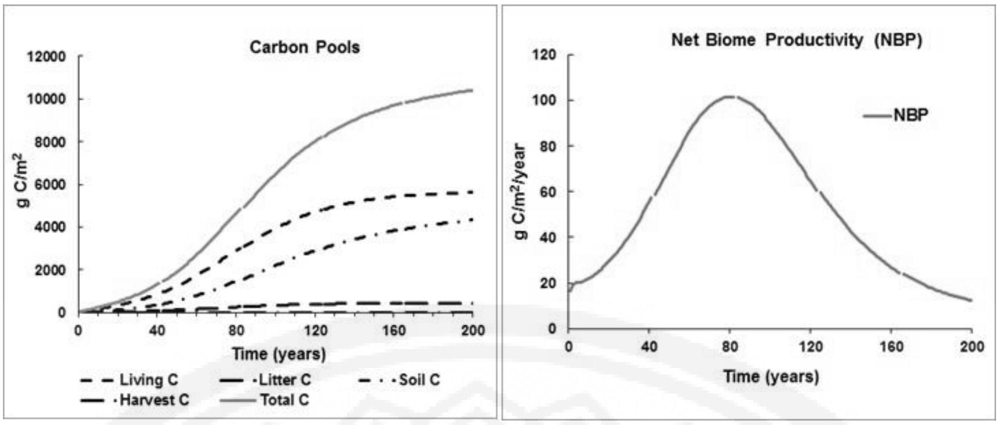

Figure 3 The dynamics of carbon stocks in virgin dry forest

Based on Table 3, some of this fixed carbon is incorporated into leaf biomass is about 0.30 (30 %), some into stem biomass 0.50 (50 %) and some into root biomass 0.20 (20 %). From one year to the next some of this carbon is retained in the leaves about 270 gC/m^2 with half of the total leaf carbon is lost to the leaf litter pool (135 gC/m^2/year) on the rate of humification around 0.4. Stem carbon is about 4950 gC/m^2, where around 1/22 for every year of the total stem carbon is released to the stem litter pool is around 225 gC/m^2/year. About 1/5 of root carbon will lost to the root litter pool with amount of 90 gC/m^2 yearly. There is no different value in the longevity and humification rate with about 1 year and 0.40, respectively.

To ensure an increase in soil carbon (C) storage, in accordance with the long-term international strategies, it is essential that forest management practices include detailed information about soil C potential. The humus carbon in the soil pool can be accumulated with amount of 3600 gC/m^2 regarding the rate of 5 % and 20 years for carbonization and time of residence, respectively. This humus carbon can be released as CO_2 into atmosphere (171 gC/m^2), while 5 % of humus carbon can be converted into the stable soil carbon by carbonization process.

Timber-based plantation forest 40 year

According to the simulation of forest plant timber based on the rotation of 40 years (Figure 4), the proportion of carbon in the living is about 41 %, carbon litter about 3 % and 54 % in the soil. When conventional logging is applied at year 40, the forest carbon stock have a similar pattern with virgin dry forest. The highest living carbon, litter carbon and total carbon changes in the second of 40 years (60.85 gC/m^2/year, 3.42 gC/m^2/year, 94.611gC/m^2/year), the highest soil carbon changes occurred in the third of 40 years (34.76 gC/m^2/year). These pattern are differently reflected in the NBP figure, with a marked increase in instantaneous emissions at year 40, 80, 120, 160 and 200 (221.70 gC/m^2/year, 526.77 gC/m^2/year, 591.24 gC/m^2/year, 561.83 gC/m^2/year, respectively). However, this is temporary, because after that the value of NBP decreases again, even at the four and five of 40 years NBP reaches minus value (-24.37 gC/m^2/year and -39.45 gC/m^2/year).

In the scenario of forest plant timber based on the rotation of 40 years, from one year to the next, some of carbon is retained in the leaves about 270 gC/m^2 with average of the total leaf carbon is lost to the leaf litter pool (135 gC/m^2/year) on the rate of humification around 0.4. In the stem is about 4910.7 gC/m^2, where around 1/22 for every year of the total stem carbon will released to the stem litter pool is around 223.1 gC/m^2/year. About 450 gC/m^2 root with average 1/5 for every year root carbon will lost to the root litter pool about 90 gC/m^2 (Table 3). There was not different value in the longevity and humification rate resulting potential of humus carbon about 3592.5 gC/m^2, 3772.1 gC/m^2 for stable soil carbon and 170.7 gC/m^2 for highest released carbon in to the atmosphere (Humus carbon).

