

Assessment of Carbon Stock in Chronosequence Rehabilitated Tropical Forest Stands in Malaysia

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Abstract

The loss and degradation in tropical forest region are some of the current global concern. Hence, these issues elevated the role of rehabilitated forests in providing ecological products and services. The information on the carbon stock is important in relation to global carbon and biomass use, but lacking from the tropical region. This paper reports the assessment of tree and soil carbon stock in a chronosequence rehabilitated tropical forest stands in Malaysia. The study site was at the UPM-Mitsubishi Forest Rehabilitation Project, UPMKB. 20×20 m plot was established each and assessed in 2009 at 1-, 10- and 19-year-old sites while an adjacent ±23-year-old natural regenerating secondary forest plot was established for comparison. The overall total carbon stock was in the order of 19-year-old > ±23-year-old > 10-year-old > 1-year-old. When forest carbon stock is low, the soil component plays an important role in the carbon storage. The forest carbon recovery is crucial to increase soil carbon stock. The variations in the carbon stock showed the different stages of the forest recovery. Species survived after 19-years of planting are potential species for carbon sequestration activities in rehabilitated forest. Human intervention in rehabilitating degraded forest areas through tree planting initiatives is crucial towards recovering the forest ecological role especially in forest carbon stock capacity.

Key Words: biomass, carbon, rehabilitated tropical forest, natural regenerating secondary forest

Introduction

Currently, the clearing and degradation of tropical forest are occurring at unprecedented rate. The United Nation Food and Agriculture Organization (FAO) reported that between 2000 and 2005, the global forest loss was 13 million ha per year. Most of these losses are occurring in the tropical region (FAO 2011). These issues would have significant impact on the global carbon cycle. This is because forest ecosystem store more carbon than other terrestrial ecosystems (Waring and Running 1998) where tropical forest stores about 56% and 32% in biomass and soil carbon,

respectively (Pan et al. 2011). The impacts to the carbon cycle are higher carbon emission rates to the atmosphere through reduce storage capacity of the above- and below-ground components of the forest ecosystem (Silver et al. 2000). This has prompted many scientists to carry out studies related to biomass and carbon storage (Bohre et al. 2014).

Forest rehabilitation is man-facilitated or intervention on the recovery process according to the natural regeneration and succession. Hence, it is a process of restoring or replacing some form of vegetative cover to an area of land so as to improve its natural productivity and its natural environ-

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mental and aesthetic values (Lim 1992). The use of indigenous tree species of which is the potential natural vegetation in forest rehabilitation initiatives has also become an important aspect of forest conservation (Miyawaki 1999; 2011). A joint research project was initiated 25 years ago on a 47.5 hectare research site in the Universiti Putra Malaysia Bintulu Sarawak Campus (UPMKB) with the objectives to conduct experimental planting of indigenous tree species, preferably the canopy species on degraded sites (Azani et al. 1995; Azani 2011; Akita 2011).

Forest rehabilitation has the potential in enhancing carbon storage through biomass and soil carbon accumulation (Ritcher et al. 1999; Silver et al. 2000; Silver et al. 2004). Forest with tree species of high growth rates as in forest plantation and natural succession could be a good option for mitigating CO₂ emissions through carbon sequestration (Montagnini and Porras 1998; Silver et al. 2000). On secondary forest succession, significant amount of carbon can accumulate in plants and soil within 20 years and some studies recorded 100 t/ha after 50 years of regeneration (Brown and Lugo 1992). As for the belowground component, carbon accumulation only occur significantly during the 20-100 years after forest rehabilitation (Silver et al. 2000). However, the capacity of carbon sequestration on the rehabilitated forest through plantation and natural regenerating forest remain unclear (Sang et al. 2013). Generally, it is thought that the aboveground biomass and carbon accumulates faster than the belowground while the slower turn-over rate in the belowground component has the potential as long-term storage capability (Silver et al. 2000).

