# Carbon sequestration of man-made forest : Sequestration estimate and its bearings on CDM

# Carbon Sequestration of Man-made Forests: Sequestration Estimate and Its Bearings on CDM

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## Abstract

Sequestered carbon by trees in plantations for industrial material supply plantations (industrial plantations) in the tropics is, in this study, estimated at about 10 tC/ha/yr in good sites. The carbon accumulated by tree planting to rehabilitate degraded lands (rehabilitation forests) is not always less than that of industrial plantations. Selecting the suitable species could be one of the most essential factors to succeed in establishing and preserving forests. Rehabilitation forests in Lombok Island and Benakat in South Sumatra sites would be regarded as the successful cases for that matter.

While the annual carbon accumulation by naturally regenerated vegetation at base lines in Lombok site amounts to 2.9-3.2 tC/ha/yr, the net carbon accumulation (subtracting the amounts at base line from the carbon sequestration of planted trees) of this site ranges from 2.9 to 5.7 tC/ha/yr. Establishing forests has markedly increased the carbon accumulation in this area. The carbon accumulation at baselines at Benakat site is 1.6-2.8 tC/ha/yr. It is almost the same as that of Lombok site. The above-ground carbon dry weight of 20-year-old *S. macrophylla* planted for rehabilitation purposes is 6.6 tC/ha/yr. These results suggest that, in short rotation, the carbon accumulation of rehabilitation forests is not markedly different from that of industrial plantations. Conserving the rehabilitation forests for a long time would, therefore, be one of the most rational practices for storing carbon on degraded lands sustainably.

## Introduction

### *Incomes, expenses, and savings*

Tree/forest growth can be interpreted as a budget and be itemized as incomes, expenses, and savings. Photosynthetic production can be signified as income, respiratory loss as expenses and growth as savings. Low savings can therefore be the result of "low income and high expenditure", "high income and high expenditure" or "low income and low expenditure".

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- Carbon sink function of terrestrial ecosystems

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In the earlier stage of tree growth, the income generated from the formation of its crown or canopy is high, and the surplus (photosynthetic production-respiration in the crown or canopy) with energy input sufficiently provides the tree with organic matters for new growth in foliages, stems, branches, and roots.

In the mature stage or climax stage, the maintenance costs of the stems, branches, and roots increase owing to their enlarged quantity, signifying the increased expenditure. In the stage thus, and further advanced, incomes decrease due to the structural factor of tree as being spatial i.e., the photosynthetic production is hindered by chronic water stresses owing to the further elongated distance that lies between the tree crown and the root system.

Low income means low distribution of organic matters to non-photosynthetic parts. If the fine root growth is disturbed, absorption of water and mineral nutrients declines, which in turn worsens the water stresses in the crown.

***Role of forests in carbon sequestration***

For easy understanding, the author would like to illustrate the process, using the goods (carbon dioxides) and warehouse (forests) relations. Forest growth means the increasing storage of goods and the size of warehouse. The warehouse, nonetheless, has limitation in size and it will be occupied to the fullest extent by goods, eventually. That is the stage of the climax forest, and in terms of goods and warehouse relation, there is no more goods coming into at this stage. This signifies the stage of no more room for the role of forest to play in carbon sequestration.

If a forest fire should occur, carbon dioxides would get released into the atmosphere just in the same manner as the goods gets released from the warehouse when it catches on a fire. In the long term perspective, such as 200 to 500 years, the carbon dioxide or goods exists only temporarily in the warehouse or trees/forests because of the life cycle of trees/forests and because such naturally caused damages on forests as natural fire, cyclone, etc., occurs frequently. Therefore, there is no room for the forest to play its role in carbon sequestration when considering such a long time span. For this reason, when we evaluate the role of forests in carbon sequestration, time span should always be kept in our mind. Debates, therefore, on carbon sequestration of forests in relation to CDM of the Kyoto Protocol should take the time span into account.

