3-1 Potential Carbon Sequestration by Rehabilitation of Degraded Peat Swamp Forests in Giam Siak Kecil-Bukit Batu Biosphere Reserve, Riau, Indonesia

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Abstract: Rehabilitation commenced in February 2010 in Giam Siak Kecil-Bukit Batu Biosphere Reserve which covers a total area of 698,663 ha. This paper highlighted research progress on rehabilitation of degraded logged over peat swamp forests, and estimation amount of sequestered carbon after ten months vegetation rehabilitation was done. Line and gap planting methods were applied. The following lands of planting were applied normal and hill planting methods. For monitoring biomass and carbon five plots of 10x10m were selected. Tree species with DBH≥3cm were identified and recorded. We used diameter increment of species planted to estimate increment of biomass, carbon storage and carbon sequestration. The allometric equation was used: Y=-2.13+2.53*ln DBH; where Y is total above-ground biomass in Kg/Mg ha^{-1} and DBH is in cm. The carbon content was calculated by multiplying the 0.5 conversion factor to the above ground biomass. The results indicate that some species of *Cratoxylon arborescens*, *Palaquium sumatranum*, *Palaquium burckii*, and *Tetramerista glabra* were promising species for rehabilitating degraded peat swamp forest areas shown by high survival rates in the range of 73.3 to 100%. The greatest growth performance are *Cratoxylon arborescens*, then followed by *Tetramerista glabra*. Biomass increased from 2.94 Kg ha^{-1} to 28.9 Kg ha^{-1}, and carbon storage increased from 1.55 Kg C ha^{-1} to 14.5 Kg C ha^{-1} with total carbon storage 12.5 Kg C ha^{-1} in experimental sites. The forest recovery through natural regeneration processes contributed in sequestrating carbon of 0.34 Mg C ha^{-1} during ten months monitoring. In the say direction, there was an increasing in biomass from 3.88 Mg ha^{-1} to 4.57 Mg ha^{-1} and carbon storage of 1.99 Mg C ha^{-1} to 2.28 Mg C ha^{-1}. The total amount of carbon sequestration was 0.35 Mg C ha^{-1} in both experimental sites and forested areas. Rehabilitation through planting trees and natural regeneration processes are important in order to restore carbon storage of remaining peat swamp forests in biosphere reserve.

Keywords: Biosphere reserve, carbon sequestration, peat swamp forest degradation, rehabilitation.

Introduction

Peat swamp forest covers an estimated 22.5 Mha in Indonesia (RePPProT 1990, Radjagukguk 1992, Sorensen 1993, Rieley *et al.* 1996a, Rieley *et al.* 1996b, Page *et al.* 2011) and mainly distributed across Sumatra, Kalimantan and Irian Jaya (Silvius 1989, Rieley *et al.* 1996a). In Sumatra, 4.04 Mha of peatland in Riau Province categorized as the Sumatran peat swamp forest eco-region recommended to be protected areas (WWF 2008, MAB Indonesia, Jarvie et *al.* 2003).

Peat swamp forests are both fragile and unique ecosystems that are both peat-forming wetlands and tropical rainforests. Water, peat and vegetation are strongly interconnected such that removing any one of these components or disturbing the balance between them may fundamentally change the nature of peatland ecosystem (Wetlands International 2007, GEC 2012).

In its natural state, peat swamp forests can serve as carbon storage, water retention, water supply, climate stabilization, maintenance biodiversity and flooding control (Rieley, 2001; Rieley & Page 2005). Tropical peat swamp forest stores large amounts of carbon in plant biomass, with typical values ranging 100-250 Mg C ha^{-1} (Page *et al.* 2011). Meanwhile, peatland of 2772 Mg C ha^{-1} is based on an average peat thickness of 5.50 m (Page *et al.* 2011). Gunawan *et al.* (2011) revealed that above-ground and below-ground carbon in forested areas was estimated to be in the range of 26.75 to 94.25 Mg C ha^{-1} and 4410 to 5775 Mg C ha^{-1} respectively. The above-ground and below-ground carbon in developed peatland areas was estimated to be in the range of 42.57 to 68 Mg C ha^{-1} and 2772 to 6552 Mg C ha^{-1}.