Such information provides the platform to develop management strategies and in setting national policy. However, carbon stock capacity of the rehabilitated forest remains unclear due to the lack of information especially from the tropical forest region. The uncertainty about how much carbon is stored in tropical forest is an important limitation for regional scale estimation of carbon fluxes and its improvement requires extensive field studies of both above- and belowground stocks (Lu et al. 2010). To understand the carbon stock, this paper attempts an initiative to assess the tree and soil carbon stock in a chronosequence rehabilitated tropical forest stands. This would be of great interest due to the significant impact on the global carbon cycle.

Materials and Methods

Study Site

The study was conducted at the UPM-Mitsubishi Corporation Forest Rehabilitation Project in UPM Bintulu Sarawak Campus, Sarawak, Malaysia. It is located about 600 kilometers northeast of Kuching (latitude 03°12'N and longitude 113°02'E). Assessments were conducted in 2009. 20×20 m research plot was established each at stand of 19-year-old (Plot 1991), 10-year-old (Plot 1999) and 1-year-old (Plot 2008). In a natural regenerating secondary forest (Plot NF), a plot was established adjacent to study site. The forest is regenerating naturally since 1987 (±23-year-old). The relative small plot size and limited number of plot (one in each planting year) was due to the small annual planting area where it is not more than 0.04 ha annually.

The Miyawaki's method applied in this project is based on the concept of vegetation association and accelerating natural regeneration (Miyawaki 1999). In this technique, indigenous species mainly from the Dipterocarpaceae and Non-Dipterocarpaceae (126 species) were planted at a high density (3 seedlings/m²). Plots 1991 and 1999 were previously an ex-shifting cultivation area. Before the commencement of the project, the area was dominated by *Ischaemum magnum*, *Miscanthus floridulus* and *Trema orientalis*. Plot 2008 was a regenerating forest which was dominated by grassland species and *Macaranga* spp. and *T. orientalis* (Yusuf and Abas 1992). The Plot NF was a logging area and the timber harvesting ceased with the opening of the university campus in 1987.

Forest enumeration was also conducted in 2009. Data analysed showed that most of the trees were small and falls within < 10 cm diameter size class (> 75%). This is a typical inverse-J pattern with high tree density (3 seedlings/m²) at the smaller diameter class. The structural characteristics performance of trees in the 19-year-old rehabilitated forest stand were better compared to the adjacent natural regenerating secondary forest (Kueh et al. 2011). The mean dbh of 10- and 19-year-old rehabilitated forests were 35% and 56%, higher, respectively compared to the natural regenerating secondary forest, despite natural regenerating secondary forest having the biggest diameter tree (59.8 cm). The mean height of 10- and 19-year-old rehabilitated

forests were 46% and 60%, higher compared to the natural regenerating secondary forest, despite natural regenerating secondary forest having the tallest tree (26.8 m) in the study area. In addition, the mean basal area of 19-year-old rehabilitated forest was 61% higher than natural regenerating secondary forest. In terms of forest stand development, these forest stands are at early stage of development with smaller size (0.8-8.2 cm), lower height (0.5-9.3 m) and lower species diversity (18-19 species) compared to a mature forest. Information on the key forest structural features is as in Table 1.

Forest Carbon Estimation

The forest carbon was estimated using the information on biomass. The carbon content in the tree samples (n=4) was determined by dry-combustion method in a LECO CHNS TruSpec 600 Analyser. The average tree carbon value was 45% and this is consistent with other reported

studies that reported 45-50% of biomass is carbon (Chan 1982; Brown 1997; Basuki et al. 2009). The biomass was estimated using a modified allometric biomass equation 1 by Kueh (2014):

$$\text{Aboveground biomass (kg)} = 0.074 * (\text{dbh})^{2.48} \dots\dots\dots (1)$$

Where, dbh=diameter breast height (1.3 m). The equation was derived from the average values between Kueh et al. (2012) [$Y=0.041*(\text{Dbh}*H)^{1.335}$] and Kenzo et al. (2009) [$Y=0.0829*(\text{Dbh})^{2.43}$] models. The former model was developed in the similar study site, and subsequent model in Niah Forest Reserve and Sungai Liku, Miri, Sarawak, Malaysia. From the analysis, Kenzo's model was chosen because of the low mean relative error (MRE) and the overall wood density in the study plots are close to this model. The forest carbon stock was estimated by multiplying the biomass estimates and carbon content.