Another serious problem that we have to keep in our mind is the decreasing warehouses, in another word, deforestation, which is one of the major concerns of global environment. We are strongly reminded, here, that the warehouses be conserved and maintained in regional, national and global levels.

As a measure of increasing the sizes of warehouses, utilization of forest products is strongly recommended. Utilization of wood in building houses and in other construction purposes increases warehouses outside the forest area. Nevertheless, here as well, the time span, that we have to remind ourselves of, shall always be taken into account of when we evaluate the role of these forest products such as houses because they have a limited life span as a warehouse. The goods go out of the warehouse after their life span is up.

An important role that the forests products (trees in particular) play in the matters of global environment is the very fact that the forest products can reduce the dependency on limited fossil fuels. It is reassuring to know that they are renewable by making best use of solar energy that abounds on earth.

***CDM***

Clean Development Mechanism (CDM) is stipulated in Article 12 of Kyoto Protocol. It has been agreed to include carbon-sink roles of afforestation and reforestation in CDM. In the near future, it is expected that CDM related plantation activities be discussed and practiced in various countries. It may, then, be important to provide scientific information on carbon accumulation in man-made forests and its bearings on CDM for policy makers.

It is important to ascertain how much carbon is accumulated if plantation forests are established for the CDM application. Carbon accumulation of naturally regenerated vegetation that is considered to be "baseline" without additional carbon sequestration activities is not regarded as the increment resulted from CDM practices. Furthermore, in order for such carbon sequestration activities to be certified as a CDM practice, it is presently so regulated that the carbon accumulation of man-made forest has to amount to higher than that of the baseline.

In terms of carbon sink activities, baseline means the carbon accumulations of secondary forests, grasslands, pastures, cultivated lands and various land uses other than tree planting. Nevertheless, there is little information about carbon accumulation in such non-tree planting vegetation.

This paper, therefore, deals with the verification of carbon accumulation from the viewpoint of man-made forests. Some of the case studies were conducted and basic data was collected.

We measured the carbon accumulation in man-made forests with some typical fast growing species, and discussed the difference of accumulation rate between different plantation types, industrial plantations and rehabilitation forests. In addition, we discuss carbon accumulation of pioneer secondary forests, shrub lands and grasslands established after forest fires, shifting cultivation and/or logged over plantation areas to treat as baselines.

**Biomass Estimation**

When we estimate biomass in various stands, applying a sampling method by felling trees may be difficult in tropical area due to the lack of measuring tools and drying oven. Therefore, estimating biomass without destructing stands is needed. Allometric relation between dry matter of each organ and diameter at breast high (DBH) will be suitable if the relation in each species can apply to various stands.

$$Y = aX^b \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

(Where Y is dry matter in each organ, X is square of DBH, and a and b are coefficients.)

Recently, data set from our field works has been completed with coefficients in allometry of various tree species of industrial plantations and rehabilitation forests.

## Results and Discussion

### *Industrial plantations*

Fast growing tree plantation is established mainly for the purpose of producing pulpwood supply and the cycle between planting and harvesting is 6 to 8 years as a general practice. Five to 7 years' rotation is suggested for higher products of pulpwood (Yonekawa and Miyawaki, 1988). Stands are generally selected at high productive site for efficient income generation from the wood products. Main species in industrial plantations in tropical and subtropical regions are such fast growing species as *Eucalyptus* and *Acacia* species.

<*Acacia*>

*Acacia mangium* is widely planted at various sites in secondary forests, shrubs and grasslands after forest fires, abandoned shifting cultivation areas, and/or logged over plantation areas. Mean annual increment (MAI) of the above ground biomass of this species, including leaves and branches, is about 10 tC/ha/yr. This figure may be applied to plantations of this species in Monsoon Asia. Root biomass is about 16% to above ground biomass from the industrial plantation in Benakat, South Sumatra.

MAI of *A. auricliformis* fluctuates in various sites. These fluctuations may be caused due to the differing purposes of each plantation. This species is planted widely in productive or degraded lands for its high adaptability to dry environment and poor soil conditions. This species will be suitable for degraded land rather than high productive land because of their growth performance.