In 2006, there were 121,000 km^2 of deforested peatland in Southeast Asia, around 45% of the total peatland area (Hooijer *et al.* 2006). Large areas of deforested peatlands have been converted to oil palm and timber plantations but there are also extensive degraded peatlands mainly located in the Indonesian provinces of Central, East and South Kalimantan and the provinces of Riau and Jambi in Sumatra where, as a result of deforestation, drainage and repeated fire, vital peatland ecosystem services have been impaired (Hooijer *et al.* 2006, Page *et al.* 2008).

Degraded forestland requires rehabilitation of wide range of characteristics and functions. It is necessary to improve biological and habitat diversity at the landscape scale, increase commercial values for timber and pulp production, increase types and amount of non timber products, improve forest functions, such as water storage, water balance, sequestration of carbon, fire protection, and climate mitigation (Kobayashi 2011, Kobayashi 2010, Kobayashi 2004).

There are enormous challenges for the restoration of tropical peatland landscapes. Some progress has been made towards understanding the restoration of tropical forests on mineral (i.e. non-peatland) soils, but at present very little is known about the restoration of large areas of degraded tropical peatland. Restoration activities are still at an early stage and, to date, have been limited to a few forest rehabilitation trials with limited attention paid to the restoration of key peatland ecosystem functions, for example, hydrology and carbon sequestration (Giesen 2004, Page *et al.* 2008).

In case of biosphere reserve, we concluded that rehabilitation should be important to be done the following are; large degraded peatland and forest areas due to high fire intensity, drainage and illegal logging activities, forest encroachment and conversion, problem on natural regeneration processes, need to promote ecosystem services of carbon storage and sustainable rural livelihoods. This paper highlighted progress on rehabilitation of degraded logged over peat swamp forests, and estimation amount of sequestered carbon after ten months vegetation rehabilitation was done either in experimental sites or forested areas.

Site and Method

The area of study is located at Riau Province in the coastal east of Sumatra Island. Riau covers an area of about 8-9 Mha. Having the largest peatland area in Sumatera, Riau province plays very significant role to the local environment as well as global environment. The strategic position of Riau province to other ASEAN countries is also become the most environmental regional concerned, especially for the transboundary haze pollution problem and illegal logging.

The remaining peat swamp forest is distributed on five large forest blocks in Riau. One of them is Giam Siak Kecil Bukit Batu which was declared as a Biosphere Reserve, having total area of 698,663 ha in 2009. This Biosphere Reserve represents tropical peat swamp forest used to conserve the peat swamp forest ecosystem, lakes and other water system (Jarvie *et al.* 2003, MAB Indonesia 2008).

Poor management and land conversion resulted in a loss of almost 300,000 ha of natural peat swamp forest between 1998 and 2002. Forest and land fires occurred annually, especially in the dry season, and the remaining peat swamp forest was subject to illegal logging activities and natural disturbances. In core and buffer areas, villagers converted the remaining natural peat swamp forest into jungle rubber gardens and oil palm plantations. Recently, the degradation of peat swamp forests of the biosphere reserve continues. Timber estates and oil palm plantation could be seen in the landcape seriously threatening the remaining peat swamp forest ecosystem (Jarvie et *al.* 2003, WWF 2008, MAB Indonesia 2008).

To implement rehabilitation we selected two types of degraded peat swamp forest: first; degraded of logged-over peat swamp forest located at a river basin of Bukit Batu River, in a core area of Riau Biosphere Reserve, and second, severely degraded areas in Tanjung Leban Village in transition zone of Riau Biosphere Reserve. The exact geographical location of logged over forest is 01°23'24.4"N, 101°51'59.1"E and degraded areas is 01°38'9.81"N, 101°46'13.8"E. For this chapter will be focus on the progress of rehabilitation study carried out in logged over forest in Bukit Batu forest block of Riau Biosphere Reserve (Figure 1).

