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Full Length Research Paper

Evaluation of carbon storage in soil and plant biomass of primary and secondary mixed deciduous forests in the lower northern part of Thailand

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Carbon sequestration in a forest ecosystem is an important determinant of the local and regional carbon stock. This study monitored forest types and carbon storage in both biomass and soil within primary mixed deciduous forests (PMDF) and secondary mixed deciduous forests (SMDF). One study plot measuring 50 x 50 m and five 10 x 10 m plots were set up at each study site for trees and shrubs inventory, respectively. The trees and shrubs were counted and identified by species. Organic carbon in biomass was estimated by using allometry equation and soil carbon concentration was analyzed by Walkley-Black method. The results revealed that PMDF had a higher level of carbon storage in biomass than SMDF by approximately two times, while soil carbon stock in PMDF was also quite higher than SMDF. The dominant species having a high carbon concentration included *Canarium subulatum, Pterocarpus macrocarpus, Dalbergia cultrate, Lagerstroemia tomentosa* and *Xylia xylocarpa* var *kerrii.* These species were found in intermediate succession, thus indicating that some may be suitable for re-planting in future restoration processes in order to accelerate natural succession and storage carbon. This may be one method to reduce the CO_2 in the atmosphere by making the SMDF act as a carbon sink.

Key words: Thailand, carbon storage, soil, plant biomass, mixed deciduous forest, northern.

INTRODUCTION

A mixed deciduous forest ecosystem is one type of tropical, seasonal forest found in Thailand (Ashton, 1995; Blasco et al., 1996) particularly in the north of the country. This forest ecosystem covers large areas and shows much variation in structure and composition. It evolves and occupies riparian areas and gentle slopes that are less than 500 m above sea level (Smitinard, 1977; Bunyavijchewin, 1985; Rundel and Boonpragob, 1995). The dominant species are *Tectona grandis* (Teak), *Pterocarpus macrocarpus*, *Xylia xylocarpa* var *kerrii*, *Afzelia xylocarpa*, *Largestroemia calyculata*, *Terminalia* spp. and *Vitex peduncularis*. Teak is the most important species economically although, it is not always present in the mixed deciduous forest ecosystem (Ogawa et al., 1961; Smitinand, 1996). In this forest type, fires occur frequently, usually starting as ground fires during the dry season (Sukwong and Dhamanittakul, 1977).

In the global carbon cycle, carbon dioxide (CO_2) is exchanged between the atmosphere and terrestrial ecosystems through processes of photosynthesis, respiration, decomposition and changes in the use and cover of the land. Tropical forest ecosystems play a particularly important role in global carbon budget (Dixon et al., 1994; Field et al., 1998). The tropical forests store on average about 50% more carbon than forest outside the tropics. The total carbon content of forest ecosystems

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in 2005 was estimated at 638 Gt (FAO, 2006). Therefore, deforestation activities in tropical area also cause carbon to be released to the atmosphere. In the forest ecosystem, particularly soil and plants, is the main stock of organic carbon. The concentration of carbon in soil has an effect on the ground above and below forest production. Some reports have revealed that soil in the forest ecosystem accumulates the largest form of Soil Organic Carbon (SOC), more than 1500 pg carbon or approximately two times as much as carbon in the air, and more than two and a half times carbon in plant structure (Schimel, 1995). This is in agreement with Eswaran et al. (1993) having indicated that more than 1576 pg carbon was accumulated in soil and that around 32% of organic carbon was stored in tropical soil, with 42% found in the soil of a tropical forest ecosystem. Therefore, if the forest ecosystem be destroyed, stored carbon would flow towards the atmosphere. Moreover, forest clearing can lead to soil degradation, erosion, and the leaching of soil nutrients, and may reduce the ability of the ecosystem to act as a carbon sink. In this paper, the concentration of carbon in both plant biomass and soil between primary and secondary mixed deciduous forests in Phetchabun province, a province in the northern part of Thailand, was investigated. The ecological characteristic presented an opportunity to study species composition, the structure of a forest ecosystem, and the effects on organic carbon storage.

