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Carbon stock estimation on the reclaimed forest of PT Newmont Minahasa Raya in Ratatotok, Southeast Minahasa

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Abstract

Describing the quality of forest ecosystems using a carbon sequestration approach is important in understanding global warming. From 1997 to 2010, PT Newmont Minahasa Raya (PTNMR) has reclaimed 215 ha bare land of ex-mining area. The area now has become a fully functioning forest ecosystem. The forest absorbs CO_2 from the atmosphere and accumulates it into a living biomass. The aim of this study was to estimate carbon sink in the Ratatotok forest, an ex-mining area. The study observed: 1) species composition at the various stages of plant development; 2) tree height and diameter to estimate the standing biomass; 3) carbon content of the understorey species; 4) carbon content of the ground litters; and 5) soil carbon content. Carbon content measurement employed a loss on ignition method, while total carbon was estimated using existing allometric equations. This study was conducted in the reclaimed areas from six different years, i.e. 1997, 2000, 2001, 2002, 2003 and 2007. The results showed that between 1997 and 2007, the forests captured a total of 247 t carbon per ha, equivalent to a total sequestration of 53,180 t of carbon in the entire reclaimed area (215 ha).

1 Introduction

Reduction of forest cover is an important issue to combat global warming. As forest areas decrease, the capture of CO_2 from the atmosphere is also lessened. Local programmes to increase CO_2 capture from the atmosphere are essential to combat global warming. PTNMR has committed to reclaim 215 ha of bare land in an ex-mining area in Ratatotok, North Sulawesi, Indonesia, and to restore it to a fully functioning forested ecosystem (Figure 1).

Since rehabilitation, the vegetation has re-established and grown and the area has turned into a more natural ecosystem (Pollo et al., 2011). As trees planted on the area are continuing to grow and capture CO_2 from the atmosphere, the forest has retained a certain carbon mass and a certain value of a growing carbon storage that sinks into its carbon pools. Hollinger (2008); Burton and Pregitzer (2008); and Scott and Brown (2008) defined carbon pools as standing trees, leaves, shrubs, litter fall, roots, soil. In order to know how much carbon is sequestered and stocked in the forest, research on carbon stock estimation is important and necessary.

2 Methodology

Field measurements were carried out on revegetated areas during 1997, 2000, 2001, 2002, 2003, and 2007 (referred to as Rec. 1997 to Rec. 2007). In each revegetated area, three different lines were determined as sampling transects. On each sampling transect, three quadrilateral sampling plots of 20 x 20 m were placed for data collecting purpose. All smaller plots were placed systematically at the beginning of the centre line in the plot of 20 x 20 m. There were 48 plots in total.

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Figure 1 Gold mining location of PTNMR in Ratatotok, Southeast Minahasa (source: PTNMR)

Five parameters are measured in the observation plots:

1. Species composition in various stages of plant development.
2. Tree height and its diameter for biomass calculation on standing trees.
3. Carbon content of understorey (seedlings and ground cover).
4. Carbon content of ground litter.
5. Carbon content of soil.

Tree species and plant life forms were directly identified in the field. The biomass of the standing trees was calculated using allometric equations based on tree diameter which was then multiplied by 0.47, a default fraction determined by McGroddy et al. (2004) to obtain a carbon fraction value. Carbon content of the understorey vegetation (seedlings and ground cover), ground litter, and on soil were analysed using loss on ignition, combusted in a muffle furnace at 360°C for 2 hours, and gravimetric methods (Heiri et al., 2001; Konen et al., 2002). All the work to obtain carbon fraction data was undertaken in the Soil Physics Laboratory of Faculty of Agriculture, Sam Ratulangi University, Indonesia.

2.1 Species composition at various stages of plant development

Species composition data were collected from quadrilateral plots which were systematically separated and adjusted directly in each transect. Stages of a plants life cycle consist of seedling, sapling, shrub and pole, and tree. Classification of each stage is as follows:

- Seedlings were classified as herbaceous, semi-woody, and the tree species were identified by diameters $\leq$ 1 cm and/or height up to 1 m.
- Sapling diameter was between 1–10 cm; height >1 m.
- Shrubs and poles diameter was between 10–30 cm.
- Tree diameter was > 30 cm (following Harlow et al., 1991).