Table 1. Selected forest structural features of the study sites

	1-year-old	10-year-old	19-year-old	±23-year-old
Mean Dbh (cm)*	0.76	6.00	8.16	3.24
Mean Height (m)*	0.46	6.15	9.30	4.02
Total Basal Area (m ² /0.04ha)*	0.02	0.80	1.56	1.64
No of Trees**	321	227	205	546
No of Species**	19	19	18	120
No of Family**	10	9	5	38
5 Most Common Families**	Dipterocarpaceae Meliaceae Clusiaceae Myrtaceae Sapotaceae	Dipterocarpaceae Anacardiaceae Fabaceae Lauraceae Mrytaceae	Dipterocarpaceae Sterculiaceae Bombacaceae Clusiaceae Myrtaceae	Dipterocarpaceae Anacardiaceae Euphorbiaceae Sapotaceae Ixonanthaceae
Species based on Dominance (%)	<i>Sandoricum borneense</i> <i>Cotylelobium burckii</i> <i>Hopea aequalis</i> <i>Azadirachta excelsa</i> <i>Dryobalanops beccarii</i>	<i>Dryobalanops beccarii</i> <i>Shorea brunnescens</i> <i>Pentaspadon motley</i> <i>Shorea ovata</i> <i>Hopea kerangasensis</i>	<i>Shorea dasyphylla</i> <i>Shorea ovata</i> <i>Scaphium macropodum</i> <i>Shorea macrophylla</i> <i>Shorea mecistopteryx</i>	<i>Parishia maingayi</i> <i>Allantospermum borneense</i> <i>Madhuca kunstleri</i> <i>Xanthophyllum ellipticum</i> <i>Hopea kerangasensis</i> <i>Szwintonia schroenkii</i>
Species based on Important Value Index	<i>Sandoricum borneense</i> <i>Cotylelobium burckii</i> <i>Hopea aequalis</i> <i>Dryobalanops beccarii</i> <i>Azadirachta excelsa</i>	<i>Dryobalanops beccarii</i> <i>Shorea brunnescens</i> <i>Shorea ovata</i> <i>Pentaspadon motley</i> <i>Hopea kerangasensis</i>	<i>Shorea dasyphylla</i> <i>Shorea ovata</i> <i>Shorea mecistopteryx</i> <i>Durio zibethinus</i> <i>Cotylelobium melanoxydon</i>	<i>Teijsmanniodendron holophyllum</i> <i>Parishia maingayi</i> <i>Allantospermum borneense</i> <i>Madhuca kunstleri</i> <i>Xanthophyllum ellipticum</i>

*Indicate that data was adapted from Kueh et al. (2011), **Indicate that data was adapted from Kueh et al. (2012).

Soil Carbon Estimation

Ten sampling points were randomly selected which covers each corner and centre in each of the research plot (20×20 m). Samples were taken at depths of 0-25 and 25-50 cm. These depth was chosen as study done in similar area (for 1-7-year-old rehabilitated forest) found that there are not significant differences in soil total carbon between 0-20 cm and 20-40 cm except 40-60 cm (Ch'ng et al. 2011). The 50 cm depth was considered in the study as reports by Paramanathan (2000) showed that the carbon content in the Nyalau Series stabilize at 0.1-0.3% after 35 cm depth while Bekenu Series stabilize at 0.1-0.2% after 36 cm depth. Each sample was a bulk of three subsamples. The soil samples were air-dried, crushed manually and sieved to pass a 2 mm size sieve. The soil carbon content (%) was determined by dry-combustion method in a LECO CHNS TruSpec 600 Analyser. By using the information of the soil carbon content (C), bulk density (ρ_b) and soil depth (D), it was possible to estimate the amount of soil carbon. The total soil carbon stock for the 50-cm depth was calculated by adding the value obtained from 0-25 cm and 25-50 cm depth.

$$\text{Soil C} = \text{C}\% \times \rho_b \times D \dots\dots\dots (2)$$

Data Analysis

In the regression analysis, age was independent variable while carbon was dependent variable using the model LN (y)=LN (a) + b[Ln (x)]. All the data were analyzed using SPSS 16.0 for Windows. The back-transformed forest and soil carbon estimates were multiplied by the Correction Factor (CF)= $e^{0.5 \times \text{MSE}}$ where MSE is the mean squared error of the regression model (Sprugel 1983).

