AIACC Working Papers

Carbon Budgets Of Terrestrial Ecosystems in the Pantabangan-Carranglan Watershed[1]

R.D. Lasco, F.B. Pulhin, R.V.O. Cruz, J.M. Pulhin and S.S.N. Roy

AIACC Working Paper No.10
June 2005

*Direct correspondence to Rodel D. Lasco
(rlasco@laguna.net)

An electronic publication of the AIACC project available form www.aiaccproject.org

[1] This paper reports on research supported in part or in whole by grant number AS21 from Assessments of Impacts and Adaptations to Climate Change (AIACC), a joint project of START, the Third World Academy of Sciences, and the UN Environment Programme. Comments are welcome and should be sent to the corresponding author.

AIACC Working Papers, published on-line by Assessments of Impacts and Adaptations of Climate Change (AIACC), is a series of working papers produced by researchers participating in the AIACC project. Full papers published in *AIACC Working Papers* have been peer reviewed and accepted for publication as being (i) fundamentally sound in their methods and implementation, (ii) informative about the methods and/or findings of new research, and (iii) clearly written for a broad, multi-disciplinary audience. Abstracts of selected papers from the AIACC project that have been published in peer-reviewed journals are also published in the working paper series. The purpose of the series is to circulate results and descriptions of methodologies from the AIACC project and elicit feedback to the authors. Because many of the papers report preliminary results from ongoing research, the corresponding author should be contacted for permission before citing or quoting papers in this series.

The AIACC project is funded primarily by a grant from the Global Environment Facility. The U.S. Agency for International Development, the Canadian International Development Agency and the U.S. Environmental Protection Agency provide additional funding for the project. The project is co-executed on behalf of the United Nations Environment Program by the global change **S**ys**T**em for **A**nalysis, **R**esearch and **T**raining (START) and the Third World Academy of Sciences. AIACC seeks to enhance capabilities in the developing world for responding to climate change by building scientific and technical capacity, advancing scientific knowledge, and linking scientific knowledge to development and adaptation planning. AIACC supports 24 regional assessments in Africa, Asia, Latin America and small island states with funding, mentoring, training and technical support. The assessments are active in 46 developing countries and engage approximately 300 developing country scientists and students, 40 developed country scientists, and institutions in both the developing and developed world.

For more information about the AIACC project, and to obtain copies of other papers published in *AIACC Working Papers*, please visit our website at **www.aiaccproject.org**.

CARBON BUDGETS OF TERRESTRIAL ECOSYSTEMS IN THE PANTABANGAN-CARRANGLAN WATERSHED[2]

R.D. Lasco, F.B. Pulhin, R.V.O. Cruz, J.M. Pulhin and S.S.N. Roy
Environmental Forestry Programme
College of Forestry and Natural Resources
University of the Philippines
College, 4031 Laguna, Philippines
(Correspondence: rlasco@laguna.net)

ABSTRACT

Climate change is predicted to affect forest ecosystems, but one of the uncertainties yet to be resolved is its impact on their carbon budgets. This study provides baseline information on the carbon stocks of the Pantabangan-Carranglan Watershed (PCW), in preparation for impacts and vulnerability studies.

Current carbon stocks in above-ground biomass, necromass, and soil were determined using field measurements and laboratory techniques, while total carbon budgets over time of natural forest ecosystem were simulated using the CO_2-Fix Model.

The study shows that natural forests have a carbon density of 300 (using the Powerfit equation) and 563 MgC/ha in aboveground biomass and necromass (using the Brown (1997) equation). Brushlands and tree plantations have lower carbon densities (generally less than 200 MgC/ha), while grasslands have less than 20 MgC/ha. The total above-ground carbon stock of the whole watershed is estimated to range from 4,800 to 8,900 MgC, depending on the biomass allometric equation used.

The results of simulation showed that while carbon in forest biomass is increasing over time by about 50 MgC per century in the PCW, the soil organic carbon was declining by roughly a similar amount. Thus, overall, the total carbon density remains stable over time after an initial decrease.

The study highlights the potential of the watershed for carbon sequestration through tree establishment in open areas.