The plot size for the seedlings was 1 x 1 m, sapling was 5 x 5 m, shrub and pole was 10 x 10 m and trees were 20 x 20 m (Brower and Zar, 1984). All plants found in each plot were recorded and tabulated.

2.2 Tree height and diameter for biomass calculation on standing tree

The standing tree for biomass calculation was obtained from sapling, shrub and pole, and tree. The total height of tree was measured using a pole. Tree diameter was measured at breast height with a phi band. Recorded diameter data was then calculated using allometric equations to predict standing tree biomass in kg/ha or t/ha. The biomass value was multiplied by default carbon fraction of 0.47 to obtain carbon value in kg/ha or t/ha. Tropical forest typically contains approximately 47–50% carbon fraction deposited as terrestrial biomass (Brown, 1997; Eggleston et al., 2006; Chojnacky and Milton, 2008). By adding a time unit, forest productivity levels can be determined.

There are several allometric equations available for biomass calculation as summarised in Table 1.

Table 1 Allometric equations used for biomass calculation

No.	Plant Species	Equation	Source
1	*Paraserienthes falcataria*	$YAG = 0.3196\ D^{1.9834}$ $YR = 0.0069\ D^{2.5651}$	Krisnawati et al. (2011)
2	*Swietenia macrophylla*	$YS = 0.044D^{2.61}$ $YB = 0.00059D^{3.46}$ $YT = 0.0027D^{2.42}$ $YSt = 0.022D^{1.96}$ $YL = 0.0138D^{1.93}$ $YTot = 0.048D^{2.68}$	Adinugroho and Sidiyasa (2006)
3	*Gmelina arborea*	$Y = 0.153 \times D^{2.217}$	Banaticla et al. (2005)
4	*Leucaena leucocephala*	$Y = 0.206 \times D^{2.305}$	Banaticla et al. (2005)
5	*Tectona grandis*	$Y = 0.153 \times D^{2.382}$	Penman et al. (2003)
6	Tree fern	$AGB = -4266348/(1-2792284 \exp(-0.313677 \times H))$	Tiepolo et al. (2002)
7	Root biomass density	$YR = \exp(-1.0587 + 0.8836 \times \text{in AGB})$	Cairns et al. (1997) in Sutaryo (2009)
8	Tropical Rain Forest	$Y = 13{,}2579 - 4{,}8945 \times (D^2) + 0.6713 \times (D^2)$	Brown et al. (1989)

Notes: Y = Biomass (kg), D = Diameter at Breast Height (cm), H = Height (m), YAG = Above Ground Biomass, YS = Stem Biomass, YB = Branch Biomass, YT = Twig Biomass, YSt = Stump Biomass, YL = Leaf Biomass, YTot = Total Above Ground Biomass.

2.3 Carbon content of understorey vegetation

Understorey vegetation consists of seedlings and ground cover plants. All understorey living plants, including their roots collected on each plot of 2 x 2 m, were combusted due to loss of ignition method. The gravimetric method showed that the carbon content of understorey vegetation indicated a loss of combusted mass.

2.4 Carbon content of ground litter

Ground litter data was collected on the same plot of 1 x 1 m on the seedling's observation plot. Methods employed for carbon content calculation were similar to those that were applied to the understorey category.

2.5 Carbon content of soil

Soil carbon content was obtained by combusting composite soil samples. The soil bulk density value was obtained by oven drying undisturbed soil samples at 105°C. Composite soil samples were taken from the field in depths of 0–10 cm, 10–20 cm, 20–30 cm. Undisturbed soil samples were taken in depths of 0–15 cm and 15–30 cm.

