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CARBON STOCKS ASSESSMENT OF A SECONDARY FOREST IN MOUNT MAKILING FOREST RESERVE, PHILIPPINES

R. D. Lasco*, I. Q. Guillermo, R. V. O. Cruz, N. C. Bantayan & F. B. Pulhin

College of Forestry and Natural Resources, University of the Philippines, College, 4031 Laguna, Philippines

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LASCO, R. D., GUILLERMO, I. Q., CRUZ, R. V. O., BANTAYAN, N. C. & PULHIN, F. B. 2004. Carbon stocks assessment of a secondary forest in Mount Makiling Forest Reserve, Philippines. Tropical forests are important source and sink of carbon (C). However, there are limited information on the ability of tropical forests to store and sequester C. This study is aimed at quantifying the C stocks of a secondary forest in Mount Makiling Forest Reserve, Philippines. The total biomass (above and below ground) of the forest was 576 Mg ha^{-1} with an annual tree biomass accumulation of 12 Mg ha^{-1} year^{-1}. At an average of 43% C content of biomass, total C stocks was 418 Mg C ha^{-1} including soil organic C which comprised about 40% of the total. Carbon sequestration rates were estimated at 5 Mg C ha^{-1} year^{-1}.

Key words: C storage – sequestration – tropical forests – climate change – forest biomass

LASCO, R. D., GUILLERMO, I. Q., CRUZ, R. V. O., BANTAYAN, N. C. & PULHIN, F. B. 2004. Penilaian stok karbon bagi hutan sekunder di Hutan Simpan Gunung Makiling, Filipina. Hutan tropika merupakan punca karbon dan tangki karbon yang utama. Namun, maklumat tentang kebolehan hutan tropika untuk menyimpan dan mensekuester karbon agak terhad. Kajian ini bertujuan untuk menyukat kuantiti stok karbon bagi hutan sekunder di Hutan Simpan Gunung Makiling, Filipina. Jumlah biojisim (atas tanah dan bawah tanah) hutan ialah 576 Mg ha^{-1} dengan penghimpunan biojisim pokok tahunan sebanyak 12 Mg ha^{-1} setahun. Pada purata 43% kandungan karbon biojisim, jumlah stok karbon ialah 418 Mg C ha^{-1} termasuk karbon organik tanah yang membentuk 40% daripada jumlah karbon. Kadar sekuester karbon dianggar pada 5 Mg ha^{-1} setahun.

Introduction

Forest ecosystems play an important role in the climate change because they can both be sources and sinks of atmospheric carbon dioxide (CO_2). They can be managed to assimilate CO_2 via photosynthesis and store carbon in biomass and in soil (Trexler & Haugen 1994, Brown *et al.* 1996, Watson *et al.* 2000). Great attention is focused on tropical forestry to offset carbon emission due to its cost effectiveness, high potential rates of carbon uptake and associated environmental and social benefits (Moura-Costa 1996, Myers 1996, Brown *et al.* 2000). Tropical forests have

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E-mail: rlasco@laguna.net

the biggest long-term potential to sequester atmospheric carbon (80% of the world's forests total) by protecting forested lands, slowing deforestation, reforestation and agroforestry (Brown *et al.* 1996). However, at present, the world's forests are estimated to be a net source of 1.8 Gt carbon per year primarily because of deforestation, harvesting and forest degradation (Watson *et al.* 2000). At least 20% of all atmospheric CO_2 emissions are from tropical deforestation.

Secondary forests are defined by CIFOR (2000) as forests regenerating naturally (majority being spontaneous woody vegetation) after significant human disturbance of the original forest vegetation, usually displaying a major change in canopy species composition from that of primary forests growing on similar site conditions in the area. Under this definition, one type of secondary forests are post-extraction secondary forests which are those forests regenerating after significant disturbance through logging. In the Philippines, the more commonly used terms to denote forests after logging are logged-over forests, residual forests and second-growth forests (Lasco *et al.* 2000). In this paper, these forest types are considered as secondary forests because in most cases there is very significant disturbance during logging. Of the remaining natural forest cover in the Philippines, secondary dipterocarp forests comprise the largest area with 2.7 Mha (FMB 1997). These forests were previously logged following the Philippine selective logging system. With the imposition of a logging ban in all old-growth dipterocarp forests in 1992, the country relies mainly on secondary forests for its wood supply (Lasco *et al.* 2001).