Results and Discussion

The rehabilitated forests have tree carbon ranging from 0.1-54.0 tC/ha. In contrast to the natural regenerating secondary forest, tree carbon was 61.0 tC/ha. Regression analysis showed that the tree carbon increase significantly with age ($p \leq 0.01$) (Table 2). These values are comparable to those reported for natural regenerating secondary forest in this region which ranges from 4.0-59.4 tC/ha (Hashimoto et al. 2000; Kenzo et al. 2010) but lower compared to those reported for lowland and hill dipterocarps in Asia (Laumonier et al. 2010; Lu et al. 2010; Ngo et al. 2013).

The total soil carbon (at 50-cm depth) was 27.0-42.0 tC/ha in rehabilitated forests and 32.0 tC/ha in natural regenerating secondary forest. Regression analysis show insignificant relationships between ages of stand and soil carbon (Table 2). These results are comparable to 8-year-old plantation in Vietnam and less than 7 year-old rehabilitated forest in Sarawak which ranged from 18.7-56.6 tC/ha (Ch'ng et al. 2011; Sang et al. 2013) but fall slightly lower than the value range (55.9-102.0 tC/ha) of the carbon stock as reported for secondary forest such as in young secondary forest in tropical regions (FAO 2010; Lu et al. 2010; Fonseca et al. 2011; Toriyama et al. 2011; Ngo et al. 2013).

Carbon is stored in the vegetation and soil, where the loss of biomass as litter acts as one of the soil carbon input. Information on the litter was obtained from study conducted by Ku (2012). Standing litter crop biomass ranged from 4.5-18.3 t/ha or standing litter crop carbon of 2.1-8.3 tC/ha in the rehabilitated forest while 7.5 t/ha (3.4 tC/ha) in the natural regenerating secondary forest (Ku 2012). The low decomposition rate ($k=0.21-0.22$) and low concentration of nitrogen were the contributing factors towards high standing litter crop. This could explain the weak relationship be-

Table 2. Relationship between age of stand with the forest carbon, standing crop litter carbon and soil carbon [Ln Y=Ln a + bLn (x)]

Ln (Y)	Ln (X)	n	a (\pm S.E.)	b (\pm S.E.)	Adjusted r^2	MSE	CF
Total Carbon	Age	4	3.35** \pm 0.07	0.39** \pm 0.03	0.978	0.01	1.00
Tree Carbon	Age	4	-2.02* \pm 0.31	2.04** \pm 0.13	0.989	0.10	1.05
Standing Crop Litter Carbon	Age	4	0.69 ^{ns} \pm 0.53	0.28 ^{ns} \pm 0.22	0.172	0.30	1.16
Soil Carbon	Age	4	3.34** \pm 0.18	0.08 ^{ns} \pm 0.07	0.071	0.03	1.02

r^2 means coefficient of determination; * and ** indicate significant differences at levels of $p \leq 0.05$ and $p \leq 0.01$, respectively; n.s., no significant differences; S.E., standard error; MSE, mean square error; CF, correction factor.

tween age and the standing crop litter (Table 2). The results were consistent with values reported in previous studies located in tropical lowland forests that recorded a range of 1.6–3.9 tC/ha (Ogawa 1978; Gong and Ong 1983).