Table 2 Number of seedlings found in all reclaimed areas

No	Species	Rec. 1997	Rec. 2000	Rec. 2001	Rec. 2002	Rec. 2003	Rec. 2007	Total	Frequency (%)
1	*Acanthus* sp.		2					**2**	**1.5%**
2	*Ageratum conyzoides*			1	1			**2**	**1.5%**
3	*Artocarpus* sp.				1			**1**	**0.7%**
5	*Cananga odorata*		1		2	1		**4**	**2.9%**
6	*Capsicum frutescens*					1		**1**	**0.7%**
7	*Cardiospermum halicacabum*						1	**1**	**0.7%**
8	*Centrosema pubescens*			2	5			**7**	**5.1%**
9	*Chromolaena odorata*	1	3	1	1		2	**8**	**5.9%**
10	*Crotalaria* sp.	1	1	3	5	3	1	**14**	**10.3%**
11	Convolvulaceae						1	**1**	**0.7%**
12	*Cyathea* sp.			1	1			**2**	**1.5%**
13	*Ficus septica*						1	**1**	**0.7%**
14	*Ficus* sp. (Liana)			1		1		**2**	**1.5%**
15	*Ficus* sp. 1			1				**1**	**0.7%**
16	*Glyrisidia maculata*					1		**1**	**0.7%**
17	Graminae		3	4	3	1	2	**13**	**9.6%**
18	*Hyptis capitata*		1					**1**	**0.7%**
19	*Imperata cylindrica*						1	**1**	**0.7%**
20	Lauraceae	1						**1**	**0.7%**
21	*Leucaena glauca*		1	1		3		**5**	**3.7%**
22	Malvaceae				1			**1**	**0.7%**
23	*Melanolepis multiglandulosa*		1					**1**	**0.7%**
24	*Melothria* sp.		1	1			1	**3**	**2.2%**
25	*Mimosa pudica*	1			5			**6**	**4.4%**
26	*Nephrolepis* sp.	1						**1**	**0.7%**
27	*Paspalum* sp.	1	3	1	6		3	**14**	**10.3%**
28	*Piper aduncum*			1			2	**3**	**2.2%**
29	*Piper* sp. (Liana)		3					**3**	**2.2%**
30	*Premna* sp.			3		1		**4**	**2.9%**
31	Pteridaceae	1						**1**	**0.7%**
32	*Pterocarpus indicus*	1	1		1			**3**	**2.2%**
33	*Pythecolobium* sp.	2						**2**	**1.5%**
34	*Sida retusa*				1		1	**2**	**1.5%**
35	*Stachytarpheta jamaicensis*		1					**1**	**0.7%**
36	*Swietenia macrophylla*	3	2					**5**	**3.7%**
37	*Terminalia catapa*						1	**1**	**0.7%**
38	Unidentified 1.			1				**1**	**0.7%**
39	Unidentified 2.					1		**1**	**0.7%**
40	*Urena lobata*	1	1				1	**3**	**2.2%**
41	Verbenaceae					2	8	**10**	**7.4%**
42	*Vitis* sp.	1						**1**	**0.7%**
	Total	**15**	**25**	**22**	**33**	**15**	**26**	**136**	**100.0%**
	Frequency (%)	**11.0%**	**18.4%**	**16.2%**	**24.3%**	**11.0%**	**19.1%**	**100.0%**	

3 Results and discussion

3.1 Species composition at various stages of plant development

3.1.1 Seedlings

Table 2 lists the numbers of seedlings found during field observations. Based on this table, there were several seedling species growing on the same environment to fill the ecological niche. There were at least six plant species found during the observation: creepers, weeds, planted ground covers, shading tree, lianas and the sown plants. Of the 42 plant species found, some grew as weeds, some were planted for a specific purpose, and some species established themselves naturally. Most of them were dispersed into the area by a dispersal agent. One of the most abundant plants found was *Crotalaria* sp. that was sown specifically as ground cover vegetation.