Based on the 1990 national inventory of greenhouse gases, 67% of total CO_2 emissions in the Philippines (128 620 Gg) came from forestry and landuse change (Murdiyarso 1996). Since the country's secondary forests are undergoing the most rapid change of all forest types due to harvesting and deforestation, they have the greatest influence on carbon budget. Lasco (1998) made preliminary estimates of the carbon storage and sequestration for all types of forest ecosystems in the Philippines. Secondary forests were calculated to store 253 Tg C and sequester 8 Tg C year^{-1} excluding those in understorey vegetation, soil and litter. In a subsequent study, Lasco and Pulhin (2000) estimated that second-growth forests in the Philippines store 378 Tg C and sequester 7.5 Tg C year^{-1}. However, these estimates relied mainly on secondary data derived from forests in other countries.

This pioneering study was designed to provide a more accurate estimate of the ability of a secondary forest ecosystem in the Philippines to store and sequester C. The result of this study is expected to provide valuable inputs in estimating the potential of forests in the Philippines to mitigate climate change. The main objective of the study was to estimate the capacity of a secondary forest in Mount Makiling Forest Reserve to store and sequester CO_2. Specifically, the study was conducted to (a) determine the biomass accumulation of a secondary forest ecosystem in Mount Makiling, (b) determine the carbon stored in the aboveground biomass, necromass and soil of a secondary forest ecosystem and (c) estimate the carbon sequestration rate of a secondary forest ecosystem.

Materials and methods

The study was conducted at the Makiling Forest Reserve, College, Laguna, Philippines located at 14° 08' N and 121° 11' E and 65 km southeast of Manila. Specifically, it was located in the 4-ha long-term monitoring plot established by the Japan International Research Center for Agriculture Sciences (JIRCAS) and the College of Forestry and Natural Resources (CFNR) in 1992. The specific area for the study was 1 ha inside the long-term monitoring plot. The community structure of the forest was described in detail by Luna *et al.* (1999).

The climate is tropical monsoon with a short dry season. Annual mean rainfall and temperature are 2397 mm and 24 °C respectively. The topography is moderately sloping with an intermittent creek passing through it. The site lies at the foot of Mount Makiling with an elevation of 400 m asl. The dominant soil type is clayey loam derived from volcanic tuff with andesite and a basalt base.

The original vegetation of the area was selectively logged from 1942 to 1944, after which the forest was allowed to regenerate with little disturbance. Comparison of current vegetation composition with a floral survey conducted 70 years ago suggests that high value dipterocarps were high graded leaving mainly non-dipterocarp species. The species distribution is inverse-J indicating late succession stage of the community. The entire 4-ha site has 3454 tree species and 183 palm species. The dominant tree species are *Celtis luzonica* and *Diplodiscus paniculatus.* Patches of gaps have abundant understorey vegetation and decaying naturally felled trees. The site is one of the remnants of a transitional tropical rain forest of the Philippines.

The study estimated the biomass of the following major C pools: aboveground biomass, belowground biomass, litter and soil. Three 10 × 100 m transects were randomly laid out in the 1-ha portion of the JIRCAS permanent monitoring plot. All sample plots for each type of pool were randomly selected from the three transects. The locations of the samples were marked with plastic straws for easier monitoring purposes.

Aboveground biomass was composed of tree biomass (stem and leaf), understorey and herbaceous vegetation. For tree biomass, complete enumeration of all trees $\geq$ 5 cm DBH (stem diameter at 1.3 m above the ground) was conducted. No destructive sampling was done on trees. DBH and total height were measured. The stem diameter was taken exactly at the same point where previous measurements by JIRCAS were made which were marked with paint. In case tree buttresses are present, DBH was taken at a point above the buttress. Individual tree biomass was obtained using the following allometric equation (Brown 1997):

$$Y = \exp(-2.134 + 2.530 \times \ln D)$$

where

Y = biomass per tree (kg)
D = DBH (cm)

A branch sample weighing about 100 g from the two most dominant tree species (*C. luzonica* and *D. paniculatus*) and the most dominant dipterocarp species (*Parashorea malaanonan*) were taken from the International Rice Research Institute (IRRI) for carbon content analysis.

For understorey vegetation, three 2 × 2 m plots were randomly laid out in each transect. All individual seedlings, saplings and woody species (< 5 cm DBH) were harvested. Fresh weight of leaves, branches and stem were determined in the field. Oven-dry weights of the different plant parts were determined in the Institute of Renewable Natural Resources (IRNR) laboratory. Carbon content analysis of plant tissues was conducted at the IRRI laboratory.