MATERIALS AND METHODS

Site description

This research was conducted in a natural mixed deciduous forest ecosystem, with no teak present, at Namko subdistrict (16°47/N, 101°08/E) in Lomsak district of Phetchabun province which is situated in the lower northern part of Thailand, 345 km north of Bangkok, the capital of Thailand. Drainage feature of this area is that of a sub-catchment and alluvian fan. The upstream rims are bounded by steep slopes to a maximum altitude of 1,746 m in the north-western area, down to gentler slopes; then flat rolling sub-catchment terrain and alluvian fan, which is at an altitude of 160 m. Topographically, the site is located in a mountain valley at an elevation of 250 m-above sea level. This area is adjacent to the natural forest at Khao Ko and Phu Hin Longkla National Parks (Yumuang, 2006). The main forest community is composed of mixed deciduous and dry evergreen forests. Two forest sub-types were examined that is Primary Mixed Deciduous Forest (PMDF), and Secondary Mixed Deciduous Forest (SMDF). The SMDF had been a cornfield thirty years ago, though, at present, this area had become abandoned land and has since recovered to a secondary forest ecosystem. Soil properties are lightly acidic, pH range ≈ 5-6 (pH in soil:water-ratio 1:1). The bulk density in SMDF ranged from 1.11 - 1.38 g/cm^2, PMDF were 1.12 - 1.27 g/cm^2.

The soil water content (SWC) in SMDF ranged from 0.20-0.21 g/g and PMDF was 0.20 g/g. The top soil in PMDF is a sandy clay loam while SMDF is a sandy clay (data from preliminary of this study). Also, this area is influenced by tropical monsoons, with occasional tropical storms in the early and middle periods of the rainy season (June-October). The annual rainfall normally exceeds 1,100 mm per year. The mean monthly temperature at Lomsak meteorological station, from 2000-2008, was about 27.77°C with a mean maximum of 33.65°C in April and a mean minimum of 22.08°C in December.

Tree and shrub sampling and determination of carbon in plant biomass

In the forest ecosystems, plants were examined and divided into two categories, that is trees and shrubs. Tree categories included trees > 4.5 cm diameter at breast height, (DBH) 1.3 m, and shrub groups having a DBH < 4.5 cm. Each study site set up a study plot of 50 x 50 m for tree inventory. The plot was divided into 10 x 10 m subquadrants. Then, five sub-quadrants were randomized for shrub inventory. Tree and shrub inventory and measurement was conducted during the dry season (January-February, 2009). All trees and shrubs were measured for DBH, height, and identified by species level. The following ecological parameters were calculated; relative density (RDe), relative dominant (RDo), relative frequency (RF) and Important Value (IV) index, density, biomass by using allometry equation (Ogawa et al., 1961), and organic carbon.

Soil sampling and carbon analysis

Soil samples were taken at the two sites that is PMDF and SMDF during the dry and wet seasons. Disturbed soil samples were collected from the top soil layer (0-30 cm) and the sub-soil layer (30-60 cm). They were analyzed for Soil Organic Matter (SOM), Soil Organic Carbon (SOC), and soil pH. The soil samples were air-dried at room temperature and sieved using 2 mm mesh. SOM was measure according to Walkley and Black (1947), then SOC was calculated from SOM. Soil pH (soil:water-ratio 1:1) was also measured.

Data analysis

Statistical analysis was applied by using Analysis of Variance (ANOVA), reported at the confidence level of 95% ($p \leq 0.05$). Duncan's multiple range test was used to analyze the significance of differences in the mean.

RESULTS

Forest characteristics

Species composition within the PMDF was made up of 36 identified tree species and 36 identified shrubs species whereas SMDF had 36 tree species and 22 shrubs species (Table 1). Tree density, comparing between PMDF and SMDF, was almost equal, but the density of shrubs in SMDF was higher than PMDF. When comparing with other studies it was indicated that tree density in the PMDF in this area was high, which may have been due to selective logging by local people in the past. Therefore, the forest structure had been changed, and tree saplings had grown and had become the main upper-storey. Thus, the density in both ecosystems was

Table 1. Ecological parameters studied for the two forest types.

Ecological parameters	Forest sub-type	
	PMDF	SMDF
Tree group		
Density; No/ha	1,152	1,168
Species composition; number of species	36	36
Total above ground biomass; tonne/ha	98.64	49.63
Shrub group		
Density; No/ha	3,740	1,080
Species composition; number of species	36	22
Total above ground biomass; tonne/ha	5.95	1.32

Table 2. Important value indices for tree groups.