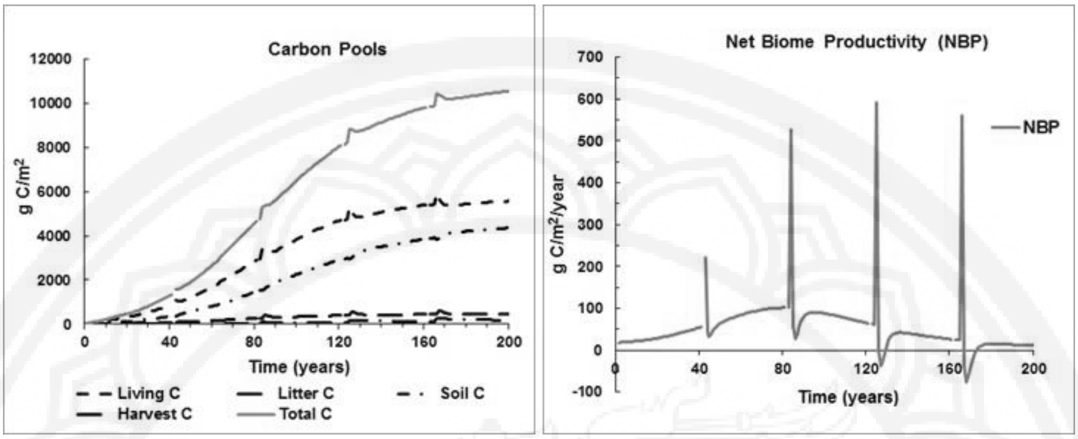

Figure 4 The dynamics of carbon stocks in forest plant timber based on the rotation of 40 years

Timber-based plantation forest 80 year

According to the simulation of forest plant timber based on the rotation of 80 years (Figure 5), the proportion of carbon in the living is about 41 %, carbon litter about 3 % and 54 % in the soil. Simulation results indicate that the changes in total carbon stock with conversion of virgin dry forest to timber forest with 80 year harvesting rotation were predominantly a result of changes in both the carbon pools and NBP. Figure 6 shows that there was a relatively consistent increasing (52.33 gC/m^2/year) in the total carbon under forest plant timber based on the rotation of 80 years, where highest change occurred in the second 80 years about 74.40 gC/m^2/year, 5.45 gC/m^2/year, 47.56 gC/m^2/year, 129.69 gC/m^2/year for living carbon, litter carbon, soil carbon and total carbon, respectively. The conversion of virgin forest to timber forest would reduce the slow NBP at the rate of 0.78 g C/m^2/year in the study area.

For the scenario of forest plant timber based on the rotation of 80 years, from one year to the next some of carbon is retained in the stem about 4912.7 gC/m^2 with average 1/22 of the total leaf carbon is lost to the stem litter pool (223.20 gC/m^2/year) on the rate of humification around 0.4. No different value with previous rotation in the longevity and humification rate was results potential of humus carbon about 3597.7 gC/m^2, 3764.5 gC/m^2 for stable soil carbon and 170.91 gC/m^2 for highest released carbon in to the atmosphere (humus carbon). The acculumation of humus carbon in the soil pool is about 3597.7 gC/m^2 with the rate of carbonisation and time of residence on 0.05 and 20, its mean around 1/20/year humus carbon will lost to the stable soil carbon (3764.5 gC/m^2) with the time of residence is about 500 (Table 3). In this process, humus carbon have a increase tendency to released CO_2 to the atmosphere (0.2 gC/m^2).