All herbaceous plants were harvested from three 1 × 1 m randomly selected plots and their fresh and over-dry weights determined. Carbon content analysis of plant tissue was also conducted at the IRRI laboratory.

Total aboveground biomass was determined using the formula:

$$\text{Aboveground biomass} = \text{tree biomass} + \text{understorey biomass} + \text{herbaceous biomass}$$

The litter layer of the forest floor was obtained from randomly laid out 50 × 50 cm plots at three locations in each transect. Fresh and oven-dry weights were determined. A 100-g sample of the oven-dried litter was taken for C content analysis at the IRRI Laboratory. Coarse woody debris was assumed to be 10% of the total aboveground biomass (Lugo & Brown 1992).

All fine roots were collected from 100 × 100 × 100 cm pits in each transect. Fresh and oven-dry weights as well as C content of the roots were determined in the laboratory. Soil samples were collected from the same pits where roots were taken for bulk density analysis using the paraffin clod method. Three soil samples were taken at different soil profiles for organic C analysis using the Walkey-Black method (PCARR 1980).

To estimate the rate of carbon sequestration of the forest ecosystem, the data on tree volumes previously collected by JIRCAS on the same site were utilised. However, only stem volume values were available in the data collected in 1992, 1994 and 1996. The DBH data were converted to biomass using the same procedure described above. Then the rate of annual biomass accumulation was calculated using the following formula:

$$\text{Annual biomass accumulation} = (\text{1998 Biomass} - \text{1992 Biomass})/\text{No. of years}$$

Descriptive statistical analyses (mean, standard deviation) were conducted on the data collected.

Results and discussion

Transect characteristics

Table 1 shows the general characteristics of each sample transect. There was high diversity of tree species with 28 to 31 species and 67 to 79 trees per 1000 m^2 transect.

Table 1 Characteristics of sample transects in Makiling Forest Reserve

Transect I Species	No.	Transect II Species	No.	Transect III Species	No.
Aglaia diffusa	2	*Aglaia diffusa*	2	*Aglaia diffusa*	2
Aglaianum meyeri	1	*Annona squamosa*	2	*Ahernia glandulosa*	3
Aphanamixis perrottetiana	1	*Aphanamixis perrottetiana*	1	*Alangium meyeri*	1
Ardisia squamolosa	1	*Celtis luzonica*	21	*Alstonia scholaris*	1
Arthcoarpus blancoi	1	*Chisocheton cuminguianus*	6	*Aphanamixis perrottetiana*	1
Buchanania nitida	1	*Chisocheton pentandrus*	1	*Buchanania nitida*	1
Casearia fuligonosa	1	*Coffea arabica*	2	*Casearia fuligonosa*	1
Celtis luzonica	20	*Danupra*	1	*Celtis luzonica*	21
Chisocheton cuminguianus	6	*Diplodiscus paniculatus*	10	*Chisocheton cuminguianus*	4
Chisocheton pentandrus	2	*Ficus congesta*	2	*Chisocheton pentandrus*	1
Diospyros pyrrhocarpa	1	*Garcinia polyantha*	1	*Dillenia philippinensis*	1
Diplodiscus paniculatus	10	*Horsfieldia obscurinerva*	1	*Dimorphacalyx luzoniensis*	1
Ervatamia pandacaqui	1	*Knema glomerata*	3	*Diplodiscus paniculatus*	5
Gomphandra luzoniensis	1	*Macaranga bicolor*	1	*Ficus congesta*	3
Lagerstroemia speciosa	2	*Malatapai*	2	*Ficus variegata*	1
Laportea luzoniensis	1	*Miscellaneous*	1	*Gymnacanthera paniculata*	2
Litsea garcinae	1	*Myristica philippensis*	3	*Knema glomerata*	1
Mastrixia philippinensis	1	*Naring*	1	*Koordersiodendron pinnatum*	1
Microcos stylocarpa	1	*Neotrewia cumingii*	1	*Laportea luzoniensis*	1
Neolitsea villosa	1	*Nepheleum mutabile*	2	*Mastrixia philippinensis*	1
Neolitsea cumingii	2	*Paitan*	1	*Microcos stylocarpa*	1
Nepheleum rambutan-ake	1	*Palaquim philippinense*	1	*Palaquim philpinensis*	1
Nepheleum mutabile	1	*Parashorea malaanonan*	1	*Planchonia spectabilis*	1
Palaquim foxwortyii	1	*Pterocymbium tinctorium*	5	*Psycotria luzoniensis*	1
Parashorea malaanonan	1	*Pygeum vulgare*	2	*Pterocymbium tinctorium*	3
Pisonia umbellifera	2	*Semecarpus gigantifolia*	1	*Saurouia latebractea*	1
Sapium luzonicum	1	*Shorea guiso*	1	*Strombosia philippensis*	3
Shorea guiso	1	*Strombosia philippinensis*	1	*Syzigium curranii*	1
Strombosia philippinensis	1	*Syzigium nitidum*	2	*Terminalia foetedissima*	2
Syzigium nitidum	2				
Pterocymbium tinctorium	1				
Total number of species	31		28		28
Total number	70		79		67
DBH (cm)	5.0–116		5.2–107		5.0–72.6
Height (m)	2.5–24		2.5–24		3.0–18
Height at 1st branch(m)	1.5–18		1.0–19		1.0–14