Table 3 Numbers of saplings found in all reclaimed areas

No	Species	Rec. 1997	Rec. 2000	Rec. 2001	Rec. 2002	Rec. 2003	Rec. 2007	Total	Frequency
1	*Abutilon* sp.			2		1	1	**4**	**1.3%**
2	*Acacia* sp.		2	6	16		5	**29**	**9.1%**
3	*Ailanthus malabarica*					1		**1**	**0.3%**
5	*Cannarium* sp.			1				**1**	**0.3%**
6	*Capsicum frutescens*			1				**1**	**0.3%**
7	*Cassia alata*			1				**1**	**0.3%**
8	*Chromolaena odorata*						1	**1**	**0.3%**
9	*Cinnamomum* sp.	1					1	**2**	**0.6%**
10	*Cyathea* sp.			4	3	1	3	**11**	**3.4%**
11	*Ficus* sp. 1			1				**1**	**0.3%**
12	*Ficus* sp. 2		1					**1**	**0.3%**
13	*Flacourtia* sp.	1						**1**	**0.3%**
14	*Glyrisidia maculata*		1	12	5	16	15	**49**	**15.4%**
15	*Gmelina arborea*		22					**22**	**6.9%**
16	*Leucaena glauca*		2			6		**8**	**2.5%**
17	*Macaranga* sp.						1	**1**	**0.3%**
18	*Mangifera* sp.			1				**1**	**0.3%**
19	*Melanolepis multiglandulosa*		4	12	2		2	**20**	**6.3%**
20	*Palaquium* sp.	1	2	1	1	1	11	**17**	**5.3%**
21	*Piper aduncum*				2		5	**7**	**2.2%**
22	*Pometia pinnata*						1	**1**	**0.3%**
23	*Pterocarpus indicus*			1				**1**	**0.3%**
24	Sapindaceae				1			**1**	**0.3%**
25	*Stachytarpheta indica*						4	**4**	**1.3%**
26	*Sterculia* sp.	2	1	2				**5**	**1.6%**
27	*Swietenia macrophylla*	55	16	15	7	6	20	**119**	**37.3%**
28	*Tectona grandis*			4	2			**6**	**1.9%**
29	*Urena lobata*		2		1			**3**	**0.9%**
	Total	**60**	**53**	**64**	**40**	**32**	**70**	**319**	**100.0%**
	Frequency (%)	**18.8%**	**16.6%**	**20.1%**	**12.5%**	**10.0%**	**21.9%**	**100.0%**	

3.1.2 Saplings

As shown on Table 3, from a total of 29 plant species and 319 recorded saplings, all saplings of *Swietenia macrophylla* and *Tectona grandis* were the offspring of trees grown in the reclaimed areas. The trees were able to produce fruits, seeds, seedlings and saplings. This implies that the ecological condition of the reclaimed areas were highly suited to the ecological needs of the plants.

3.1.3 Shrubs and poles

Table 4 shows numbers of saplings found during field observation. Based on the data, there were three tree species, namely *Glyrisidia maculata*, *Swietenia macrophylla* and *Tectona grandis* which were growing abundantly within the study site. They were easily identified in the field. These trees are categorised as a fast growing species, with a diameter size between ≥ 10–30 cm. This indicates that the plants have grown well in the reclaimed area

3.1.4 Trees

The number of trees found on sampling plots in all reclaimed areas is summarised in Table 5.

As shown on Table 5, there were 105 trees with a diameter ≥ 30–67 cm. The most common plant, as shown on Table 4, was *Glyrisidia maculata*, a shading tree. This species cannot be seen in the tree form with a diameter ≥ 30 cm. This is most probably caused by lack of light to support its continued development. The most abundant tree was *Swietenia macrophylla.* Table 6 summarises a combination of all the plants life cycle stages found in the sampling plots by species type.

Table 4 Numbers of shrubs and poles found in all reclaimed areas

No	Species	Rec. 1997	Rec. 2000	Rec. 2001	Rec. 2002	Rec. 2003	Rec. 2007	Total	Frequency
1	*Paraserianthes falcataria*		1	1	4			**6**	**1.8%**
2	*Artocarpus* sp.						1	**1**	**0.3%**
3	*Cyathea* sp.			1			1	**2**	**0.6%**
4	*Garuga floribunda*				1			**1**	**0.3%**
5	*Glyrisidia maculata*	2	5	29	5	14	46	**101**	**30.6%**
6	*Leucaena glauca*					4		**4**	**1.2%**
7	*Macaranga* sp.						1	**1**	**0.3%**
8	*Melanolepis multiglandulosa*			1		1	4	**6**	**1.8%**
9	*Melochia* sp.				1	1	2	**4**	**1.2%**
10	*Mimusops elengi*	2						**2**	**0.6%**
11	*Palaquium* sp.	1					2	**3**	**0.9%**
12	*Pterocarpus indicus*		6					**6**	**1.8%**
13	*Spathodea campanulata*				1			**1**	**0.3%**
14	*Pterospermum* sp.		1					**1**	**0.3%**
15	*Swietenia macrophylla*	2	18	25	8	33	11	**97**	**29.4%**
16	*Tectona grandis*		9	19	44	21		**93**	**28.2%**
17	*Trema orientalis*						1	**1**	**0.3%**
	Total	**7**	**40**	**76**	**64**	**74**	**69**	**330**	**100.0%**
	Frequency	**2.1%**	**12.1%**	**23.0%**	**19.4%**	**22.4%**	**20.9%**	**100.0%**	