Species	PMDF			Species	SMDF		
	RDo	RDe	IV		RDo	RDe	IV
S. siamensis	19.99	17.71	37.69	*M. leucantha* var *buteoides*	25.03	32.88	57.91
C. subulatum	14.23	18.40	32.64	*Bauhinia* sp.	20.53	4.79	25.33
P. macrocarpus	8.83	6.94	15.78	*M. brandisiana*	7.23	11.99	19.22
Colona sp.	5.26	7.29	12.56	*D. nigrescens*	5.74	4.79	10.53
D. cultrate	4.33	4.51	8.84	*A. comosa*	4.50	3.08	7.58
H. odorata	2.86	5.90	8.76	*P. macrocarpus*	4.04	3.77	7.81
S.obtuse	4.01	3.13	7.13	*M. tomentosa*	3.26	4.11	7.37
L. tomentosa	4.87	1.74	6.61	*C. latifolia*	1.87	3.08	4.95
M. tomentosa	3.74	2.43	6.17	*A. littoralis*	1.73	2.05	3.79
X. xylocarpa var *kerrii*	5.18	0.69	5.87	*D. mollis*	2.37	1.71	4.08
M. brandisiana	2.66	3.13	5.78	*B. scandens*	2.46	2.40	4.85
S. oleosa	2.37	3.13	5.49	*C. formosum*	1.21	2.05	3.27
V.peduncularis	2.91	1.39	4.30	*L. undulata*	0.75	1.71	2.46
B. lanzan	1.36	2.78	4.13	*E. subumbrans*	1.36	1.03	2.38
B. ceiba	1.89	2.08	3.97	*Diospyros* sp.	2.30	1.71	4.01
Others	15.51	18.75	34.28	Others	15.62	18.85	34.46
Total	100	100	200	Total	100	100	200

quite high. Tree biomass in PMDF was two times that of biomass in SMDF, and in the shrubs category, the mass of shrubs in PMDF was five times that of SMDF. The important value indices of trees and shrubs are shown in Tables 2 to 3.

Estimates of carbon stock in forest ecosystem

Carbon storage in a forest ecosystem is divided into five carbon storage pools that is living trees, down dead woods, under-storey vegetation, forest floor, and soil (Birdsey and Heath, 1995). Meanwhile, carbon flux in living trees is the largest carbon sequestration which could account for 76-90% of total carbon sequestration in forest ecosystems (Liu et al., 2006). However, this study estimated that the level of carbon sequestration in aboveground living trees and soil, when comparing between trees and shrubs, was that the total carbon sequestration contained in the aboveground biomass of trees was more than shrubs. Thus, the trees category had more significant carbon sinks. The trends found in this study showed that organic carbon stock in plant biomass was higher in a PMDF (mature forest) than in a SMDF ecosystem (recovering forest). However, the annual accumulation rate in PMDF may be less than SMDF, which was the growth of the recovering forest. Because of PMDF, which is a mature eco-system, had a quite low growth rate.

The estimation of each tree species, organic carbon

Table 3. Important value indices for shrub groups.

Species	PMDF				Species	SMDF			
	RDe	RDo	RF	IV		RDe	RDo	RF	IV
S. oleosa	14.81	9.09	5.41	29.31	*Goniothalamus* sp.	14.97	9.69	6.41	31.07
T. mucronata	9.26	7.01	10.81	27.08	*C. latifolia*	8.02	9.28	3.85	21.15
V. peduncularis	7.41	12.16	5.41	24.97	*Bauhinia* sp.	5.88	6.74	6.41	19.03
B. lanzan	5.56	7.57	8.11	21.24	*C. formosum*	7.49	5.86	5.13	18.47
M. leucantha var *buteoides*	7.41	5.05	8.11	20.57	*D. castanea*	6.42	6.47	5.13	18.02
Bauhinia sp.	5.56	6.64	8.11	20.30	*M. brandisiana*	4.28	7.99	5.13	17.39
D. nigrescens	5.56	9.75	2.70	18.00	*V. peduncularis*	5.35	1.70	5.13	12.17
H. cordifolia	5.56	5.62	5.41	16.58	*G. sootepensis*	4.28	2.91	3.85	11.03
D. castanea	3.70	9.20	2.70	15.60	*D. mollis*	3.74	3.43	3.85	11.02
Vitex sp.	3.70	4.65	5.41	13.76	*Streblus* sp.	2.67	5.63	2.56	10.87
Others	31.48	23.27	37.84	92.59	Others	36.90	40.33	52.56	178.51
Total	100	100	100	300	Total	100	100	100	300

Table 4. Organic carbon storage in stem (S), branch (B) and leaves (L) of trees in PMDF and SMDF.