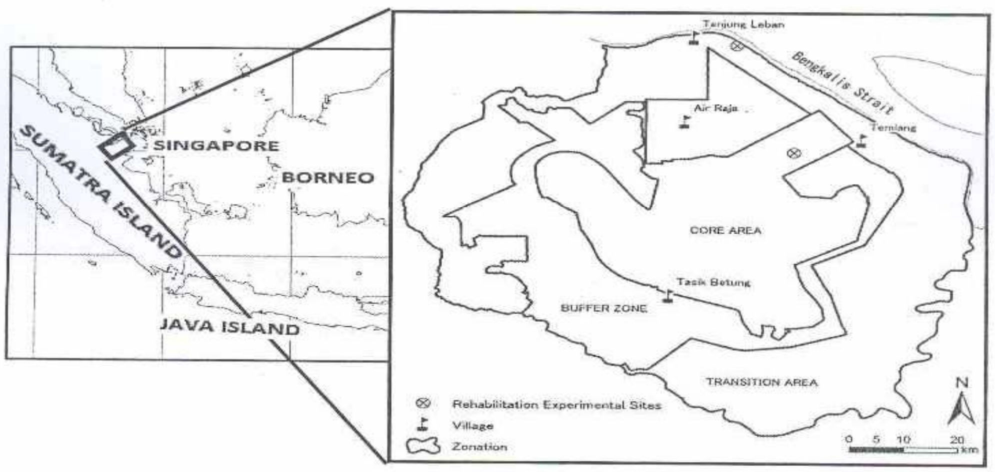

Fig 1. Study area and rehabilitation experimental sites.

. Enrichment planting methods were developed on areas where seeds or seedlings of target tree species was lacking. Line and gap planting method is commonly used in logged over forest.

Treatments for line planting:

a. Lines will be set on the west-east direction with width determined in relation to the height of substorey (e.g. 5, and 10 m); (Figure 2).
b. Distance between lines will be 5-10 m; and

c. Tree species in the area has been selected for transplanting.
d. To get the seedling we use some of techniques as following: cuttings methods, wildings, and seed germination.
e. Totally experimental area is seven line planting covered 3500 m2.
f. Totally two typical canopy tree species of peat swamp forest planted (e.g. Callophylum lowii and Palaquium sumatranum).

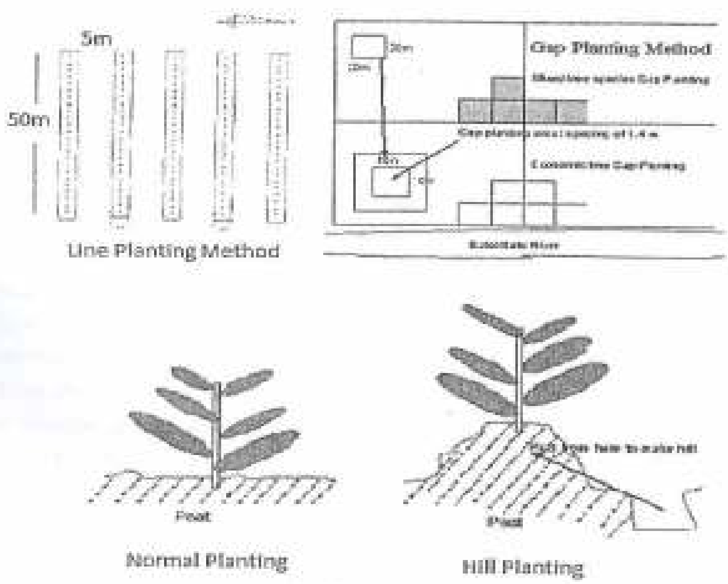

Fig 2. Rehabilitation methods.

Treatments to be taken for gap planting:

1. Gap size will be 10 m x 10 m.
2. Totally 25 economical gap planting of *Dyera lowii* has been tried.
3. Totally six mixed gap planting of mixing tree species has been tried (e.g. *Dyera lowii, Palaquium sumatranum, Palaquium burckii, Callophyllum lowii, Cratoxylon arboresecens,* and *Tetramerisitra glabra*)
4. Tree species suitable for the site condition will be selected. Wildings has been be applied (Figure 2).

The following lands of planting methods were applied at these location are normal and hill planting methods (Figure 2). Normal planting method; a hole in the peat is dug and seedlings are planted in this hole. Hill planting method; the peat is accumulated as a Hill and the seedlings are planted on this hill.

All of planted seedlings are monitored to determine the survival rate, height and their growth.