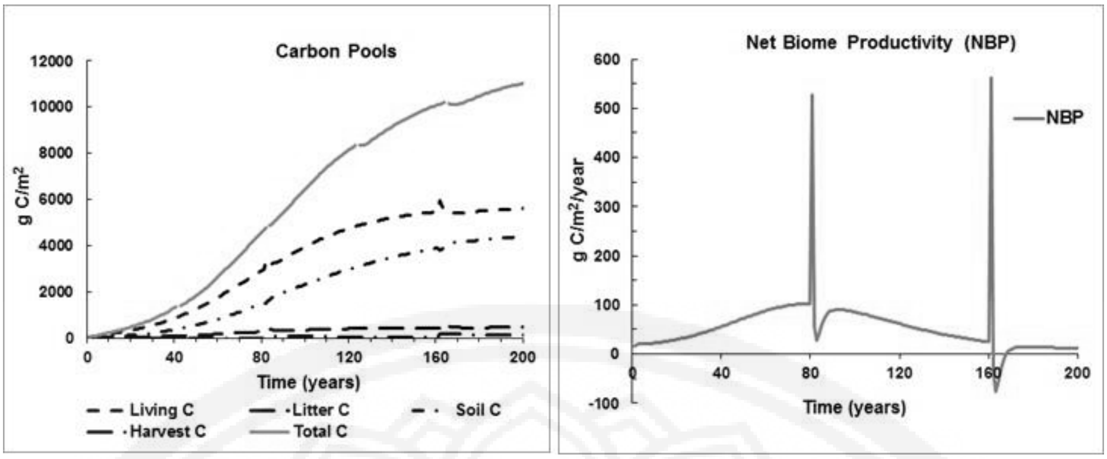

Figure 5 The dynamics of carbon stocks in forest plant timber based on the rotation of 80 years

Non timber-based plantation forest 40 year

In this research area, the proportion of carbon in the living in, is about 37 %, carbon litter about 3 % and 47 % in the soil, respectively. Totally, carbon pool consistent increasing, where highest change occurred in the five of 80 years (105.92 g C/m^2/year, 13.36 g C/m^2/year, 101.56 g C/m^2/year and 275.70 g C/m^2/year for living carbon, litter carbon, soil carbon and total carbon, respectively). The conversion of virgin forest to non timber forest would reduce the slow NBP at the rate of 0.92 g C/m^2/year, 0.88 g C/m^2/year, 2.69 g C/m^2/year in the third, four, and five of 40 years, increasing rate of NBP in the first and second of 40 years (1.003 g C/m^2/year and 1.176 g C/m^2/year).

Based on Table 3, in the scenario of forest plant non timber based on the rotation of 40 years, some of carbon is retained in the stem about 4680.9 gC/m^2 with an average of 1/22 in the total leaf carbon is lost to the stem litter pool (212.21 gC/m^2/year) on the rate of humification around 0.4 and potential of humus carbon about 3383.9 gC/m^2, 3457.6 gC/m^2 for stable soil carbon and 160.6 gC/m^2 for highest released carbon in to the atmosphere (humus carbon).

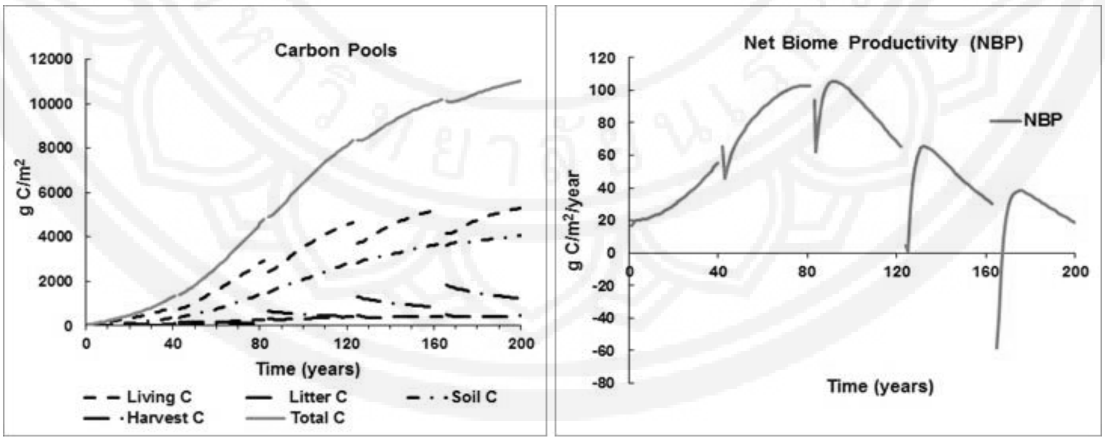

Figure 6 The dynamics of carbon stocks in forest plant non timber based on the rotation of 40 years