Species	PMDF				Species	SMDF			
	S	B	L	Total		S	B	L	Total
C. subulatum	9.79	1.86	0.39	12.04	*M. leucantha* var *buteoides*	5.21	0.92	0.22	6.35
S. siamensis	7.34	1.43	0.29	9.05	*Bauhinia sp.*	3.79	0.80	0.13	4.72
P. macrocarpus	3.03	0.60	0.12	3.75	*D. nigrescens*	1.35	0.26	0.05	1.66
D. cultrate	2.13	0.48	0.06	2.67	*M.brandisiana*	1.26	0.21	0.05	1.53
L. tomentosa	2.11	0.46	0.07	2.64	*P. macrocarpus*	1.07	0.20	0.04	1.32
X. xylocarpa	2.03	0.48	0.05	2.56	*H. perforate*	0.93	0.17	0.04	1.14
Colona sp.	1.69	0.31	0.07	2.07	*A. comosa*	0.77	0.15	0.03	0.95
S. obtuse	1.20	0.24	0.05	1.48	*M. tomentosa*	0.57	0.10	0.02	0.69
M. tomentosa	1.19	0.24	0.05	1.47	*Diospyros* sp.	0.50	0.09	0.02	0.62
V. peduncularis	0.99	0.19	0.04	1.22	*D. mollis*	0.48	0.09	0.02	0.58
Others	9.42	1.81	0.37	11.60	Others	4.3	0.77	0.18	5.3
Total	40.92	8.10	1.56	50.58	Total	20.23	3.76	0.8	24.79

Unit: tonne/ha.

pool revealed that *Canarium subulatum* had the highest concentration of Organic Carbon (OC) in PMDF, followed by *Shorea siamensis*, *Pterocarpus macrocarpus, Dalbergia cultrate*, *Lagerstroemia tomentosa,* and *Xylia xylocarpa* var *kerrii*, respectively. Meanwhile in SMDF, *Milletia leucantha* var *buteoides* showed the highest value, followed by *Bauhinia* sp., *Dalbergia nigrescens*, *Millettia brandisiana* and *Pterocarpus macrocarpus*, respectively (Table 4). The total of OC of tree in PMDF was higher than SMDF by about two times. Most of OC accumulated in the stem of the tree in both PMDF and SMDF. Meanwhile, the total OC of shrub in SMDF was higher than PMDF about five times (Table 5). This study showed that PMDF had a high potential for storage of organic carbon in their plant biomass. The evaluations of total organic carbon storage in plant structure, both of PMDF and SMDF, are shown in Table 6. Soil pH in both SMDF and PMDF was acidic. The analysis of soil organic carbon in the dry and wet season is shown in Tables 7 and 8, respectively. PMDF demonstrated that SOC was higher than SMDF where there was degraded land. This assertion was supported by the finding that logged forest had less carbon stock due to the harvesting of timber. Harvesting caused forest floor carbon storage to decline by a remarkably consistent 30% (Nave et al., 2010).

DISCUSSION

Characteristics and carbon stock in forest ecosystem

The dominant tree species in the PMDF were *Shorea*

Table 5. Organic carbon storage in stem (S), branch (B) and leaves (L) of shrubs in PMDF and SMDF.