The Survival rate are determined by formula:

$$\frac{\text{Number of alive species}}{\text{Total number of species}} \times 100$$

For statictical analysis carried out by windows 7 of microsof excell 2007 and SPSS 15 programs.

Increment of biomass and carbon storage

For biomass and carbon plot monitoring, five plots of 10x10m in Bukit Batu forest block were selected. Tree species with DBH≥3cm were identified for biomass and carbon storage estimation. We also used the increment of diameter of tree species to estimate the change in biomass, carbon storage and carbon sequestration.

Total aboveground biomass in each plot was also estimated using an allometric equation developed by Brown (1997). The Allometric equation was developed for tropical forests using data collected by several authors from different tropical countries and at different times. The allometric equation is:

$$Y=\exp(-2.134+2.53*\ln(D)) \quad \text{..(Eq1)}$$

Where Y is total above-ground biomass in kg/tree and D=diameter at breast height (DBH in cm).

The above ground carbon storage was calculated by assuming that the carbon storage is 0.5 of the total above ground biomass (Brown & Lugo. 1982; Brown *et al.* 1989; Houghton *et al.* 1997).

Quantification of carbon sequestration during a period of time. The most common is based on the amount of carbon fixed in biomass at a certain point in time, usually the end of a rotation period. This will be called "carbon fixed" and it can be exemplified as the amount of carbon stored in planted trees at a certain time t after planting (Figure 3).

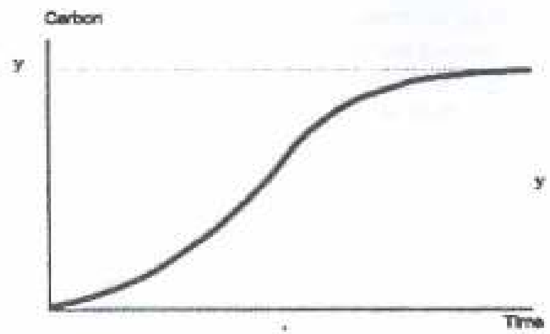

Fig 3. Carbon stored (y) by planted trees at time t after planting.

On a yearly basis, the procedure for quantifying sequestration is to measure the trees every year, calculate their growth increment and calculate the amount of carbon fixed during that period (C1, C2 and C3, respectively) (Figure 4) (Costa 1996). Many estimates for carbon sequestration found in the existing scientific literature use this concept (Putz and Pinard 1993, Freedman *et al.* 1992, van Kooten *et al.* 1992).

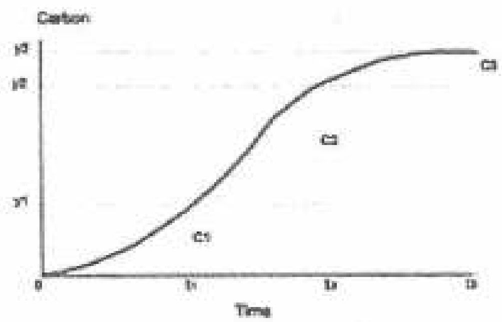

Fig.4. Quantification of yearly amounts of carbon fixed (C1,C2,C3) by planted trees.

Results and Discussions

The vegetation rehabilitation was applied in logged over forest areas. The survival rates of the seedlings for both hill planting and normal planting method are presented in figure 5 and figure 6. In general, survival rate of seedlings decrease after ten month planted. The survival rate within five month range 57.14% to 100%, and ten month after planted range 51.4 to 100%. The highest survival rate of tree species was *Palaquium burckii* and *Cratoxylon arborescens* with about 100% survival in hill planting, then followed by *Tetramerista glabra* range 84.6% to 96.2%. The lowest of survival was *Dyera lowii* of 64.66% to 71.78%.