<*Eucalyptus*>

MAI of *Eucalyptus globulus* is about 16 tC/ha/yr at Manjimup, Western Australia and it might be the highest among the industrial plantation. MAI of another species, *E. grandis* in South Africa and *E. nitens* in Chili ranged from 8 to 11 tC/ha/yr. Root biomass is 14 to 16% to above ground biomass in these species. These species are suitable for subtropical regions.

*E. camaldulensis* introduced from Australia is widely planted in Monsoon Asia especially in Thailand (Kamo, 1990) as multipurpose tree for social forestry (Ishizuka, 1996a, b). Its MAI is about 5 tC/ha/yr at Sonbe, Viet Nam and lower than the amounts of *A. mangium* and *A. auricliformis* at the same site. The volume growth is annually about 20 cubic meters in dry tropical regions and is about 30 cubic meters in wet regions (Ishizuka, 1996a, b). The growth is strongly affected by site conditions in spite of higher growth adjustment capability to environmental stresses (Ishizuka, 1996a, b).

### *Rehabilitation forests*

Establishing forests in degraded land gives us social benefits such as water conservation, erosion control, agricultural use of litter, and commercial wood products. MAI of 3-year-old *Cassia siamae*, *Azadirachta indica* and *Dalbergia latifolia* plantations is 6 to 9 tC/ha/yr in Lombok Island, Indonesia for the purpose of round wood, fuel wood, and fodder productions.

MAI of 20-year-old *Swietenia macrophylla* plantation is 6.6 tC/ha/yr at Benakat, Sumatra. These plantations were established by the effort of JICA for rehabilitating degraded land after severe shifting cultivation. The plantations are well managed for a long time protecting from fire and illegal logging by the local forestry office. Root biomass is about 30% to above ground in this species. Higher portion of root biomass may be important to improve carbon sequestration and commercial values of forests.

Industrial plantation with short rotation may be effective to carbon sequestration in short period. We, therefore, need to study the carbon sequestration and release in the cycle of 6 to 9 years with a view to sustaining continuous carbon sequestration. On the other hand, rehabilitation forests obviously accumulate carbon for a long time even with their slow growing characteristics.

***Base line***

Carbon accumulation in perennial grass and shrub (*Chromolanea odorata* and *Lantana camara*) is 2.6 to 3.2 tC/ha/yr at degraded land in Lombok Island, Indonesia. These species have short life span. *C. odorata* accumulates carbon of 10 tC/ha in three-years-old and the accumulation decreases to 8.3 tC/ha with increasing dead organs in 5-years-old (Slaats *et al.*, 1996). This species is commonly growing in the area after forest fires in Borneo for 2 years. However, it completely disappeared from the area after 3 years (Nykvist, 1996).

Secondary forests after forest fires accumulated carbon of 2.9 to 5.7 tC/ha/yr at Bukit Soeharto in East Kalimantan. These amounts are higher than those of herbs and shrubs in Lombok Island. This might be caused by the species composition in secondary forests. In *Macalanga gigantea* plot, carbon accumulation is relatively lower in trees and higher in forest floor vegetation. Carbon accumulation seems to be lower in pioneer secondary forests than man-made forests in spite of fast growing after forest fires.

When we apply CDM to tree planting projects, it may be difficult to predict or measure the amount of base line at a preset area because of the uncertain history of land use or large fluctuation of natural vegetation growth. Standardized values of base line should be given to each region from these reasons for keeping transparency in the carbon sequestration credit of CDM. If quantitative values for baseline be given to each region and/or fixed at divisional areas, it might be practical to CDM projects.

We present here the preliminary mesh data of the values of base line from modelling analysis in Monsoon Asia (Fig.1). The prediction is based on three components; potential productivity predicted from meteorological mesh data (Ohta *et al.*, 1993; Uchijima and Ohta, 1996), decreasing productivity by forest fires, and human impacts such as caused by cultivation.