1. INTRODUCTION

Climate change is one of the primary concerns of humanity today. The most recent IPCC assessment report concludes that there is strong evidence that human activities

---

[2] This paper reports on research supported in part or in whole by grant number AS21 from Assessments of Impacts and Adaptations to Climate Change (AIACC), a joint project of START, the Third World Academy of Sciences, and the UN Environment Programme. Comments are welcome and should be sent to the corresponding author.

have affected the world's climate (IPCC 2001). The rise in global temperatures has been attributed to emission of greenhouse gasses, notably CO_2 (Schimell et al. 1996).

There is great interest on the role of terrestrial ecosystems in the global carbon cycle. It is estimated that about 60 Pg C is exchanged between terrestrial ecosystems and the atmosphere every year, with a net terrestrial uptake of 0.7 ±1.0 Pg C (Schimel et al. 1996). The world's tropical forests, which cover 17.6 M km^2, contain 428 Pg C in vegetation and soils (Watson et al. 2000). However, land use change and forestry (LUCF) activities, mainly tropical deforestation, are significant net sources of CO_2, accounting for 1.6 Pg/yr out of the total anthropogenic emissions of 6.3 Pg/yr (Houghton et al. 1996; Watson et al. 2000).

Philippine forest ecosystems have likewise been a source and sink of carbon. From the 1500s to the modern era, it is estimated that deforestation has contributed 3.7 Gt C to the atmosphere (Lasco 1998). Of this amount, 70% (2.6 Gt) was released this century alone. However, present land-use cover also absorbs carbon through regenerating forests and planted trees. The vast areas of degraded land in the Philippines in fact offer great potential for carbon sequestration through rehabilitation activities such as reforestation and agroforestry.

In the last five years, several studies have investigated the carbon stocks of forest ecosystems and other land cover types in the Philippines (e.g., Lasco et al. 2001; Lasco et al. 2000). However, the carbon stocks in the Pantabangan-Carranglan Watershed (PCW) have not been adequately characterized. Thus, the main objectives of this study were to quantify the carbon stocks of the various land cover types in the Pantabangan watershed. Specifically, the study aimed to:

- Determine the biomass and carbon density of the forest ecosystems and other land cover types in the Pantanbangan-Carranglan Watershed;
- Simulate the carbon stocks of natural forest ecosystems using the CO_2-Fix model; and
- Assess the capacity of the watershed to mitigate climate change through carbon sequestration.

2. METHODS

2.1 Site Description

This description of the study site below was partly based on the "Watershed Atlas of Philippine Watersheds" (Bantayan et al. 2000), as well as our own primary data collection activities.

(a) Geographical location

The Pantabangan-Carranglan Watershed lies between 15º 44' to 16º 88' north latitude and 120º 36' to 122º 00' east longitude (**Fig. 1**). It is bounded in the north, northwest and northeast by the Caraballo Mountain Ranges, and in the south, southeast, and southwest by the Sierra Madre Ranges.

The Municipality of Pantabangan is about 176 km away from Manila, about 59 km away from Cabanatuan City (the capital of Nueva Ecija), and about 38 km away from the nearby City of San Jose.

(b) Climate

The Pantabangan-Carranglan Watershed belongs to Philippine Climatic Type I. This type has two pronounced seasons: it is dry from December to April and wet during the rest of the year. A small part of the watershed which is near the boundary of the sub-province of Aurora falls under Climatic Type II, which is characterized by having no dry season and very pronounced maximum rainfall from November to January. Total annual rainfall from four rainfall stations ranges from 1,777 mm to 2,271 mm.

Air temperature in the Pantabangan-Carranglan Watershed from 1961-1999 is fairly uniform. The mean monthly temperature ranges from 25.7º C to 29.5º C. The lowest and highest temperatures in the watershed occurred in January 1963 at 23.8º C and May 1970 at 30.6º C, respectively.