Non timber-based plantation forest 80 year

Based on Figure 7, the potential of carbon in the living is about 39 %, carbon litter about 3 % and 50 % in the soil. Carbon pools in this scenario has a tendency to increase, which highest changes at second of 80 years (53.46 gC/m^2/year, 6.715 gC/m^2/year, 47.092 gC/m^2/year, 123.456 gC/m^2/year for living carbon, litter carbon, soil carbon and total carbon, respectively). As well as NBP, has a tendency to decline at second 80 years until the end of simulation (0.708 gC/m^2/year), but in the first 80 years, NBP has increase by average of 1.091 gC/m^2/year. Even in the year 160, the value of NBP reaches -74.381 gC/m^2/year.

In the scenario of forest non timber based on rotation of 80 years (Table 3), some of carbon is retained in the stem about 4707.6 gC/m^2 with average 1/22 of the total stem carbon is lost to the stem litter pool (213.5 gC/m^2/year) on the rate of humification around 0.4 and potential of humus carbon about 3424.3 gC/m^2, 3599.4 gC/m^2 for stable soil carbon and 162.6 gC/m^2 for highest released carbon in to the atmosphere (humus carbon).

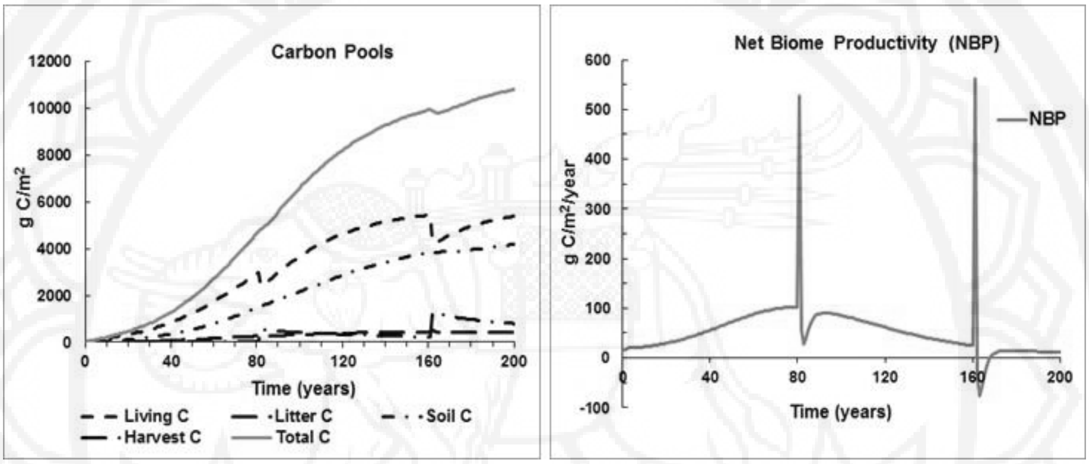

Figure 7 The dynamics of carbon stocks in forest plant non timber based on the rotation of 80 years

Traditional agroforestry (Mamar forest)

According to the simulation of traditional agroforestry system (Mamar forest), the proportion of carbon in the living is about 44 %, carbon litter about 4 % and 52 % in the soil (Figure 8). Where all of carbon pools increases with time simulation. The fitted carbon pools increment curves reached a maximum in the first 100 years (51 %), this is due to the dominance of an increase in soil carbon around 32 %. Carbon pools in this scenario increases during the simulation time, highest change occurred in the year 200 for all carbon pools (273.558 gC/m^2/year, 38.265 gC/m^2/year, 344.042 gC/m^2/year, 1324.194 gC/m^2/year, respectively).