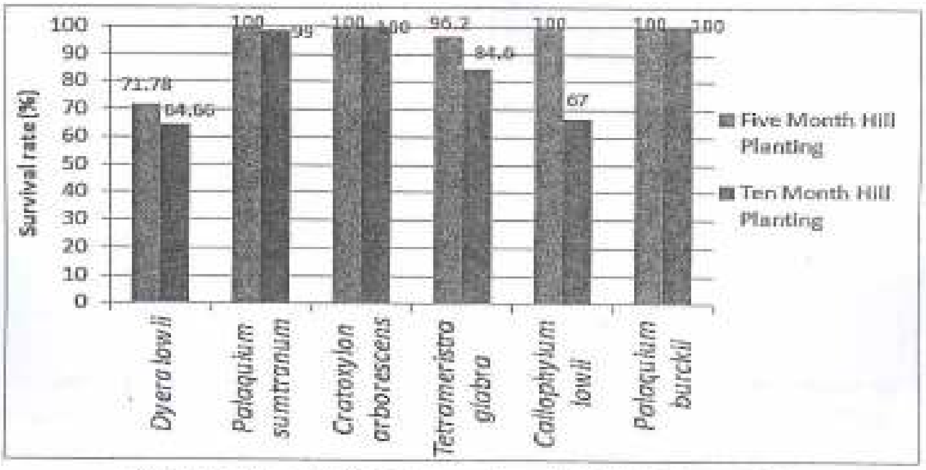

Fig 5. Survival rate (%) of tree species with hill planting method.

In normal planting the highest survival rate are *Cratoxylon arborescens* of 100%, then *Palaquium sumatranum* range 77.2% to 90.91%. The lowest survival rate are *Callophylum lowii* of 52.38% to 57.14%.

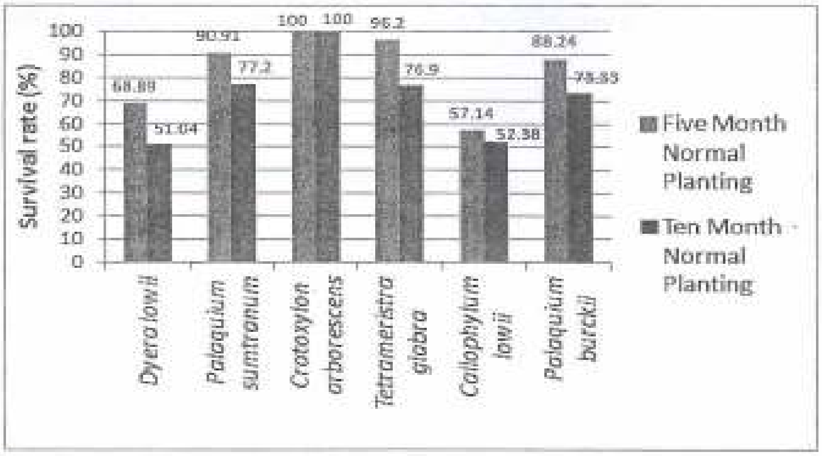

Fig 6. Survival rate (%) of tree species with normal planting method.

Generally hill planting method is better method than normal planting shown by high survival rate of planted trees. A number of factors have been identified as causes of mortality of tress. In the early establishment, some of seedling died due to wetter of peatland. The seedling for the first stage can't be adaptive in wet situation. The other factors the seedlings is still small to transplanted on the field, such as seedlings of *Callophylum lowii*. The insect also causes seedling of *Dyera lowii* was died.

The average height and diameter increment from October 2010 till April 2011 are shown in Table 1. The highest growth performance is *Cratoxylon arborescens* with mean of height increment by normal planting 44.7± 28.8, hill planting 34.4± 14.0, and diameter increment by normal planting 0.8 ± 0.16, hill planting 0.7 ± 0.21 (Figure 7). Followed by *Tetramerista glabra* with mean of height increment by normal planting 13.1± 7.94, hill planting 15.1± 4.68, and diameter increment by normal planting 0.6 ± 0.2, hill planting 0.7 ± 0.2 (Figure 8).

Table 1. Height and diameter increment (cm) of trees species of peat swamp forest, 5 months after planting.