Overall, the total tree and soil carbon stock was in the order of 19-year-old > 10-year-old > 1-year-old where tree carbon stock increased significantly with age of the forest (Table 2). Similar trends have been reported for tropical forest rehabilitation where the first 20 years showed a high rate of aboveground biomass accumulation and storage (Silver et al. 2000). Based on Fig. 1, the aboveground carbon stock component (tree carbon and standing crop litter carbon) significantly affects soil carbon storage in 19-year-old rehabilitated and natural regenerating secondary forests. The aboveground carbon stock component contributed about 64–67% of total carbon stock in the 19-year-old rehabilitated and natural regenerating secondary forests. The younger rehabilitated forest (10- and 1-year-old) recorded low aboveground carbon stock 36% and 8% of the total carbon stock, respectively.

The rehabilitated forests had stands with smaller mean dbh (0.8–8.2 cm), lower total basal area (0.5–39.0 m²/ha) and shorter mean height (0.5–9.3 m). This explains the lower forest carbon recorded in this study. Physical structural characteristics of forest can affect total aboveground biomass and carbon stored. These were consistent with other

studies who reported that 55-year-old secondary forest with mean basal area of 6.4 m²/0.25 ha and mean height of 19.0 m stored 264.0 t/ha of biomass while in a primary forest with basal area of 7.8 m²/0.25 ha and mean height of 22.1 m stored 358.4 t/ha of biomass (Brearley et al. 2004). In addition, the low forest carbon stock at 1-year-old rehabilitated forest also indicates an early stage of succession in the plot. Early succession areas dominated by *Imperata cylindrical* and *Pteridium* spp. had low biomass of 6.2 t/ha in comparison to 21.0 t/ha of upland with high number of larger sized trees (Lim and Basri 1985).

The accelerated forest structural development in 19-year-old rehabilitated forest had comparable forest carbon stock with the natural regenerating secondary forest (Fig. 1). Such similar trend was also reported where higher number of large trees over 30 cm dbh will contribute to the higher aboveground biomass and carbon for primary forest when compared to the secondary forest in Singapore (Ngo et al. 2013). Furthermore, this could be due to the effect of higher site fertility index at similar site as reported by Akbar et al. (2010) compared to other study plots.

With these findings, the rehabilitated forests are at different stages of forest carbon recovery. This also reflects the different stages of forest growth. The 1-year-old rehabilitated forest is still at the gap phase or early stage of succession. The 10-year-old rehabilitated forest is at the

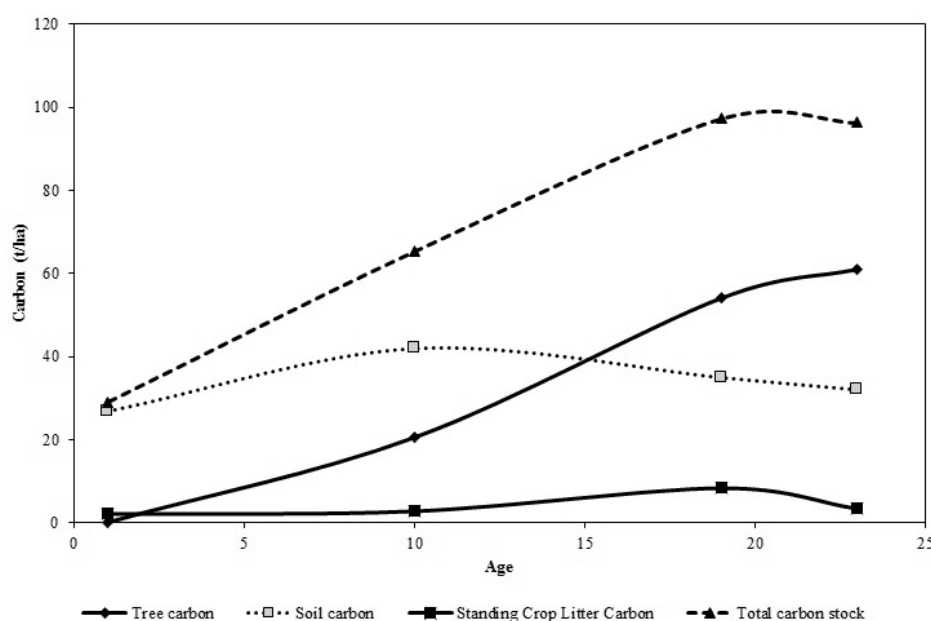


Fig. 1. Carbon stock at the study plots.

building phase or between early and mid stage of succession. The 19-year-old rehabilitated and natural regenerating secondary forests are between building and young mature phase or between mid to young late stage of succession. After 19 years, the rehabilitated forest is yet to recover from the aspect of the total aboveground carbon.