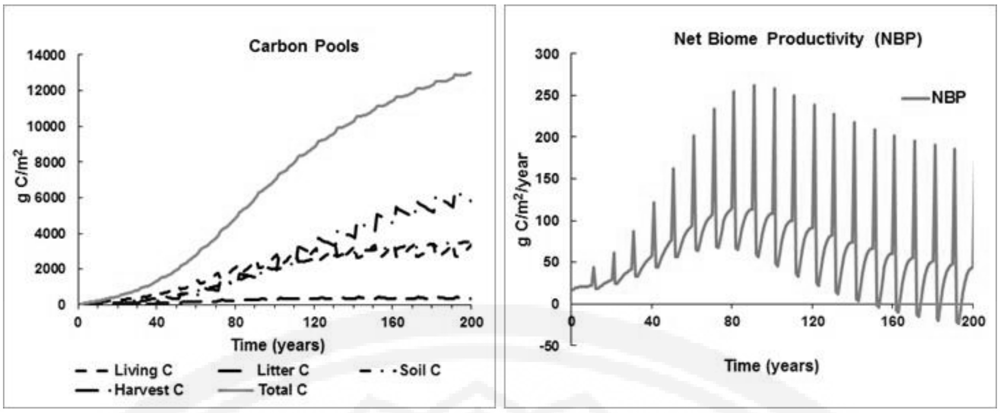

Figure 8 The dynamics of carbon stocks in traditional agroforestry (Mamar forest)

In the scenario of mamar forest, some of carbon is retained in the stem about 4861.5 gC/m^2 with average 1/22 of the total leaf carbon is lost to the leaf litter pool (220.8 gC/m^2/year) on the rate of humification around 0.4 and potential of humus carbon about 3280.1 gC/m^2, 3363.3 gC/m^2 for stable soil carbon and 155.5 gC/m^2 for highest released carbon in to the atmosphere (Table 3).

Based on the analysis of cluster, showed the highest distance (2779.17) there are between site 1 (Virgin dry forest) to site 6 (Mamar forest) and the smallest distance (275.74), between site 2 (Timber-based plantation forest 40 year) to site 5 (Non timber-based plantation forest 80 year). The number of cluster in the community similarity is about 5 clusters. On dendogram below shows clearly that the first group is composed of site 2 (Timber-based plantation forest 40 year) and site 5 (Non timber-based plantation forest 80 year), where this plot have a value of carbon storage are almost same and its followed by a second group: site 2 (Timber-based plantation forest 40 year) and site 3 (Timber-based plantation forest 80 year), third group : site 2 (Timber-based plantation forest 40 year) and site 4 (Non timber-based plantation forest 40 year), four group : site 1 (Virgin dry forest) and site 2 (Timber-based plantation forest 40 year), and the last group : site 1 (Virgin dry forest) and site 6 (Traditional agroforestry) (Figure 9).

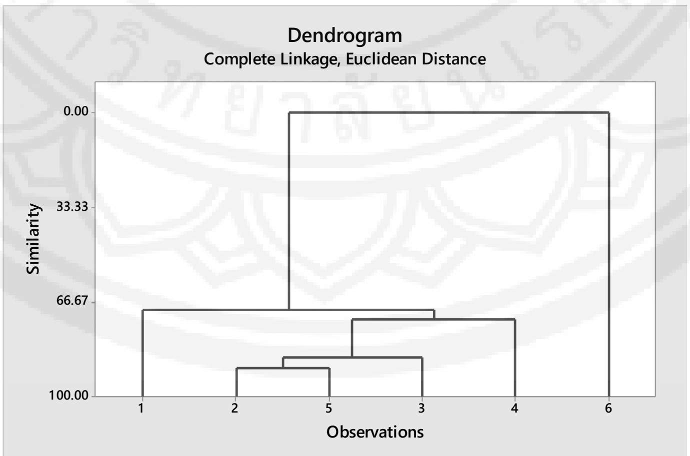

Figure 9 The degree of similarity dendrogram on community carbon storage

Discussion

The impact of natural and traditional forest management to the carbon stock

In a tropical forest ecosystem, the living biomass of trees, the understory vegetation and the deadwood, which includes the standing deadwood and the fallen deadwood like fallen stems and fallen branches, woody debris and soil organic matters constitute the main carbon pool. Among the above mentioned carbon pools, the above-ground biomass of the tree is mainly the largest carbon pool and it is directly affected by deforestation and forest degradation (Gibbs et al., 2007 as cited in Vashum & Jayakumar, 2012). The change in the forest areas and the changes in forest biomass due to management and regrowth greatly influence the transfer of carbon between the terrestrial forest ecosystem and the atmosphere (Houghton, 2005 as cited in Vashum & Jayakumar, 2012).