Table 5 Number of trees found in all reclaimed areas

No	Species	Rec. 1997	Rec. 2000	Rec. 2001	Rec. 2002	Rec. 2003	Rec. 2007	Total	Frequency
1	*Paraserianthes falcataria*		1	10	9	2		**22**	**21.0%**
2	*Gmelina arborea*		8					**8**	**7.6%**
3	*Anthocephalus macrophylla*	1						**1**	**1.0%**
4	*Palaquium* sp.	3						**3**	**2.9%**
5	*Pterocarpus indicus*				1			**1**	**1.0%**
6	*Swietenia macrophylla*	25	31	2				**58**	**55.2%**
7	*Tectona grandis*		2	3	2	4		**11**	**10.5%**
8	*Trema orientalis*					1		**1**	**1.0%**
	Total	**29**	**42**	**15**	**12**	**7**	**0**	**105**	**100.0%**
	Frequency	**27.6%**	**40.0%**	**14.3%**	**11.4%**	**6.7%**	**0.0%**	**100.0%**	

Table 6 Numbers of plant life forms found in all reclaimed areas

No	Species	Rec. 1997	Rec. 2000	Rec. 2001	Rec. 2002	Rec. 2003	Rec. 2007	Total	Frequency
1	*Abutilon* sp.			1		1	1	**3**	**1.6%**
2	*Acacia* sp.		1	1	1		1	**4**	**2.1%**
3	*Acanthus* sp.		1					**1**	**0.5%**
4	*Ageratum conyzoides*			1	1			**2**	**1.0%**
5	*Ailanthus malabarica*					1		**1**	**0.5%**
6	*Anthocephalus macrophylla*	1						**1**	**0.5%**
7	*Artocarpus* sp.				1		1	**2**	**1.0%**
8	*Cananga odorata*		1		1	1		**3**	**1.6%**
9	*Cannarium* sp.			1				**1**	**0.5%**
10	*Capsicum frutescens*			1		1		**2**	**1.0%**
11	*Cardiospermum halicacabum*						1	**1**	**0.5%**
12	*Cassia alata*			1				**1**	**0.5%**
13	*Centrosema pubescens*			1	1			**2**	**1.0%**
14	*Chromolaena odorata*	1	1	1	1		2	**6**	**3.1%**
15	*Cinnamomum* sp.	1					1	**2**	**1.0%**
16	*Crotalaria* sp.	1	1	1	1	1	1	**6**	**3.1%**
17	Convolvulaceae						1	**1**	**0.5%**
18	*Cyathea* sp.			3	2	1	2	**8**	**4.1%**
19	*Ficus septica*						1	**1**	**0.5%**
20	*Ficus* sp. (Liana)			1		1		**2**	**1.0%**
21	*Ficus* sp. 1			2				**2**	**1.0%**
22	*Ficus* sp. 2		1					**1**	**0.5%**
23	*Flacourtia* sp.	1						**1**	**0.5%**
24	*Garuga floribunda*				1			**1**	**0.5%**
25	*Glyrisidia maculata*	1	2	2	2	3	2	**12**	**6.2%**
26	*Gmelina arborea*		2					**2**	**1.0%**
27	Graminae		1	1	1	1	1	**5**	**2.6%**
28	*Hyptis capitata*		1					**1**	**0.5%**
29	*Imperata cylindrica*						1	**1**	**0.5%**
30	Lauraceae	1						**1**	**0.5%**
31	*Leucaena glauca*		2	1		3		**6**	**3.1%**
32	*Macaranga* sp.						2	**2**	**1.0%**
33	Malvaceae				1			**1**	**0.5%**
34	*Mangifera* sp.			1				**1**	**0.5%**
35	*Melanolepis multiglandulosa*		2	2	1	1	2	**8**	**4.1%**
36	*Melochia* sp.				1	1	1	**3**	**1.6%**
37	*Melothria* sp.		1	1			1	**3**	**1.6%**
38	*Mimosa pudica*	1			1			**2**	**1.0%**
39	*Mimusops elengi*	1						**1**	**0.5%**
40	*Nephrolepis* sp.	1						**1**	**0.5%**
41	*Palaquium* sp.	3	1	1	1	1	2	**9**	**4.7%**
42	*Paraserianthes falcataria*		2	2	2	1		**7**	**3.6%**
43	*Paspalum* sp.	1	1	1	1		1	**5**	**2.6%**
44	*Piper aduncum*			1	1		2	**4**	**2.1%**
45	*Piper* sp. (Liana)		1					**1**	**0.5%**
46	*Pometia pinnata*						1	**1**	**0.5%**
47	*Premna* sp.			1		1		**2**	**1.0%**
48	Pteridaceae	1						**1**	**0.5%**
49	*Pterocarpus indicus*	1	2	1	2			**6**	**3.1%**
50	*Pterospermum sp.*		1					**1**	**0.5%**
51	*Pythecolobium* sp.	2						**2**	**1.0%**
52	Sapindaceae				1			**1**	**0.5%**