The soil carbon (which is first top 50 cm) was about 33-36% of the total carbon stock in the 19-year-old rehabilitated and natural regenerating secondary forests. As for younger rehabilitated forests of 10- and 1-year-old, soil carbon contributed 64% and 92% of total carbon stock, respectively. The presence of forest as in the older rehabilitated forest restored the soil organic matter as this forest provides organic matter inputs in the form of above- and belowground litter. Studies conducted in primary forest, Singapore found that the soil carbon contributed 33% in contrast to 52% in secondary forest (Ngo et al. 2013). As for the soil carbon stock, there was a weak relationship with age (Table 2). Similar trend has been reported by Sang et al. (2013) where 17-year-old *Acacia mangium* plantation showed higher aboveground biomass but similar soil carbon stock in comparison to secondary forest in Vietnam. This is because belowground carbon accumulates more slowly than aboveground carbon. Studies found that carbon accumulation would increase significantly during the 20-100 years of forest rehabilitation (Silver et al. 2000). This could be due to the slower rate of root biomass accumulation.

Lower tree carbon stock was recorded in the young rehabilitated forest particularly the 1- and 10-year-old rehabilitated forests but had soil carbon stock of 27.0 tC/ha and 42.0 tC/ha, respectively. This could be due to the previous vegetation which contributed to the soil organic matter and soil carbon prior to the tree planting. This suggests the importance of soil component as carbon storage. The aboveground wood component has a high long term storage capacity. However, they also found that carbon movement is very slow for the belowground component but it has high storage capacity (Chambers et al. 2001).

As the forest grows older, the forest biomass and carbon also recovers. In the 10- and 19-year-old rehabilitated forests, the amount of carbon increased from 32 to 56% of the overall total carbon stock. When forest carbon stock is low as in the young rehabilitated forest, the soil component plays an important role in the carbon storage. Over 90% of

the total carbon stock was stored in the younger rehabilitated forest. The comparable soil carbon stock could be associated with the increase in fine root biomass which was due to the vegetation clearing prior planting. This is where the fine root turnover contributes to the increase in soil carbon stocks in a secondary forest in Singapore (Ngo et al. 2013). The aboveground biomass and carbon recovery is crucial for the increase in soil carbon storage. Therefore, their synergic and symbiotic role between aboveground forest development and belowground carbon stock should be considered in any forest rehabilitation management activities.

The major contributors of the tree biomass and carbon in the 19-year-old rehabilitated forest were *Shorea macrophylla* and *S. dasyphylla* (Table 3). They contributed about 60% of total biomass and carbon. The contribution of these species are supported by the fact that they ranked top five dominant species. As for the 10-year-old rehabilitated forest, both emergent species namely *S. brunnescens* and *Dryobalanops beccarii* contributed about 54% of the total biomass and carbon. Both species were found to be the most common species in the study plot. In the one-year-old rehabilitated forest, *Sandoricum borneense* and *Cotylelobium burckii* contributed almost 40% of the total biomass and carbon. Both species are commonly found in the study plot where both contributed 21.2% and 15.3%, respectively, of the total species. In the natural regenerating secondary forest, *Nephelium maingayi* and *Teijsmanniodendron holophyllum* contributed almost 38% of the total biomass and carbon. *T. holophyllum* had the highest Importance Value (IV) index (115.3) suggesting the importance of the species in the study plot. However, as for *N. maingayi* only had IV index value of 42.3. The highest biomass recorded by this species as it has the biggest dbh (59.80 cm) size recorded in the plot. The species recorded in the 19-year old rehabilitated forest are the fittest tree species which survived 19 years of competition within the forest stand. These are potential species which can play important role in carbon sequestration in rehabilitated forest.