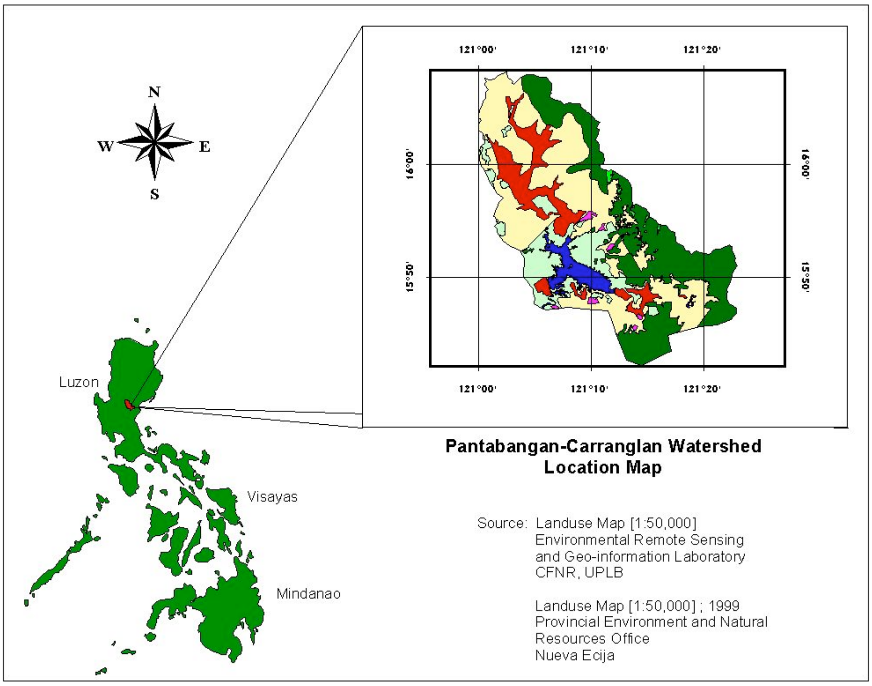

Fig. 1 Location map of the Pantabangan-Carrranglan Watershed

The predominant wind direction in the watershed is east to northeast, with a speed of 2 meters per second (mps). The area experiences windy days from December to February. The watershed is within the typhoon belt, with most typhoons occurring between September and October.

(c) Topography and geology

The PCW has a complex land configuration. Topography ranges from the nearly level to the undulating and sloping to the steep, hilly, and rugged. The highest peaks are 1,650 and 1,410 masl, respectively. The PCW has a mean slope of 40%.

Areas on the surrounding upland, hills and mountains within the watershed limit are underlain by intrusive and extrusive igneous rocks, and by sedimentary rock materials. The diorite and quartz materials that belong to the middle and upper miocene age extend to the northwestern edge and towards the Canili-Diayao watershed.

The Caraballo Mountain and Mt. Deugonog areas are made up of metavolcanic minerals. The northwestern part of the watershed extending towards the south and southeastern part, including Mt. Carranglan, Maluyan, and Pantabangan, features consolidated conglomerates with interlayer of sandstone, mudstone and shade of upper Miocene age to Pliocene age can be found.

(d) Soil

Soils at PCW are derived mostly from weathered products of metavolcanic activities and diorite. Surface soil textures range from silty clay loam to clay loam to clay. Soils in the watershed are classified into four types: the Annam, Bunga, Guimbaloan, and Mahipon. The Annam soil type is primarily a mountain soil derived from weathered igneous rocks. It is moderately deep from 50 to 130 centimeters. The dominant soil color is brown and clayey, And it is recommended for tree and forest crops. At the start of the plantation, this soil may not need liming but eventually will develop higher acidity if nitrogen fertilizer is applied.

Guimbaloan soil occurs on moderately sloping or undulating terrain, and on hilly to steep hilly and mountainous relief. This type of soil is derived from basalt and metavolcanic materials. It is predominantly clayey, about 50 cm deep, and well-drained. The surface soil is dark clay to dark grayish brown with manganese concentrations.

The Bunga soil type occurs on a level to nearly collu-alluvial landscapes. The dominant color is dark gray brown with strong brown and light gray mattles. It has a clayey texture, with a depth of 147 to 155 cm, and is moderately well drained.

Mahipon, which usually occurs on level to nearly level collu-alluvial landscape, is derived from quartenary (one million) alluvial/tallus deposits and terrace gravels. The soil is clayey in texture but has a restricted internal drainage. It is moderately acidic.

(e) Land cover and land use

As of 1999, the major land cover types in the PCW are natural forests (secondary), grasslands, reforestation areas, and A and D (alienable and disposable) lands (**Fig. 2**). Of these, the grasslands occupy the largest portion, followed by secondary forests (**Fig. 3**). The forest cover in the watershed is predominantly secondary forest. Grazing and reforestation activities are conducted in open and grassland areas covered with cogon (*Imperatra cylindrica*) as predominant vegetation.