Generally, different forest management scenarios resulted in different pattern of forests to act as carbon sink as well as in different time scales of the forests acting as either a sink or a source, all harvesting reduces forest carbon when starting with a standing forest and rotation length overrides retention due to silvicultural treatment as the significant factor influencing dry forest carbon.

In this case, carbon stocks produced using the carbon accounting simulation software (CASS) for improved forest management were clearly influenced by presence or absence of harvesting activities. Virgin dry forest and traditional agroforestry system (mamar forest) scenarios were optimal for carbon stocks, but we did not consider leakage, land-use change nor natural disturbance risk from wind and fire. Carbon stock of the living, litter and soil all decreased from virgin forest to the type of forest plantation, carbon concentration of these biomass in the mamar forest were slightly higher than those of virgin forest and logging treatments (ranging from 0 to 52 %). Carbon stock of the living and soil increased with a decreasing harvest and reached the highest stock in the traditional agroforestry.

The impact of plantation forest management to the carbon stock

The substantial finding was that initial stocking were influential in determining carbon stocks for 80 and 40 years of logging rotations (Timber and non timber-based plantation forest, respectively). All model predictions of carbon pools showed that carbon pools were very sensitive to the best decrease rates associated with different logging rotation and percentage of disturbance cause by harvesting activity. The resulting carbon emissions due to virgin dry forest, timber and non timber-based plantation forest and mamar forest showed a total loss or emission form each pools between 160.6 – 171 gC/m^2 were the highest emitted from humus carbon. But the whole treatment had a significant impact on soil carbon, as shown in the graph carbon pool which has a tendency to increase until the end of the simulation. It also meant that the treatment given information that is important for the purposes of soil conservation activities, particularly for the purpose of conservation of soil carbon.

Labile fractions have been used as sensitive indicators of changes in soil quality (Haynes, 2005). The intensity of cultivation supports the process of mineralization and decrease of organic matter in the soil, which often causes the deterioration of physical, chemical and biological properties of soil. While no-tile and reduced tillage usually promote carbon storage in the surface soil, incorporation of crop residues by mouldboard ploughing can increase the SOC content at or near the bottom of the plough layer (Feiziene, Feiza, Kadziene, & Slepetiene, 2007). In arable cropping systems, organic matter storage in soil in usually positively related to C input, which includes above-ground residues and root biomass. For many plants as much as 30 – 50 % of the C fixed in photosynthesis is initially trans-located belowground. Root biomass increased by mineral fertilization does not always cover SOM mineralization lisses. The way the root biomass will continue in the soil-whether it will fully mineralize and increase CO_2 emission and plant nutrient researves, will assimilate and be fixed in microorganism biomass or partly changed **is** incorporated into much more stable humic substance composition-will depend on root chemical composition and environmental conditions (Moran, McFarland, Melendez, Kalivas, & Seamans, 2005). Evidence also indicate that below-ground plant C is a major source for subsequent conversion into more stable form of SOC (Wilts, Reicosky, Allmaras, & Clapp, 2004; Baker et al., 2007).

Contribution agroforestry system to carbon stock conservation in dry areas

In this study, traditional agroforestry system (Mamar forest) showed constant accumulation of carbon in the living, litter and soil. Mamar forest is a form of land use in Timor island that develop in around water sources and village to increase a carrying capacity of the environment through mixed cropping system between forestry and agriculture. Based on the research of Njurumana, Hidayatullah, and Butarbutar (2008), indicated that application of local agroforestry (Mamar system) has potential to rehabilitate forests and land. It can be seen from average of soil properties in this area, that's 7.305, 1.687 %, 12.687 %, 0.442 %, 40.492 ppm, 1.107 me/100g, 0.07 me/100g, 0.215 me/100g, 0.337 me/100g, 20.565 me/100g, clay, dark brown-gray, 1.175 gr/cm^3, 55.28 % for pH, C-Org, organic matter, N, P, K, Na, Ca, Mg, CEC, texture, colour, volume density and porosity, respectively. Agroforestry has emerged as a promising landuse system for reducing or offsetting deforestation (Soto-Pinto, Anzueto, Mendoza, Ferrer, & de Jong, 2010), while at the same time sequestering carbon and contributing to climate change mitigation (Dossa, Fernandes, Reid, & Ezui, 2008). As comparation materials, Schmitt-Harsh as cited by Jose and Bardhan (2012) observed that coffee agroforests in Guatemala stored somewhere between 74.0 and 259.0 Mg C/ha with a mean of 127.6 Mg C/ha. The average carbon stocks of coffee agroforests were significantly lower than estimated for the mixed dry forests (198.7 Mg C/ha); however, individual tree and soil C pools were not significantly different suggesting that shade trees played an important role in facilitating C sequestration and soil conservation in these systems. Because successful restoration of soil fertility normally requires a long fallow period for sufficient restoring of soil fertility lost during cropping (Sánchez, 1995 as cited in Boonyanuphap, Sakurai, & Tanaka, 2007).