Table 6 Numbers of plant life forms found in all reclaimed areas continued...

No	Species	Rec. 1997	Rec. 2000	Rec. 2001	Rec. 2002	Rec. 2003	Rec. 2007	Total	Frequency
53	*Sida retusa*				1		1	**2**	**1.0%**
54	*Spathodea campanulata*				1			**1**	**0.5%**
55	*Stachytarpheta indica*						1	**1**	**0.5%**
56	*Stachytarpheta jamaicensis*		1					**1**	**0.5%**
57	*Sterculia* sp.	1	1	1				**3**	**1.6%**
58	*Swietenia macrophylla*	4	4	3	2	2	2	**17**	**8.8%**
59	*Tectona grandis*		2	3	3	2		**10**	**5.2%**
60	*Terminalia catapa*						1	**1**	**0.5%**
61	*Trema orientalis*					1	1	**2**	**1.0%**
62	Unidentified 1.			1				**1**	**0.5%**
63	Unidentified 2.					1		**1**	**0.5%**
64	*Urena lobata*	1	2		1		1	**5**	**2.6%**
65	Verbenaceae					1	1	**2**	**1.0%**
66	*Vitis* sp.	1						**1**	**0.5%**
	Total	**25**	**35**	**38**	**33**	**26**	**36**	**193**	**100.0%**
	Frequency	**13.0%**	**18.1%**	**19.7%**	**17.1%**	**13.5%**	**18.7%**	**100.0%**	

As shown on Table 6, from the 66 plant species found in all sampling plots, there were four common species namely, *Crotalaria* sp., *Glyrisidia maculata*, *Palaquium* sp. and *Swietenia macrophylla*. *Crotalaria* sp. is a species used as a ground cover to protect bare soil from erosion. This pioneer species was planted while waiting for other tree species to form a forested area. *Glyrisidia maculata* was planted to serve as a shading tree to reduce sunlight intensity. This species was also planted to create suitable microclimate surrounding each main tree to allow the trees to cover the reclaimed areas. *Palaquium* sp. and *Swietenia macrophylla* were planted as the main tree vegetation in the reclaimed area.

3.2 Carbon content of standing trees

Table 7 shows that there were 753 trees with diameter ≥ 10–67 cm on a combined total of 19,200 m^2 of sampling plots. If the value was converted to numbers of trees per ha, then the total number of trees per ha is 392, or 84,280 trees in an area of 215 ha. This number of trees in a commercial plantation would be considered of reasonable economic value. The biggest average tree diameter was found in the plots located in the reclaimed year of 2000. Since it was located on a hilly area, it was different from the branching free trees found on the 2002 reclaimed area which is situated on flat ground and where, on average, the tree growth reached 3.63 m. In general, the location of the tree considerably influenced its growth quality.

As shown on Table 7, there were six tree species which reached a diameter corresponding to the largest growth stage. These are considered fast growing species. *Anthocephalus macrophyllus* and *Trema orientalis* naturally invaded the reclaimed areas with an annual growth increment of 4.45 and 3.7 cm/year, respectively. The fastest growth increment was found in *Paraserianthes falcataria* with 5.18 cm/year during 2003.

Table 8 summarises the biomass and carbon contents in kg/ha on roots and standing trees.

As shown on Table 8, an average sum of root and standing carbon content was 240,513 kg/ha. In general, carbon content of the reclaimed forest of year 2000 was the highest compared to the others. It was even higher than the trees planted in 1997. This fits with the above explanation.

Based on research done in Indonesia by Dharmawan and Siregar (2009) in Masripatin et al. (2010), and Samsoedin et al. (2009) in Masripatin et al. (2010), above ground carbon stock in a natural lowland tropical rainforest with a diameter at breast height ranging from 7–70 cm was 230.10–264.70 t/ha. This research found that the standing stock biomass was 435,326 kg/ha or 204,603 kg/ha of carbon or 205 t/ha of carbon which indicated that the reclaimed forest functions similar to that of a natural forest.