Rice, vegetables, corn, cassava, onion and other agricultural crops are grown on cultivated lands (A and D; ISF, and occasionally, grassland areas). Rice, onions and vegetables are the primary crops raised on the lowland areas of the municipality of Carranglan; most of the areas devoted for rice production are rainfed. Water pumped from wells and run-of-the-river irrigate some areas for rice production. Other crops, like banana, cassava, sweet potato, and corn, are normally grown on swidden farms.

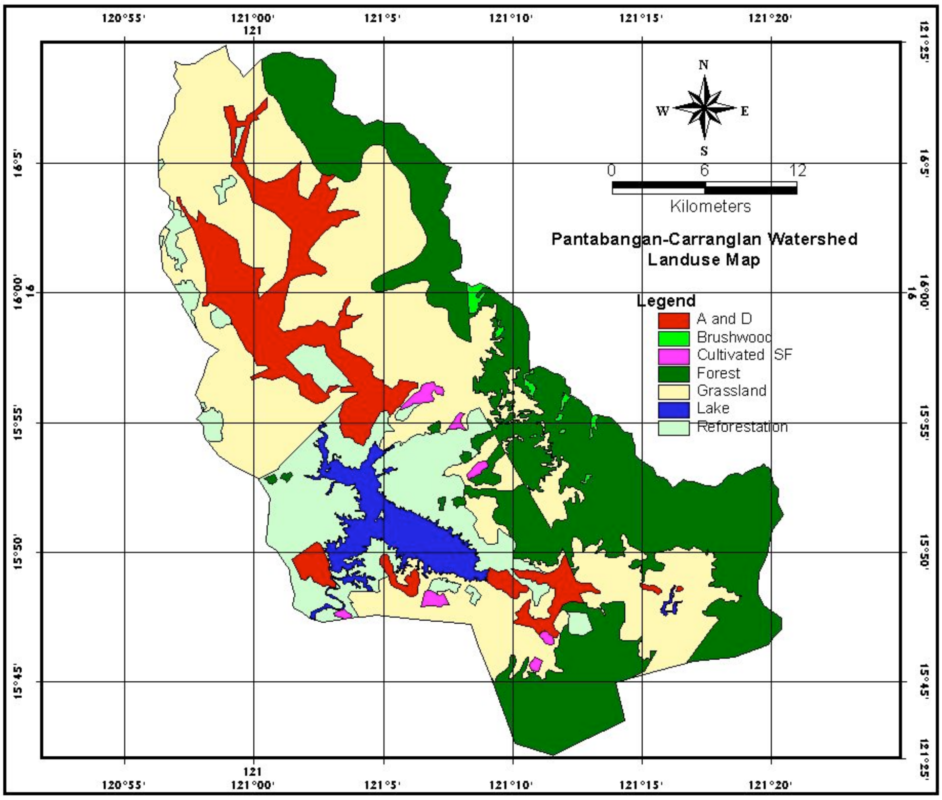

Fig. 2 Land use map of the Pantabangan-Carranglan Watershed, Philippines

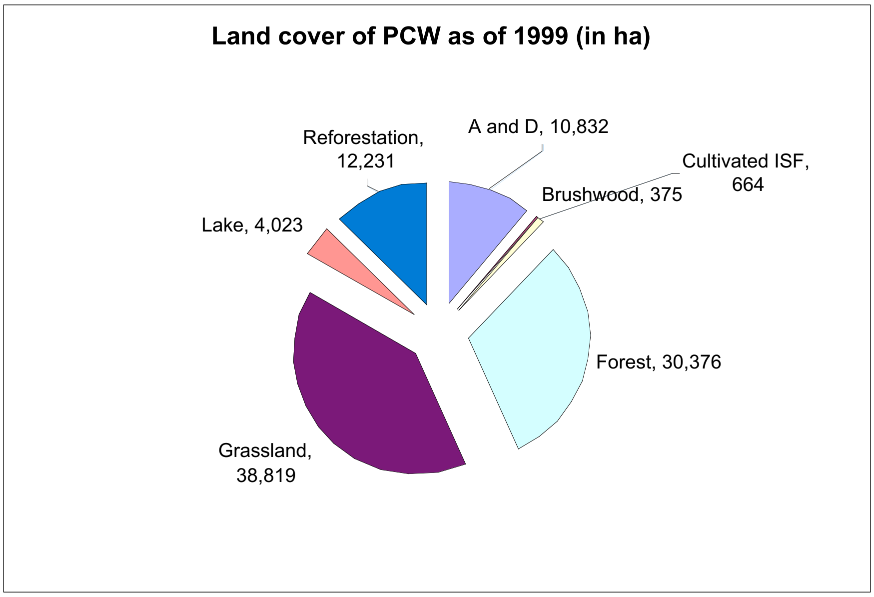

Fig. 3. Area of each land use in the Pantabangan-Carranglan Watershed, Philippines

2.2 Field Measurements of Biomass and Carbon Analysis

2.2.1 Sampling plots and field measurements

1. Natural forests

This study used the point-centered quarter method (Mueller-Dombois and Ellenberg 1974), which) is a plotless method of sampling that is designed to determine the number of trees per unit area that can be calculated from the average distance between the trees.