Biomass production

The mean biomass density in 1998 was equivalent to 576 Mg ha^{-1} (Table 2). Of these, 93% was accounted for by tree biomass. This implies that changes in tree cover will have the most effect on the total biomass of the forest. This is consistent

Table 2 Biomass density of a secondary forest in Makiling Forest Reserve (Mg ha^{-1})

	Transect			Mean	SE
	I	II	III	biomass density	
Tree	873.73	415.6	324.81	538.05	294.23
Understorey	19.53	5.81	1.49	8.94	9.42
Herbaceous	0.1	0.5	0.07	0.22	0.24
Total aboveground	893.36	421.91	326.37	547.21	303.55
Litter	4.99	4.43	5.90	5.11	0.74
Root	21.28	27.23	23.55	24.02	3.00
Total	919.63	453.57	355.82	576.34	301.29

with the findings of other researchers. In general, understorey biomass accounts for less than 2% of the total biomass of closed forest formations (Brown & Lugo 1984). For example, in Sri Lanka, Brown *et al.* (1991) reported that larger trees (> 50 cm DBH) already account for 40 to 50% of stand biomass.

There is very limited information on biomass density of natural forests in the Philippines. In Mindanao island, Kawahara *et al.* (1981) reported a much lower biomass density of 261.8 Mg ha^{-1} for a similar type of forest using destructive sampling. However, in Leyte island, a similar forest type had 446 Mg ha^{-1} using the same allometric equations (Lasco *et al.* 1999). The above results are not strictly comparable since they were obtained at various locations in the Philippines. Despite this limitation, it seems disturbing to note that results using global allometric equations tend to be higher than that of destructive sampling. In developing countries where resources are limited it would be expected that most forest C estimates may rely on allometric equations derived from literature. This practice may result in overestimation of actual C contents. Thus, the results of this study should be used as preliminary estimates of forest C pending data from destructive sampling.

In terms of national greenhouse gas inventories, the values obtained here were generally higher than previously used biomass densities for the Philippines. Lasco (1998) used 175 Mg ha^{-1} while Lasco and Pulhin (2000) used 258.4 Mg ha^{-1} to estimate national C stocks of secondary forests. The default value recommended by the 1996 Intergovernmental Panel on Climate Change Revised Guidelines (Brown *et al.* 1996) for national greenhouse gas inventory is 275 Mg ha^{-1} for tropical forests in wet regions of insular Asia which is lower than the results of this study. However, the same guidelines indicate that old-growth forests in the Philippines have a range of 370 to 520 Mg ha^{-1} which is comparable to our results. This suggests that the Makiling forest can be considered an old-growth forest in terms of biomass density. This is consistent with the observation of Luna *et al.* (1999) that these forests are in late successional stage. They have apparently had time to recover much of their biomass since they were high graded in the 1940s. The results imply that for countries without primary data, the default values could be used as an initial approximation of the biomass present in tropical forests.

Understorey tree biomass comprised only 2% of total biomass (Table 2). In Leyte island, a similar forest type comprised 1% of total biomass (Lasco *et al.* 1999). The biomass of herbaceous vegetation in the Makiling forest was 0.2 Mg ha^{-1}. This is relatively small compared with the results (1.7 Mg ha^{-1}) of Kawahara *et al.* (1981) in Mindanao island. This may be attributed to the presence of a thicker understorey layer of woody species in the Makiling forest which reduced light availability in the forest floor.