Species	Num of Tress	Height Increment (cm)		Diameter Increment (cm)	
		Normal	Hill	Normal	Hill
Dyera lowii	900	4.4+ 3.2	4.9+ 3.2	0.3+ 0.2	0.3+ 0.2
Tetramerista glabra	52	13.1± 7.9	15.1± 4.7	0.6± 0.2	0.7± 0.2
Palaquium burckii	32	10.8± 13.7	9.6 ± 9.8	0.5± 0.2	0.5 ± 0.2
Palaquium sumatranum	118	11.6+ 13.3	6.9+11.3	0.4+ 0.2	0.3+ 0.1
Cratoxylon arborescens	12	44.7± 28.8	34.4± 19.0	0.8± 0.16	0.7± 0.2
Callophylum lowii	75	3.9± 3.3	10.8± 7.8	0.06± 0.05	0.09± 0.09

The growth performance after ten month rehabilitation was presented in Table 2. There were increasing diameter increment and height increment in both hill and normal planting method shown by positive correlation analysis (r). Hill planting was better method compare to normal planting. However species of *Tetramerista glabra* and *Palaquium buckii* show results reversely. Nevertheless tree species of *Cratoxylon arborescens, Callophylum lowii, Dyera lowii* and *Palaquium sumatranum* show well height increment in normal planting method. This results was similar shown by increasing of diameter increment in hill planting compare to normal planting method.

Table 2. Growth performance of tress species after ten month planted.

Species	Height Increment (cm)			Diameter Increment (cm)		
	Normal Planting	Hill Planting	Correlation (r) and t-paired test (α 0.05)	Normal Planting	Hill Planting	Correlation (r) and T-Paired test (α 0.05)
Tetramerista glabra	69.5–27.9	59.2–18.7	r=0.3; p=0.001	0.9–0.2	1.0–0.2	r=0.2; p=0.1
C. arborescens	122±42.0	144±49.0	r=0.7; p=0.4	1.0±0.1	1.2±0.2	r=0.5; p=0.09
Callophylum lowii	16.6±5.08	35.2±8.7	r=0.1; p=0.2	0.1±0.05	0.2±0.1	r=0.2; p=0.2
Dyera lowii	22.3–19.2	23.5–20.8	r=0.2; p=0.3	0.6–0.4	0.7–0.5	r=0.2; p=0.03
P. sumatranum	14.8–11.3	19.2–15.8	r=0.2; p=0.4	0.3–0.1	0.3–0.9	r=0.4; p=0.06
Palaquium burckii	18.2±14.4	14.6±14.4	r=0.1; p=0.7	0.5±0.1	0.6±0.2	r=0.2; p=0.03

The highest diameter increment are *Cratoxylon arborescens* of 1.2 cm ±0.2 in hill planting method, and 1.0 cm ±0.1 in normal planting method (Figure 7), followed by tree species of *Tetramerista glabra* of 1.0 cm$\pm$0.2 in hill planting, and 0.9 cm$\pm$0.2 in normal planting method (Figure 8). The lowest diameter increment both hill and normal planting method was *Palaquium sumatranum*. Meanwhile the highest height increment of tree species *Cratoxylon arborescens* and *Tetramerista glabra* in both of experiment method was hill and planting method. *Palaquium sumatranum* and *Palaquium burckii* was the lowest of height increment in hill and normal planting method respectively. From T-paired test show that growth performance of *Tetramerista glabra*, *Dyera lowii*, and *Palaquium sumatranum* were significant different ($p<0.05$). Meanwhile *Palaquium burckii*, *Callophyllum lowii* and *Cratoxylon arborescen* show not significant different ($p>0.05$).

Total amount of above biomass and carbon content were increasing during the ten months rehabilitation (Figure 9). Biomass increased from 2.94 Kg ha^{-1} to 28.9 Kg ha^{-1}, and carbon storage increased from 1.55 kg C ha^{-1} to 14.5 kg C ha^{-1} in experimental sites. Carbon sequestered by vegetation rehabilitation increased from 3.77 Kg C ha^{-1} to 12.05 Kg C ha^{-1}.

Fig.7. Growth Performance of *Cratoxylon arborescens*

Fig.8. Growth Performance of *Tetramerista glabra*

These increases in biomass, carbon storage and carbon sequestration in forested areas by natural regeneration processes are shown in figure 10. The forest recovery through natural regeneration processes contributed in sequestrating carbon of 0.34 Mg C ha^{-1} within ten months of monitoring. In the say direction, there was an increasing in biomass from 3.88 Mg ha^{-1} to 4.57 Mg ha^{-1} and carbon storage of 1.94 Mg C ha^{-1} to 2.28 Mg ha^{-1}.