Four parallel lines were randomly laid out, each comprised of five sampling points with a 50-meter distance from each other. Each sampling point was divided into quarters by running an imaginary cross line. One of the lines is the compass direction and the other is the line perpendicular to it and passing through the sampling point. In each quarter, the distance from the sampling point to the nearest tree encountered was recorded. However, it should be noted that species name, diameter at breast height, and height of the trees with dbh of ≥ 10 cm were the only ones recorded (Figure 4) .

2. Brushland areas

For the brushland areas, ten transects measuring 10m x 10m were established.

3. Tree plantations

In plantation areas, the study used the transect method. Two 5m x 40m plots were established in each plantation type. If trees with dbh > 50 cm are present, whether they are included in the sample plots or not, an additional sample of 20m x 100m was established. In plots measuring 5m x 40m, all trees with dbh of >5 cm are measured and identified, while in plots 20m x 100m, only trees with a diameter >30 cm are measured.

2.2.2 Tree biomass

All trees inside the established transects (brushland and tree plantation) and in the five sampling points along the parallel line (natural forests) were enumerated. The following data were obtained: species name, dbh (stem diameter at 1.3 m aboveground), total height and height at first branch.

2.2.3 Understorey and herbaceous vegetation

Four frames measuring 1m x 1m were randomly laid-out near the sampling points. All herbaceous and woody vegetation (less than 5 cm dbh) inside the frames was collected. The fresh weight of the samples was determined after which they were oven-dried.