Species	PMDF				Species	SMDF			
	S	B	L	Total		S	B	L	Total
S. oleosa	0.09	0.08	0.08	0.26	*Goniothalamus* sp.	0.32	0.28	0.28	0.88
M. leucantha var *buteoides*	0.06	0.05	0.05	0.16	*C. latifolia*	0.18	0.15	0.15	0.48
T. mucronata	0.05	0.04	0.04	0.13	*C. formosum*	0.16	0.14	0.14	0.45
B. ceiba	0.04	0.03	0.03	0.10	*D. castanea*	0.14	0.12	0.12	0.38
B. lanzan	0.02	0.02	0.02	0.07	*Bauhinia* sp.	0.13	0.11	0.11	0.35
X. xylocarpa	0.02	0.02	0.02	0.06	*Unknow* sp 1	0.11	0.10	0.10	0.31
Bauhinia sp.	0.02	0.02	0.02	0.06	*V. peduncularis*	0.11	0.10	0.10	0.31
H. cordifolia	0.02	0.02	0.02	0.06	*M. brandisiana*	0.09	0.08	0.08	0.26
C. tabularis	0.02	0.02	0.02	0.06	*G. sootepensis*	0.09	0.08	0.08	0.25
L. tomentosa	0.02	0.02	0.02	0.06	*D. mollis*	0.08	0.07	0.07	0.22
B. scandens	0.01	0.01	0.01	0.03	*Vitex* sp.	0.07	0.06	0.06	0.19
D. nigrescens	0.01	0.01	0.01	0.03	*Streblus* sp.	0.06	0.05	0.05	0.16
Colona sp.	0.01	0.01	0.01	0.03	*H. perforate*	0.06	0.05	0.05	0.16
Vitex sp.	0.01	0.01	0.01	0.03	*M. leucantha* var *buteoides*	0.05	0.04	0.04	0.13
V. peduncularis	0.01	0.01	0.01	0.03	*M. tomentosa*	0.05	0.04	0.04	0.13
M. brandisiana	0.01	0.01	0.01	0.03	*B. scandens*	0.05	0.04	0.04	0.13
H. isora	0.01	0.01	0.01	0.03	*H. orixense*	0.05	0.04	0.04	0.13
S. siamensis	0.01	0.01	0.01	0.03	*L. tomentosa*	0.05	0.04	0.04	0.13
M. tomentosa	0.01	0.01	0.01	0.03	*D. nigrescens*	0.04	0.03	0.03	0.10
-	-	-	-	-	*H. isora*	0.04	0.03	0.03	0.10
-	-	-	-	-	Others	0.26	0.22	0.22	0.70
Total	0.48	0.42	0.42	1.32	Total	2.17	1.89	1.89	5.95

Unit: tonne/ha.

Table 6. Organic carbon (OC) in above ground biomass for trees and shrubs in PMDF and SMDF.

Study site/plant type	Stem	Branch	Leaves	Total
PMDF				
Trees	40.92	8.1	1.56	50.58
Shrubs	0.48	0.42	0.42	1.32
Total	41.40	8.52	1.98	51.90
SMDF				
Trees	20.23	3.76	0.8	24.79
Shrubs	2.17	1.89	1.89	5.95
Total	22.40	5.65	2.69	30.74

Unit: tonne/ha.

Table 7. Chemical soil properties in top and sub soil layer during the dry season.

Parameter	Top soil		Subsoil	
	SMDF	PMDF	SMDF	PMDF
SOM (%)	3.15 ± 1.01^{a}	3.26 ± 0.68^{a}	2.53 ± 0.93^{a}	2.80 ± 0.76^{a}
SOC (%)	1.83 ± 0.58^{a}	1.89 ± 0.39^{a}	1.47 ± 0.54^{a}	1.63 ± 0.44^{a}
pH	5.91 ± 0.22^{a}	6.34 ± 0.14^{b}	6.03 ± 0.16^{a}	6.33 ± 0.15^{a}

Values with the different letter in the same row are significantly different (Duncan test; p<0.05)

Table 8. Chemical soil properties in top and sub soil layer during the wet season.

Parameter	Top soil		Subsoil	
	SMDF	PMDF	SMDF	PMDF
SOM (%)	1.73 ± 0.05[a]	1.80 ± 0.05[a]	1.46 ± 0.03[a]	1.32 ± 0.03[b]
SOC (%)	1.01 ± 0.03[a]	1.05 ± 0.02[a]	0.85 ± 0.02[a]	0.76 ± 0.02[b]
pH	5.82 ± 0.03[a]	6.13 ± 0.12[b]	6.04 ± 0.14[a]	6.26 ± 0.06[a]

Values with the different letter in the same row are significantly different (Duncan test; $p<0.05$).