Table 7 Averages of height, diameter and branch-free bole length of trees found on sampling plots

No.	Area	Σ Trees	Diameter (cm)	Height (m)	Branching Free (m)	Largest Diameter (cm)	Tallest (m)
1	Rec. 1997	96	14.02	8.37	2.37	67 (*Anthocephalus macrophyllus*)	30.25 (*Palaquium* sp.)
2	Rec. 2000	134	19.09	11.45	3.33	45.5 (*Swietenia macrophylla*)	26.5 (*Gmelina arborea*)
3	Rec. 2001	155	13.62	9.70	2.85	43.8 (*Paraserianthes falcataria*)	26 (*Paraserianthes falcataria*)
4	Rec. 2002	116	14.94	10.93	3.63	36 (*Paraserianthes falcataria*)	24.5 (*Paraserianthes falcataria*)
5	Rec. 2003	113	13.79	10.19	3.28	46.6 (*Paraserianthes falcataria*)	22 (*Trema orientalis*)
6	Rec. 2007	139	8.63	7.75	2.34	18.5 (*Trema orientalis*)	15.5 (*Trema orientalis*)
	Total	**753**	**84.09**	**58.39**	**17.81**		
	Average	**126**	**14.01**	**9.73**	**2.97**		

Table 8 Root and standing tree biomass and carbon content of standing trees

No.	Area	Width (ha)	Σ Trees	Root Biomass (kg/ha)	Standing Biomass (kg/ha)	Σ Biomass (kg/ha)	Root to Standing Biomass (%)	Carbon (kg/ha)	Total Carbon (t)
1	Rec. 1997	16.4	96	93,457	585,173	678,630	15.97	318,956	5,321
2	Rec. 2000	16.5	134	137,601	818,324	955,926	16.81	449,285	7,413
3	Rec. 2001	54.71	155	78,339	424,918	503,256	18.44	236,531	12,941
4	Rec. 2002	51.58	116	66,197	367,783	433,980	18.00	203,971	10,521
5	Rec. 2003	7.0	113	57,237	300,722	357,959	19.03	168,241	1,178
6	Rec. 2007	68.81	139	25,594	115,035	140,629	22.25	66,096	4,548
	Total	**215**	**753**	**458,424**	**2,611,955**	**3,070,380**	**110.50**	**1,443,078**	**41,831**
	Average	**35.83**	**126**	**76,404**	**435,326**	**511,730**	**18.42**	**240,513**	**6,972**

However to the contrary, the ratio between root and standing biomass was inverted, the younger the vegetation, the higher the value. This can be explained by the fact that soil formation is slower than that of root penetration into a deeper soil solum.

3.3 Carbon content of understorey

Table 8 shows an average sum of understorey carbon content of 240,513 kg/ha. As shown in the data, carbon content of understorey in 2007 was the highest. As this area was reclaimed within five years, the tree canopy had just started to grow. Therefore, there were still gaps among vegetation which allowed the sunlight to reach the forest floor. This created a niche for other plants to grow. Not surprisingly, the carbon content of this area was the lowest. The soil condition of this area was also poor as it had a high clay

content. This affected the drainage and aeration. During the rainy season, the water inundates the area. Therefore, only plants that are tolerant to high moisture survive, especially during a long rainy season. Typically, weed plant species have a wide range of tolerance to this particular ecological condition.

Table 9 Carbon content of the understorey

No.	Area	Width (ha)	Dry Weight (kg)	Dry Weight Average (kg)	Dry Weight (kg/ha)	Total Carbon (t)
1	Rec. 1997	16.4	0.83	0.275	2,750	45
2	Rec. 2000	16.5	1.81	0.2007	2,007	33
3	Rec. 2001	54.71	4.46	0.4955	4,955	271
4	Rec. 2002	51.58	5.74	0.6381	6,381	329
5	Rec. 2003	7	0.98	0.1087	1,087	8
6	Rec. 2007	68.81	8.69	0.9657	9,657	665
	Total	**215**	**22.5**	**2.68**	**26,837**	**1,531**
	Average	**35.83**	**0.47**	**0.45**	**4,473**	**225**