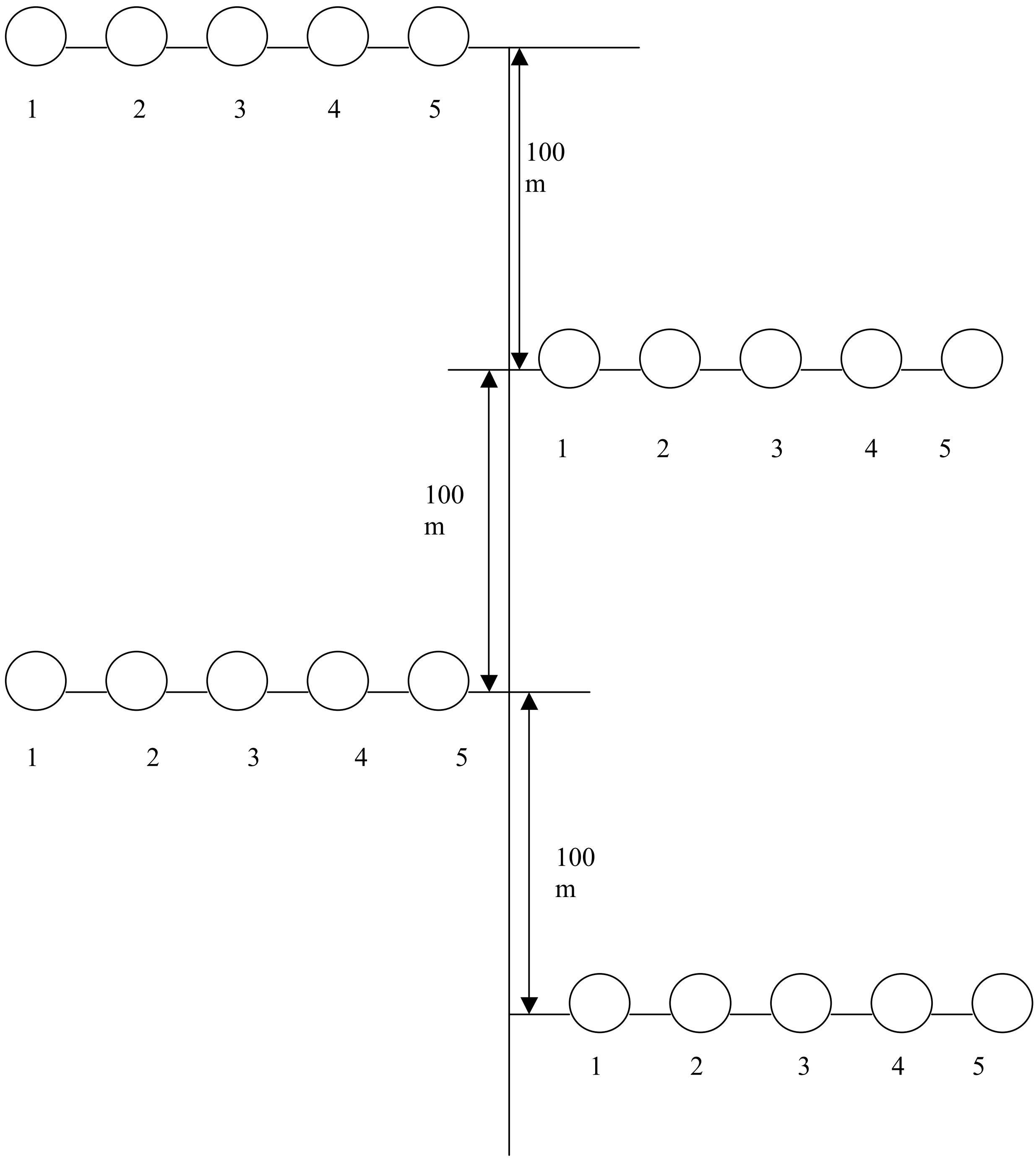

Figure 4. Field layout using the plotless method

.2.4 Standing litter

Inside the same sampling frames used for measuring understorey and herbaceous vegetation, a 0.5m x 0.5m transect was established for litter collection. Total fresh weight of all the samples was taken, after which about 300 grams were reserved for air- and oven-drying. Samples were dried inside the oven with a temperature of ± 102°C for at least 48 hours or until the weights of the samples become constant.

Coarse litter was collected in the 0.5m x 0.5m quadrat within the understorey sample plot. Similar to understorey, a sub-sample of about 300 g was taken for oven-drying and carbon content analysis.

2.2.5 Grassland

Ten 1m x 1m sampling frames were laid on the ground. Grasses inside the sampling frames were harvested for biomass determination. Similarly to understorey and litter, fresh samples were weighed and a sample of 300 g was set aside for oven drying.

2.2.6 Soil organic carbon

Soil samples were collected within the sample plots of second growth, brushland and grassland areas at 30 cm depth. These samples were air-dried and taken to the Soils Laboratory of the Soil Science Department of the College of Agriculture, University of the Philippines, Los Baños for analysis.

For bulk density determination, samples were collected using a ring metal with height of 10 cm and diameter of 3 cm at 20-30 cm depth.

2.2.7 Biomass calculation

Tree biomass was calculated using the following allometric equation (Brown 1997):

$$Y\ (kg) = EXP(-2.134+2.53*LN(D)$$

Biomass values for litter, understorey and grass were calculated using the following formula:

$$ODWt = \frac{TFW - (TFW*(SFW-SODW))}{SFW}$$

where,

ODW = total oven dry weight
TFW = total fresh weight
SFW = sample fresh weight
SODW = sample oven-dry weight

Table 1. Characteristics of study plots in natural forests

Study Plot	Location	Elevation (masl)	No. of Species	Dbh range (cm)	Total Height (m)
STRIP 1			9	10-59	12-27
STRIP 2			13	4-20	11-27
STRIP 3			17	12-51	14-25
STRIP 4			13	10-38	10-23

Table 2. Characteristics of study plots in brushland areas

Study Plot	Location	Elevation (masl)	No. of Species	Dbh range (cm)	Total Height (m)
BR-1			1	8-9	5
BR-2			1	7	4
BR-3			2	5-9	4-5
BR-4			2	5-8	3-6
BR-5			2	5-6	3-5
BR-6			1	20	7
BR-7			2	14-18	3-4
BR-8			1	9	4
BR-9			3	7-10	4-5
BR-10			1	7-15	3-4