The intervention by rehabilitating degraded forest areas through tree planting activities had enhanced their capability to store soil carbon rather than relying on natural recovery. This finding suggested the importance of forest rehabilitation activities which is a part of an effective carbon

Table 3. Top five species' biomass and carbon contribution

Species	Biomass (t)	Carbon (tC)	Percentage of Biomass (%)	Percentage of Carbon (%)
19-year-old				
<i>Shorea macrophylla</i>	1.29	0.59	32.0	31.7
<i>Shorea dasyphylla</i>	1.13	0.51	28.1	27.8
<i>Shorea leprosula</i>	0.89	0.40	22.0	21.7
<i>Durio zibethinus</i>	0.55	0.25	13.7	13.6
<i>Scaphium macropodum</i>	0.34	0.15	8.4	8.3
10-year-old				
<i>Shorea brunnescens</i>	0.56	0.25	30.7	30.7
<i>Dryobalanops beccarii</i>	0.43	0.19	23.5	23.5
<i>Shorea ovata</i>	0.18	0.08	10.1	10.1
<i>Pentaspadon motley</i>	0.14	0.06	7.7	7.7
<i>Parishia maingayi</i>	0.13	0.05	7.1	7.1
1-year-old				
<i>Sandoricum borneense</i>	2.41x10 ⁻³	1.08x10 ⁻³	19.4	19.4
<i>Cotylelobium burckii</i>	1.74x10 ⁻³	0.78x10 ⁻³	20.4	20.4
<i>Dryobalanops beccarii</i>	1.17x10 ⁻³	0.52x10 ⁻³	14.5	14.5
<i>Shorea macrophylla</i>	1.49x10 ⁻³	0.67x10 ⁻³	14.1	14.1
<i>Hopea aequalis</i>	1.27x10 ⁻³	0.57x10 ⁻³	7.3	7.3
±23-year-old				
<i>Nephelium maingayi</i>	1.26	0.57	23.5	23.6
<i>Teijsmanniodendron holophyllum</i>	0.75	0.34	14.0	14.0
<i>Shorea monticola</i>	0.42	0.19	7.9	7.9
<i>Schoutenia glomerata</i>	0.31	0.14	5.8	5.8
<i>Parishia maingayi</i>	0.26	0.12	4.8	4.8

recovery. This active management were suggested to accelerate regeneration and carbon accumulation in secondary forest (Ngo et al. 2013). Hence, rehabilitation forest can play a significant role as carbon sink in mitigating greenhouse gases and climate change. The choice of species is important in rehabilitating degraded forest while the remnant important species in regenerating secondary forest will play their role in carbon sequestration. Long-term monitoring of the soil carbon recovery is still required as the rate of recovery for the belowground carbon stock is slow. These could provide a better understanding on the trend of the carbon recovery and the stock capacity of a rehabilitated forest.

Conclusions

This quantification of carbon stock in Sarawak's rehabilitated forest revealed that the oldest rehabilitated forest stand recovery in terms of carbon stock was comparable to

the natural regenerating secondary forest. In general, the carbon stock in rehabilitated forests is lower than other sites reported for Southeast Asia forests. This information may provide an indication on forest recovery where the amount carbon stock is used as means of comparison to the primary forest. These forests were different in terms of carbon stock among different age stands of rehabilitated forest that reflected the different stages of forest recovery. The above-ground component (forest carbon and standing litter crop carbon) of the rehabilitated forest showed faster carbon recovery than the belowground component (soil carbon). This information also indicates that the soil component is essential to soil carbon stock in a rehabilitated forest especially when forest carbon stock capacity is low.

Long-term monitoring is still required to provide better understanding on the carbon dynamics especially the sequestration capacity, sink capability and sources in the rehabilitated forest. The Miyawaki's method applied has

prompted the 19-year-old rehabilitated forest to store more carbon. Species that survived in high density forest are the fittest species which are potential species in tree planting programme. Forest rehabilitation activities also showed the potential in promoting carbon recovery. In conclusion, human intervention in rehabilitating degraded forest areas through tree planting initiatives is crucial towards recovering the forest ecological roles especially in carbon storage capacity.

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