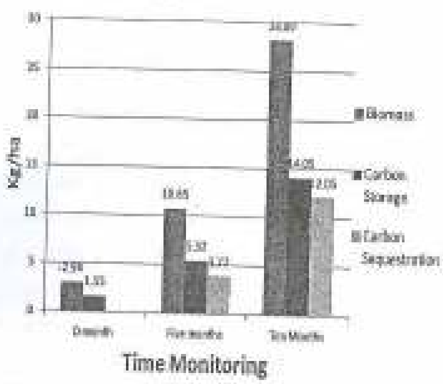

Fig 9. Rehabilitation experimental sites

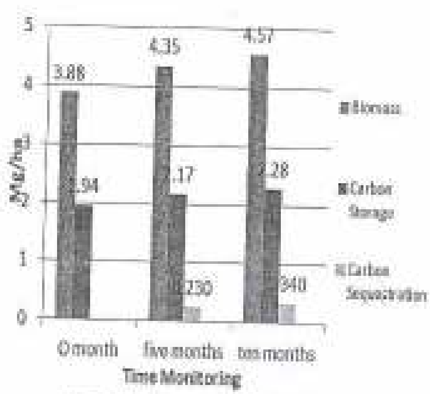

Fig 10. Forested areas

In this research, the effect of vegetation rehabilitation on the total accumulation of carbon storage was counted. Our results showed that total amount of carbon sequestration was 0.35 C Mg ha^{-1} in both experimental sites and forested areas which indicates that the combination of forest recovery by vegetation rehabilitation and natural regeneration processes have great potential to enhance carbon storage among forest rehabilitation efforts. These results, however, still need to be monitored and confirmed after several years of forest rehabilitation was done.

Survival rate of peat swamp forest species during five and ten month monitoring varies between species. We classified two categories of survival rate are high with range 84.6% to 100% and moderate with range 51.04% to 71.78%. High survival rate are *Cratoxylon arborescens*, *Palaquium burckii*, *Tetramerista glabra*, and *Palaquium sumatranum* in both hill and normal planting method. Moderate survival rate are *Dyera lowii* and *Callophylum lowii*. Generally our result show lightly higher compare than survival rate to other rehabilitation working.

In Jambi peat swamp forest, rehabilitation was carried out use species of *Dyera lowii*, *Combretocorpus rotundus*, *Palaquium sp*, *Shorea pauciflora*, *Tetramerista glabra*, *Melanorhea wallichii*, and *Alstonia penaumotophora*. The average survival rate range 40% to 70% (Arinal and Suryadiputra, 2004). Moreover Muus (1996) revealed enrichment line planting of secondary shrub carried out using *Dyera lowii*, *Gonystylus bancanus* and *Endospermum diadenum* with survival rates have been high on the whole more than 90%. In Kalimantan rehabilitation trials indicate that *Shorea balangeran* and *Palaquium* are best suited for replanting, as they have considerably higher survival rates (65-100%) compared to the other species (6-65%) (Takahashi *et al.* 2001). Survival rate ranged from 65-85% one year after planting in Kalimantan. *Dyera lowii*, *Shorea belangeran* and *Alstonia pneumatophora* appeared to have the best performance in terms of survival and growth (Wibisono *et al.* 2011).

Several restoration trials have been undertaken of peat swamp forest species of *Gonystylus bancanus* in Peninsular Malaysia (Ismail *et al.* 2007). Trials in secondary peat swamp forests in Selangor showed that line planting with a maintenance of planting lines once every three months gave better results in terms survival was 81% nine months after planting and similar restoration trials in Pahang had 72% survival three months after planting. Restoration trial in recently logged forest in Pekan showed a large degree of variation in survival percentage ranging from 61 to 82%. Causes of mortality included tree fall and drought (Lian Chua, 2008). Survival rate and growth of planted seedlings in a degraded forest usually differ among species even in the same taxonomic group (Suzuki & Jacalne 1986, Kenzo *et al.* 2007).

Rehabilitated area are noted to be important sites of carbon stocks and therefore, increase environmental values. Gunawan *et al* (2011) revealed that amount

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