Table 3. Characteristics of study plots in plantation areas

Study Plot	Location	Elevation (masl)	No. of Species	Dbh range (cm)	Total Height (m)
Narra 20 x 100 5 x 40 5 x 40	N15°48'43.8" E121°03'14.2	**412**	 2 5 2	 30-43 5-29 5-27	 17-25 1-20 4-22
Mixed Plantation 20 x 100 5 x 40 5 x 40			 3 7 5	 30-67 5-25 8-29	 7-24 4-18 1-18
Mahogany 5 x 40 5 x 40			 2 2	 5-26 5-26	 2-15 4-12
Ipil-ipil 5 x 40 5 x 40			 2 2	 5-24 5-19	 5-17 6-13
Gmelina 20 x 100 5 x 40			 2 2	 30-52 10-29	 7-31 6-10
Eucalyptus 20 x 100 5 x 40 5 x 40			 2 2 1	 31-33 14-28 11-19	 7-13 3-12 2-12
Benguet Pine 5 x 40 5 x 40			 1 4	 5-23 39-74	 3-18 6-15
Acacia 5 x 40 5 x 40	N 15°45'44" E121°04'19.8	567	 5 4	 6-29 5-28	 4-24 4-26

2.3 Computer Simulation Using CO_2-Fix Model

The carbon density of the various land cover types over time will be simulated using the CO_2 Fix model, a model which has been used in previous studies (Nabuurs et al. 2001). It is a tool which quantifies the carbon stocks and fluxes in the forest, soil organic matter compartment, and the resulting wood products at the hectare scale. The latest version of the model was improved to include the following features (Nabuurs et al. 2001):

- the ability to simulate multi-species and uneven aged stands in multiple cohorts (defined as groups of individual trees or groups of species which are assumed to exhibit similar growth and which may be treated as single entities within the model);
- the ability to parameterize the growth also by stand density;
- the ability to deal with inter-cohort competition;
- allocation, processing lines, and end-of-life disposal of harvested wood;
- soil dynamics;
- the ability to deal with a wider variety of forest types, including agroforestry systems, selective logging systems, and post harvesting mortality; and
- output viewing charts.

In modeling the growth of the stand, two basic approaches could be used:

- tree growth as a function of tree or stand age, and
- tree growth as a function of tree size or stand basal area, volume, or biomass

Described below are the main components of the model from CO_2 Fix V 2.0 (Nabuurs et al. 2001).

1. Biomass Components

The model had been parameterized to Pantabangan condition. Where the age of the stand is known, biomass growth is in the form of current annual increment (CAI) of stemwood volume, in m^3 ha^{-1} yr^{-1}. Moreover, biomass of other stand components such as branches, foliage and roots was also calculated as an additional fraction to the growth rate of the tree biomass. The carbon content of the wood components and wood density of the sample species were input.

2. Turnover rate

Data on the annual rate of mortality (turnover) of the biomass components was used, while the stem turnover rate was described by the mortality rate of the stand. The mortality of each species was described as being due to either senescence or old age and density-related competition, and was differentiated from the mortality caused during and after logging operations. It is assumed that all trees have a maximum age, and the annual mortality increases when the age of the stand approaches this maximum; thus, in this model, mortality is parameterized as a percentage of the standing biomass.

3. Interactions (Competitions)

Growth of trees in a stand is affected by interactions caused by the presence of other trees. There are two ways of parameterising competition:

- Competition relative to the total biomass in the stand (e.g., in a Eucalyptus stand only) and
- Competition relative to each cohort (e.g., Eucalyptus and Acacia plantation).

A default value of '1' was used for no competition at all.

4. Parameterising the Soil

The model required inputs on the mean annual temperature of the soil (˚C), precipitation in the growing season (PREC, mm) and Potential Evapotranspiration in the growing season (PET, mm). PREC and MAT data can be found at www.worldclimate.com, or mean monthly temperatures can be computed using 'PET.xls' file installed in the CO_2FIX installer. Values of litter in the soil were also input.

3. RESULTS AND DISCUSSION

3.1 Above-ground Biomass and carbon density

Field measurements coupled with the use of allometric equation showed a wide range of biomass density in the land cover in the PCW (**Tables 4 and 5**). Two estimates are presented here, one using the allometric equation from Brown (1997) and the other using the Power Fit developed at the Environmental Forestry Programme (Banaticla 2002). Brown's equation is based on 168 trees that were destructively sampled in the humid tropics where annual rainfall was 1500-4000 mm. Power fit equations, on the other hand, are equations derived using a non-linear estimation procedure by fitting the biomass data from previously conducted studies in the Philippines to the power function: $Y = aD^b$, with Y = biomass of tree, D = diameter at breast height, and a, b=parameter estimates.