We assume that land for CDM project would be restricted to abandoned secondary forests and grasslands after shifting cultivation. We give the coefficient of 30% of potential productivity to the forest area, which might suffer forest fires. The coefficient is derived from mean MAI of regenerated forests in Bukit Soeharto (Table 1) divided by potential productivity corresponding to the one degree mesh included the forests. We assume that the productivity would be kept at the same level in the regenerated area if the burned area be abandoned and recovered to regenerated forests.

We also assume the coefficient of 80% of the value to the areas of agricultural lands or abandoned shifting cultivation areas. The value is originated by productivity change by cultivation (Iwaki, 1981). Land use form in a given grid is calculated from grid data of population (Ohta and Uchijima, 1997) and divided into forests, agricultural area or grasslands, and urban lands. Table 2 shows the regional mean value of baseline calculating from mesh data. These data is still of preliminary and we need more detailed analysis of human impacts to land productivity.

***Preliminary expectations of carbon gain in CDM***

Three hundreds and thirty seven million tons of carbons were released in the atmosphere in 1990 in Japan. If we would try to sequestrate one percent of these released carbons through the use of CDM, Japan would need 581 thousands ha of land in developing countries to plant trees based on the carbon sequestration of 8.8 tC/ha/yr in man-made forests and 3 tC/ha/yr in baselines (above ground).

Japan Overseas Plantation Center for Pulpwood (2001) expects 196.5 thousands ha plantations in 2000 and 213.9 thousands ha in 2010 respectively. It is, therefore, clear that other types of CDM projects should also be earnestly pursued and other effective measures be taken in Japan.

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## Table 1 Carbon Accumulation in man-made forest and base line(BL)