The necromass layer in Makiling forest was 5.1 Mg ha^{-1} (Table 2) which is lower (12 Mg ha^{-1}) than a similar forest in Leyte island (Lasco *et al.* 1999). Fine root biomass was about 4% of total biomass which is comparable (3%) to the Leyte forest (Lasco *et al.* 1999). Typically, root biomass in tropical forests is 25% of total biomass which is much higher than the results we obtained (Moura-Costa 1996). This could be due to the fact that tap roots and other large roots were not included in this study.

In comparison with other land cover types in the Philippines where data are available, the Makiling forest has a higher biomass than tree plantations. Tree plantations such as *Gmelina arborea, Paraserianthes falcataria* and *Sweitenia macrophylla* in various parts of the Philippines have been reported to have a biomass ranging from 67 to 261 Mg ha^{-1} (Kawahara *et al.* 1981, Lasco & Pulhin 2000).

Carbon stocks

The C content (Table 3) of the various plant tissues in Makiling forest ranged from 27% (herbaceous) to 44% (wood). These value are lower than the generally used default value in national greenhouse gas inventories for forest biomass which is 50% (Brown *et al.* 1996). This new data could be used in the national greenhouse gas inventory of Philippine forests to minimise uncertainty.

Table 3 Carbon content and mean carbon density of a secondary forest in Makiling Forest Reserve

	C content (%)	Carbon density (Mg C ha^{-1})
Tree	44	236.74
Understorey	40	3.58
Herbaceous	27	0.06
Total aboveground		240.38
Litter	38	1.94
Roots	39	9.37
Soil	1.56	166.07
Total		417.76

In 1998, total C storage of the Makiling forest ecosystem amounted to 418 Mg C ha^{-1}, of which 240 Mg C ha^{-1} were found in aboveground biomass (Table 3). These values are in general agreement with the range of values reported worldwide (Brown *et al.* 2000). For example, forest protection projects are estimated to have up to 252 Mg C ha^{-1} in presumable aboveground biomass. C sequestration projects can have up to 440 Mg C ha^{-1}.

Among the various C pools (Table 3), the largest fraction was accounted for by tree biomass (57%). On the other hand, soil organic C (SOC) comprised 40% of total C of the forest. Together with the roots, belowground C storage in soil amounted to 42% of total C storage. This finding is lower than the general observation that about $\frac{2}{3}$ of terrestrial C is found below ground (Bolin & Sukumar 2000). Due to its slow turnover, belowground C can be maintained longer. Thus, the soil is a significant storage pool of C in the forest ecosystem. However, this pool could be easily lost if the forest is destroyed since SOC is generally dependent on the vegetative cover. The soil C data obtained in this study is a little higher than the International Panel for Climate Change (IPCC) default value for volcanic soils (130 t C ha^{-1}) (Brown *et al.* 1996).

Total C stored in coarse wood debris was not determined in this study but could be significant since it was observed that naturally felled logs were present in the site. These decaying logs which were 10 to 110 cm in diameter could be as much as 8.5% of total aboveground biomass (Lasco *et al.* 2000).

Secondary forests in the Makiling reserve cover 2263 ha out of a total area of 4244 ha. Using the data obtained in this study, these forests have a total C stocks of 950 822 Mg C. However, this estimate is preliminary because the C density was obtained only from a small proportion of plots.

Carbon sequestration

In terms of biomass change, the Makiling forest accumulated 12 Mg ha^{-1} $year^{-1}$ from 1992 to 1998 (Figure 1). This is higher than that reported by Kawahara *et al.* (1981) for the Mindanao forest cited earlier (5.2 Mg ha^{-1} $year^{-1}$). The C sequestration rate was calculated to be 5 Mg C ha^{-1} $year^{-1}$ (Figure 1). This value fell within the range of IPCC default values (3–11 Mg C $year^{-1}$) for tropical forests in insular Asia (Brown *et al.* 1996). Relative to other landuses in the Philippines, secondary forests have lower sequestration rates than tree plantations (6.9 Mg ha^{-1} $year^{-1}$) but higher than agroforestry farms (2.7 Mg ha^{-1} $year^{-1}$) (Lasco & Pulhin 1998).