Hãger attempted to unravel the relationship between species composition, diversity, and C storage in coffee agroforests of Costa Rica. Total C stocks were 43 % higher on organic farms than on conventional farms ($P < 0.05$) and although vegetation structure was different, there was no difference in species diversity between organic and conventional farms. Combined effect of farm type, species richness, species composition and slope explained 83 % of the variation in total C storage across all farms. Organic coffee agroforestry farms may contribute to climate change mitigation and biodiversity conservation in a synergistic manner which has implications for the effective allocation of resources for conservation and climate change mitigation strategies in the agricultural sector (Jose & Bardhan, 2012).

Estimation of NBP requires information on carbon transfers off the land base in addition to NEP (Schulze, Seavy, & Whitacre, 2000). In this study, when logging treatments (Timber and non timber-based plantation forest) is applied at year 40 and 80 the forest carbon stock can be seen to decrease for while. These changes are similarly reflected in the NBP, with a marked increase in instantaneous emissions after logging rotation. NBP of the managed forests is determined mainly by changes in age at which forest is usually harvested (the length of rotation). NBP is positive when the length of rotation is increasing, and negative otherwise.

According to Roxburgh (2004), CASS model is to provide an overview of the major processes which combine and interact to determine carbon dynamics in terrestrial ecosystems. Because process description is kept to a minimum, and emphasis is placed on simplicity and transparency, the CASS model has a number of limitations. Two major limitations are : in 'real' ecosystems the cycles of carbon, water and nutrients such as nitrogen and phosphorus run in parallel, and also interact with one another. An obvious shortcoming of the CASS approach is that these additional cycles are treated as 'external inputs' to the system (e.g. through modifying effects of water availability and nutrients on growth), and are not explicitly represented as parallel and interacting cycles per second. And the plant growth in CASS follows the 'Maximum productivity model' (Medlyn et al., 2003), whereby maximum productivity for the vegetation type is specified, and then modified according to a range of environmental factors. Whilst adequate for illustrating the major components of terrestrial carbon dynamics, this approach has limitations if the underlying processes contributing to plant growth are of interest.

Conclusion

Carbon Accounting Simulation Software (CASS) programme was efficiently conducted to simulate the dynamics of carbon stocks in the tropical lowland savanna of Camplong Nature Recreation Park, East Nusa Tenggara Province, Indonesia. The dynamic simulations using CASS were able to forecast the carbon stocks through 200 years under 3 scenarios, which are different in long-term effects of forest management. Based on the analysis presented, the following conclusions can be drawn: (1) that both traditional agroforestry system (mamar forest) and virgin dry forest in Nusa Tenggara Timur province store substantial amounts of carbon pools (2) comparison of trees on the timber-based plantation forest (58 %, 14 %, 14 %, 4 % and 10 % for *Melaleuca cajuputi*, *Cassia fistula* L, *Senna siamea*, *Prunus arborea* and others species) and non timber-based plantation forest (39 %, 31 %, 10 %, 3 % and 17 % for *Tectona grandis*, *Senna siamea*, *Delonix regia*, *Acacia leucophloea* and others species) provides good impact on the enhancement of carbon stocks and (3) harvesting activities that influence carbon pools recovery, for example by affecting site quality to disturbance, are of consequence to carbon storage. In tropical lowland savanna, managing the forest for timber is compatible with maximizing carbon storage if appropriate harvesting practices are used.

For the future research, we recommend, (1) studies that run for longer time periods (> 200 years) and address different in the ecosystem, land-use and natural disturbance (2) studies that include plant community characteristics such as ecological traits and species and genotype diversity to detect functional ecosystem responses to changing precipitation regimes

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