| | age | density | Biomass(tC/ha) and MAI(tC/ha/yr) | | | | | | stem V | BL | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (n/ha) | stem | bark | branch | leaf | above | root | (m3/ha) | (tC/ha/yr) | |
| *Eucalyptus globulus* | 5 | 1225 | 55.3(11.1) | 9.3(1.86) | 8.5(1.7) | 8.45(1.69) | 81.5(16.3) | 12.2(2.44) | 246.2 | | yamada et al,1999 |
| Manjimup, w,Aust.* | 8 | 1225 | 93.5(11.7) | 13.5(1.69) | 11.4(1.43) | 10.2(1.28) | 128.5(16.1) | 18.5(2.31) | 408.9 | | |
| *E. globulus* | 5 | 1467 | 29.1(5.82) | 3.83(0.77) | 6.09(1.22) | 5.0(1.0) | 43.0(8.6) | 7.25(1.45) | 144.5 | | JOPP, 2000 |
| Canente, Chili* | 7 | 1840 | 52.0(7.43) | 6.56(0.94) | 8.13(1.16) | 7.2(1.03) | 74.0(10.6) | 12.5(1.78) | 254.7 | | |
| *E.grandis* | 5 | 1135 | 30.8(6.16) | 4.1(0.83) | 2.9(0.58) | 1.6(0.32) | 39.4(7.88) | 8.9(1.11) | 198.3 | | Yamada et al .2000b |
| Melmoth, S.Africa* | 8 | 1333 | 53.7(6.71) | 6.4(0.8) | 4.65(0.58) | 2.15(0.27) | 66.9(8.36) | 8.9(1.11) | 338.2 | | |
| *E. nitens* | 7 | 1383 | 41.6(5.82) | 5.23(0.77) | 6.67(1.22) | 7.59(1.08) | 61.1(8.6) | 10.0(1.45) | 223.9 | | JOPP, 2000 |
| Canente, Chili* | 8 | 1517 | 45.9(5.74) | 5.8(0.73) | 7.28(0.92) | 8.42(1.05) | 67.5(8.44) | 11.1(1.39) | 247.8 | | |
| | 11 | 1048 | 68.5(6.23) | 7.65(0.70) | 10.6(0.96) | 10.8(0.98) | 97.6(8.87) | 15.5(1.41) | 345.1 | | |
| *E.camaldulensis(1)* | 6 | 1089 | 20.1(3.35) | 4.65(0.78) | 1.95(0.83) | 0.85(0.14) | 30.5(5.08) | | 75.1 | | Yamada et al, 2000a |
| *Acacia mangium(1)* | 6 | 1289 | 46.3(7.72) | 7.75(1.29) | 4.9(0.82) | 1.65(0.28) | 60.6(10.1) | | 229 | | Yamada et al, 2000c |
| *A. mangium(2)* | 6 | 1369 | 57.3(9.55) | 9.18(1.53) | 16.4(2.73) | 3.24(0.54) | 86.1(14.4) | 13.2(2.2) | 287.4 | 1.6-2.8 | JIFPRO,2002 |
| *A. mangium(3)* | 7 | 506 | 42.3(6.04) | 4.0(0.57) | 6.1(0.87) | 2.3(0.33) | 54.6(7.8) | | 221.9 | | Yamada et al.2000a |
| *A. auricliformis(2)* | 6 | 1500 | 33.9(5.65) | 5.05(0.84) | 6.3(1.05) | 2.65(0.44) | 47.9(7.98) | | 171.4 | | Yamada et al,2000a |
| *Cassia siemea(4)* | 3 | 935 | 12.4(4.13) | 1.65(0.55) | 9.75(6.5) | 2.1(0.7) | 25.8(8.6) | | 37.3 | 2.6-3.2 | Morikawa et al,2002 |
| *Azadirachta indica(4)* | 3 | 1111 | 11.3(3.75) | 2.05(0.68) | 7.15(2.38) | 2.3(0.77) | 22.75(7.58) | | 44.4 | 2.6-3.2 | Morikawa et al. 2002 |
| *Dalbergia ltifolia(4)* | 3 | 1025 | 7.3(2.43) | 2.05(0.68) | 7.8(2.6) | 0.5(0.17) | 17.65(5.88) | | 26.4 | 2.6-3.2 | Morikawa et al,2002 |
| *Swietenia macrophylla(2)* | 20 | 1117 | 81.5(4.08) | 12.0(0.6) | 31.7(1.59) | 4.07(0.2) | 129.3(6.47) | 36.6(1.83) | 437.4 | 1.6-2.8 | JIFPRO,2002 |
| *Peronema canescens(2)* | 10 | 446 | 7.53(0.75) | 1.46(0.15) | 4.43(0.44) | 0.88(0.09) | 4.7(0.47) | 3.04(0.3) | 47.8 | 1.6-2.8 | JIFPRO,2002 |
| (secondary forests)(5) | | | | | | | | | | 2.9-5.7 | Morikawa et al,2002 |
| (alang-alang)(5) | | | | | | | | | | 0.6-1.3 | Morikawa et al,2002 |

(1)Sonbe, Viet Nam*, (2)Benakat, Sumatra, Indonesia**, (3)Madang, PNG*, (4)Lombok Island, Indonesia** and (5)Samarinda, E. Kalimantan, Indonesia

*; Indusrtial plantations and **; rehabilitating forests

Table 2 Mean predicted baseline in major islands.

| Area | n | baseline production mean ± SD | |
|---|---|---|---|
| Sumatra I. | 53 | 3.48 | 0.42 |
| Kalimantan I. | 72 | 4.09 | 0.20 |
| Sulawesi I. | 28 | 3.67 | 0.53 |
| Java I. to Timor I. | 34 | 1.60 | 1.10 |
| Maluku Is. | 15 | 4.08 | 0.26 |
| Irian Jaya | 49 | 4.10 | 0.20 |
| Papua New Guinea | 44 | 3.72 | 0.50 |
| Philippines | 33 | 1.91 | 1.27 |
| Malay Pen. | 24 | 3.18 | 0.43 |
| Indo China Pen. | 107 | 2.43 | 0.78 |