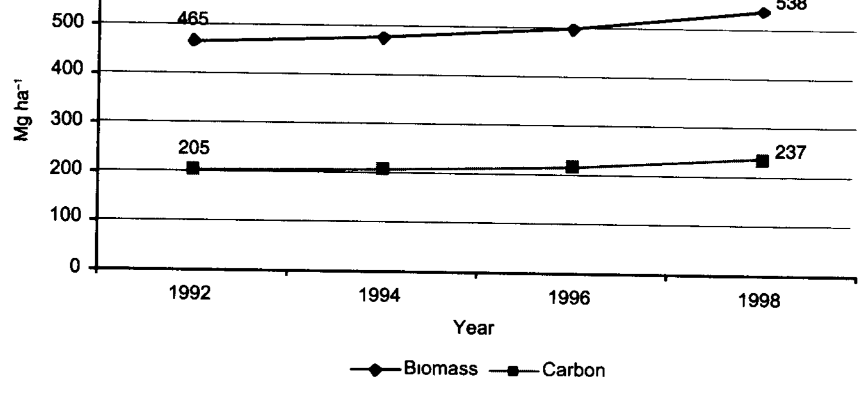

Figure 1 Tree biomass and carbon density

Implications

As implied earlier, the main usefulness of the results of this study is in the conduct of national greenhouse gases inventory. At present, the Philippines is relying mainly on IPCC default values. C storage and sequestration rates of secondary forests obtained in this study will help reduce error in national estimates as mandated by the UN Framework Convention on Climate Change (UNFCCC). However, there is a need to expand the database to include forest areas in other parts of the Philippines to improve the accuracy of national estimates.

At present there are 2.7 M ha of secondary forests in the Philippines (FMB 1997). Using the C density obtained in this study, these forests harbour 1134 Mt C. This is higher than the earlier estimates which were based on secondary information (253 and 298 Mt respectively) (Lasco 1998, Lasco & Pulhin 1998). Moreover, earlier estimates do not include SOC. Using the C sequestration rate obtained in this study, Philippine secondary forests could sequester 14 Mt C year^{-1}. This estimate is higher than the earlier estimate (8 Mt C year^{-1}) of Lasco (1998) which is based on literature review.

In addition, the data obtained in this study could also help quantify C emissions due to secondary forest logging and deforestation. In the Philippines, secondary forests could be suffering most from land cover and landuse change stress. The logging ban in 1992 has shifted logging to second-growth forests. Consequently, their biomass and C stored could be declining in proportion to the rate of harvest estimated at 0.16 M m^3 in 1997 (FMB 1997). In addition, most of the deforestation is likely to be destroying secondary forests because they are more accessible due to the presence of logging roads. This loss is currently estimated at 100 000 ha year^{-1}. Using the carbon density we obtain, this is equivalent to a loss of 25.4 Mt C year^{-1}.

Finally, the Kyoto Protocol has given hopes that tropical forestry options could be used to mitigate C specifically under the Clean Development Mechanism. Due to their rapid growth, there are fears that natural tropical forests could be replaced with fast-growing tree plantations. This study has shown that second-growth forests contain more biomass and C than tree plantations. Thus, cutting natural forests may mean losing more C than would be stored in tree plantations. In addition, the data from this study will be useful in quantifying C benefits of Clean Development Mechanism projects involving secondary forests.

Conclusions

For the first time in the Philippines, this study attempted to quantify the C storage and sequestration of a secondary tropical forest in the Philippines. The study revealed that a secondary forest in Mount Makiling can store 418 Mg C ha^{-1} and sequester 5 Mg C ha^{-1} year^{-1}. The main limitation of the study was its reliance on allometric equations and the limited number of plots used. It is recommended that similar studies be conducted in other areas of the Philippines to obtain a more comprehensive estimate of natural forest C stocks and rate of sequestration.

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References

BROWN, S. 1997. Estimating biomass and biomass change of tropical forest: a primer. Forestry paper 134. Food and Agriculture Organisation, Rome.

BROWN, S., GILLESPIE, A. J. R. & LUGO, A. E. 1991. Biomass of tropical forests of south and southeast Asia. *Canadian Journal of Forestry Research* 21: 111–117.

BROWN, S. & LUGO, A. E. 1984. Biomass of tropical forests: a new estimate based on forest volumes. *Science* 2233: 1290–1293.

BROWN, S., MASERA, O. & SATHAYE, J. 2000. Project-based activities in Watson, R. T. *et al.* (Eds.) *Land Use, Land-Use Change, and Forestry.* Cambridge University Press, Cambridge.