siamensis (genera Shorea), *Canarium subulatum*, *Pterocarpus macrocarpus* and *Colona* sp. The report of species composition in mixed deciduous in Thailand by Marod et al. (1999) reporting that *Shorea siamensis* was the dominant species, occurred in the mixed deciduous forest in Mae Klong Watershed Research station, Kanchanaburi province. While in this study it showed that *Milletia leucantha* var *buteoides*, *Bauhinia* sp., *Millettia brandisiana* and *Dalbergia nigrescens* were dominant in the secondary forest. Many researches have indicated that *Xylia xylocarpa* var *kerrii*, *P. macrocarpus*, *S. oleosa*, *S. pinanta* and *Diospyros mollis* were dominant in natural mixed deciduous forests (Ogawa et al., 1961; Bunyavejchewin, 1983; Gajaseni and Jordan, 1990). For shrub groups, *Goniothalamus* sp., *Cananga latifolia* and *Bauhinia* sp. were dominant in SMDF. And in PMDF the dominant were *Schleichera oleosa*, *Terminalia mucronata* and *Vitex peduncularis*.

Forest ecosystems are sources of atmospheric carbon when they are disturbed by human and natural activity, yet on the other hand, they become atmospheric carbon sinks during re-growth. Because they store quantity of carbon in vegetation and soil through photosynthesis and litter decomposition. Thus, the destruction of the primary forest in this area in the past, for use as agricultural land, released and increased carbon into the atmosphere. Meanwhile, land use change, particularly the conversion of forest land to agricultural eco-systems, also depleted the soil carbon stock. This assertion was supported by Lal (2005) who stated that degraded agricultural soils have lower SOC stock than their potential capacity, due to land use change. With the widespread land-use conversion in this area from abandoned cornfield to forest since the 1980s, SMDF were responsible for the carbon sources. However, this area can be managed to conserve significant quantities of carbon in this region. But, the carbon accumulation rate in any particular region is influenced by many factors including climate, solar radiation, disturbance, age of forest, species composition, and soil characteristics (Birdsey and Heath, 1995). The restoration of SMDF to a carbon sequestration pool must use management techniques such as re-planting to accelerate succession processes. Furthermore late successional hardwood species may be selected for establishment. In addition, Yashiro et al. (2008) made the suggestion that selectively logged forests may be converted into a weaker sink of methane (CH_4) and greater source of nitrous oxide (N_2O), at least for a short period, due to the increased soil nitrogen availability and soil compaction. Thus, if we can protect the tropical forest, particularly PMDF, it could be an effective ecosystem for reducing greenhouse gas, particularly CO_2, in the atmosphere, acting as one strategy for solving global warming. The species which has the potential to accumulate organic carbon should be considered for use to restore species in other highly degraded mixed deciduous forest ecosystems, such as *C. subulatum, P. macrocarpus, D. cultrate, L. tomentosa* and *X. xylocarpa* var *kerrii.*

Management strategies to enhance carbon sequestration

A mixed deciduous forest is an economically important forest ecosystem, and as a result, a large area of this forest had been disturbed through logging and agriculture resulting in a highly degraded land. Also land-use change or deforestation can modify soil carbon contents because carbon storage in the soil of a forest eco-system is a significant component of the global carbon cycle. This research showed that SMDF has the potential to enhance carbon stock through plant biomass and soil. However, Lal (2005) indicated that the magnitude and quality of soil carbon stock is depended on the complex interaction between climate, soil, tree species and management, and the composition of litter, as determined by the dominant species. Thus, one management strategy is ecological restoration by increasing the rate of native species establishment, particularly with high carbon stock in biomass and late successional species such as *C. subulatum*, *P. macrocarpus*, *D. cultrate*, *L. tomentosa* and *X. xylocarpa* var *kerrii*. But central to a forest's community is its diversity of species.

Thus, some communities and ecosystems might be more stable if you increase the diversity, even though some individual species may not persist. Therefore, if we try to restore an area of highly degraded land with some high carbon stock species in the early stages we will accelerate the natural recovery processes, we should select a variety of native species for conserve bio-diversity. Some studies have indicated that some primary species, as well as a few climax species, could regenerate naturally in the understory layer (Kaewkrom et al., 2005), therefore, selection of some species for re-planting may be useful. The advantage of carbon sequestration in a secondary forest is an important strategy to ameliorate changes of CO_2 into the atmosphere by acting as an important carbon sink.

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