3.4 Carbon content of ground litter

Table 10 shows carbon content of the ground litter. Based on the data, an average sum of carbon content was 8,845 kg/ha. There were two areas producing high carbon content, the reclaimed areas of 1997 and 2002. These two areas had high litter decomposition as the vegetation had formed a dense canopy. The litters were produced primarily by a deciduous tree, *Tectona grandis.*

Table 10 Carbon content of the ground litter

No.	Area	Width (ha)	Dry Weight (kg)	Dry Weight Average (kg)	Dry Weight (kg/ha)	Total Carbon (t)
1	Rec. 1997	16.4	4.03	1.3445	13,445	221
2	Rec. 2000	16.5	8.03	0.8917	8,917	147
3	Rec. 2001	54.71	6.25	0.6941	6,941	380
4	Rec. 2002	51.58	9.69	1.0769	10,769	556
5	Rec. 2003	7	6.61	0.7343	7,343	51
6	Rec. 2007	68.81	5.09	0.5653	5,653	389
	Total	**215**	**39.69**	**5.31**	**53,068**	**1,743**
	Average	**35.83**	**6.62**	**0.88**	**8,845**	**291**

3.5 Carbon content of soil

Based on the Table 11, the years with the highest dry weight were 1997 and 2007, when the average sum of soil carbon content was 46.38 and 41.52 kg/ha respectively.

The carbon distribution in tropical forest ecosystems is different to more temperate regions. The majority of carbon in the tropics is accumulated at the standing biomass, with only a small fraction found in the soil as a result of the more rapid decomposition in a tropical climate (Tasirin, 1994). In 1997 the high carbon content can be explained as a result of high soil retention in addition to the age of plants. High soil carbon

content in 2007 was probably due to a high rate of decomposition and availability of understorey to supply organic carbon to the soil.

Table 11 Carbon content of soil

No.	Area	Width (ha)	Dry Weight (gr)	Dry Weight Average (gr)	Dry Weight (gr/ha)	Dry Weight (kg/ha)	Total Carbon (kg)
1	Rec. 1997	16.4	13.9127	4.6376	46,376	46.38	761
2	Rec. 2000	16.5	8.0007	2.6669	26,669	26.67	440
3	Rec. 2001	54.71	34.2972	3.8108	38,108	38.11	2,085
4	Rec. 2002	51.58	32.1785	3.5754	35,754	35.75	1,844
5	Rec. 2003	7	34.4813	3.8313	38,313	38.31	268
6	Rec. 2007	68.81	37.3661	4.1518	41,518	41.52	2,857
	Total	**215**	**160.2365**	**22.6737**	**226,737**	**226.74**	**8,255**
	Average	**35.83**	**26.7061**	**3.7789**	**37,789**	**37.79**	**1,376**

Table 12 shows a total carbon content in the reclaimed forest. Values in the table were summarised from Tables 8–11.

Table 12 Carbon content in the reclaimed forest

			Carbon Content (t/215 ha)					
No.	Area	Width (ha)	Standing Trees	Understorey	Ground Litter	Soil	Carbon (t/215 ha)	Carbon (t/ha)
1	Rec. 1997	16.4	5,321	45	221	761	6,257	29
2	Rec. 2000	16.5	7,413	33	147	440	8,033	37
3	Rec. 2001	54.71	12,941	271	380	2,085	15,676	73
4	Rec. 2002	51.58	10,521	329	556	1,844	13,250	62
5	Rec. 2003	7	1,178	8	51	268	1,505	7
6	Rec. 2007	68.81	4,548	665	389	2,857	8,458	39
	Total	**215**	**41,831**	**1,531**	**1,743**	**8,255**	**53,180**	**247**
	Average	**35.83**	**6,972**	**225**	**291**	**1,376**	**8,863**	**41**

Based on Table 12 data, it is shown that the carbon content of the reclaimed forest was 247 tonne/ha or in total, the forest stored 53,180 t of carbon per 215 ha. This indicated that the forest has sequestrated CO_2 quickly from the atmosphere. The growing forest ecosystem continues to store carbon into the carbon pools. These findings imply that the forest ecosystem has a potential economic value for carbon storage.

4 Conclusion

Within 5–15 years after planting, trees on the reclaimed forests captured a total of 247 t carbon/ha, or a total sink of 53,180 t of organic carbon in the 215 ha, and the forest performed as a carbon storage.

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