BROWN, S., SATHAYE, J., CANNEL, M. & KAUPPI, P. 1996. Management of forests for mitigation of greenhouse gas emissions. In Watson, R. T. *et al.* (Eds.) *Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses.* Cambridge University Press, Cambridge.

BOLIN, B. & SUKUMAR, R. 2000. Global perspective. In Watson, R. T. *et al.* (Eds.) *Land Use, Land-Use Change and Forestry.* Cambridge University Press, Cambridge.

CIFOR (CENTER FOR INTERNATIONAL FORESTRY RESEARCH). 2000. Towards sustainable management and development of tropical secondary forests in Asia: the Samarinda Proposal for Action. Background paper for the Center for International Forestry Research (CIFOR) satellite meeting. IUFRO World Forestry Congress 2000. 8 August 2000. Kuala Lumpur.

FMB (FOREST MANAGEMENT BUREAU). 1997. *Philippine Forestry Statistics.* Department of Environment and Natural Resources (DENR), Quezon City.

KAWAHARA, T., KANAZAWA, Y. & SAKURAI, S. 1981. Biomass and net production of man-made forest in the Philippines. *Journal of Japan Forestry Society* 63: 320–327.

LASCO, R. D. 1998. Management of Philippine tropical forests: implications to global warming. *World Resource Review* 10: 410–418.

LASCO, R. D., LALES, J. S., GUILLERMO, I. Q. & ARNOUEVO, T. 1999. CO_2 absorption study of the Leyte geothermal forest reserve. Report of a study conducted for the Philippine National Oil Company. College of Forestry and Natural Resources, College.

LASCO, R. D. & PULHIN, F. B. 1998. *Philippine Forestry and Carbon Dioxide (CO_2) Sequestration: Opportunities for Mitigating Climate Change.* University of the Philippines, College.

LASCO, R. D. & PULHIN, F. B. 2000. Forest land use change in the Philippines and climate change mitigation. *Mitigation and Adaptation to Climate Change Journal* 5: 81–97.

LASCO, R. D., PULHIN, F. B., VISCO, R. G., RACELIS, D. A., GUILLERMO, I. Q. & SALES, R. F. 2000. Carbon stocks assessment of Philippine tropical forest ecosystems. Paper presented at the Science-Policy Workshop on Terrestrial Carbon Assessment for Possible Carbon Trading under CDM Projects. 28–29 February 2000. Bogor.

LASCO, R. D., VISCO, R. G. & PULHIN, J. M. 2001. Secondary forests in the Philippines: formation and transformation in the 20th century. *Journal of Tropical Forest Science* 13(4): 652–670.

LUGO A. E. & BROWN, S. 1992. Tropical forests as sinks of atmospheric carbon. *Forest Ecology and Management* 54: 239–255.

LUNA, A. C., OSUMI, K., GASCON, A. F., LASCO, R. D., PALIJON, A. M. & CASTILLO, M. L. 1999. The community structure of a logged-over tropical rainforest in Mount Makiling Forest Reserve, Philippines. *Journal of Tropical Forest Science* 11(2): 446–458.

MOURA-COSTA, P. 1996. Tropical forestry practices for carbon sequestration. In Zchulte, A. & Schone, D. (Eds.) *Dipterocarp Forest Ecosystems: Towards Sustainable Management.* World Scientific, Singapore.

MURDIYARSO, D. 1996. Inventory of Asian GHG emissions and sinks in 1990. In Bratz *et al.* (Eds.) *GHG Emission Inventories*. Kluwer Academic, Dordrecht.

MYERS, N. 1996. The world's forests: problems and potentials. *Environmental Conservation* 23: 156–168.

PCARR (PHILIPPINE COUNCIL FOR AGRICULTURE AND RESOURCES RESEARCH). 1980. *Standard Methods of Analysis for Soil, Plant, Tissue, Water and Fertilizer.* PCARR, Los Banos.

TREXLER, M. C. & HAUGEN, C. 1994. *Keeping it Green: Tropical Forestry Opportunities for Mitigating Climate Change.* World Resources Institute, Washington, D. C.

WATSON, R. T., NOBLE, I. R., BOLIN, B., RAVINDRANATH, N. H., VERADO, D.J. & DOKKEN, D.J. (Eds.). 2000. *Land Use, Land-Use Change, and Forestry.* Cambridge University Press, Cambridge.