It will be noted that Brown's equation gave about 50% higher biomass estimate than the Power fit equation, which is the same trend as in other Philippines studies (Banaticla 2002). There is a large difference in the biomass values obtained using the two equations, because Brown's equation is not calibrated to this specific site. Site conditions and tree species used to calibrate the equation by Brown may be entirely different from those species and conditions in the study area. Thus, with the absence of site-specific biomass equations for the PCW, biomass estimates using Brown and Power fit equations can be used as a high and low estimate for the biomass in the watershed.

Among all the land cover types, secondary forests have the highest above-ground biomass density, while grasslands have the lowest. Secondary forests form the only remaining natural forest cover in the watershed. The original forest cover has been slowly decimated over the years as result of timber cutting and shifting cultivation activities. After years of repeated cultivation and burning, grasslands have become the dominant vegetative cover.

In trying to revegetate the denuded areas, there have been several attempts to reforest the watershed. The various reforestation species have biomass density values (about 70 Mg on the average using Power Fit equation) that are lower than natural forests, but much higher than grassland areas. This implies that reforestation activities are helping increase the biomass of denuded areas. However, their biomass is typically lower than that of natural forests.

The results of the study are consistent with above-ground biomass density values obtained in other parts of the country using the Brown (1997) equation (Lasco and Pulhin 2003; Lasco et al. 2002; Lasco et al. 2000; Kawahara et al. 1981). For example, a secondary forest in Makiling Forest was found to have 547 Mg/ha (Lasco et al. 2001), while in Leyte a similar forest type has 446 Mg/ha (Lasco et al. 2002). They are also consistent with the IPCC default values for natural forests in the Philippines which is 370-520 Mg/ha (Houghton et al. 1997). Similarly, the biomass density is within the range of other forest types in SE Asia (Lasco 2002).

It will be noted that except for grassland areas, most of the above-ground biomass is stored in trees. This is consistent with findings from other studies where more than 90% of biomass is commonly found in the bigger trees (Lasco et al. 1999; Guilespie et al. 1992).

The plantation species have differing biomass density. This could be due to a number of reasons, such as age differences between and among species. In addition, it could also be due to the uneven site conditions obtained in the PCW.

Table 4. Biomass of various land cover in Pantabangan-Carranglan watershed using allometric equation of Brown (1997)

LAND USE	**BIOMASS DENSITY (Mg/ha)**			
	Tree	**Herbaceous/ Understorey**	**Litter**	**TOTAL**
Second Growth	546.6	0.16	16.53	563.29
Brushland	113.35	0.42	7.57	121.34
Grassland		17.15		17.15
Acacia auriculiformis	286.01	0.04	0.62	286.67
Benguet Pine	181.22	0.42	0.83	182.47
Eucalyptus	54.29	0.22	0.72	55.23
Gmelina	108.97	0.15	0.66	109.78
Ipil-ipil	82.55	0.24	0.39	83.18
Mahogany	152.56	0.08	0.41	153.05
Mixed species	87.19	0.4	2.99	90.58
Narra	145.24	0.33	0.72	146.29

Table 5. Biomass of various land cover in Pantabangan-Carranglan watershed using the Power Fit equation

LAND USE	**BIOMASS DENSITY (Mg/ha)**

	Tree	Herbaceous/ Understorey	Litter	TOTAL
Second Growth	282.91	0.16	16.53	299.60
Brushland	72.38	0.42	7.57	80.37
Grassland		17.15		17.15
Acacia auriculiformis	120	0.04	0.62	120.66
Benguet Pine	95.67	0.42	0.83	96.92
Eucalyptus	28.47	0.22	0.72	29.41
Gmelina	55.66	0.15	0.66	56.47
Ipil-ipil	42.95	0.24	0.39	43.58
Mahogany	80.43	0.08	0.41	80.92
Mixed species	45.38	0.4	2.99	48.77
Narra	76.09	0.33	0.72	77.14
Ave for tree plantations	68.08	0.24	0.92	69.23

As expected, the carbon density values of the various land cover follow the trend of biomass density (**Fig. 4**). Similarly, the area distribution of carbon density is a reflection of the land cover types of the watershed (**Fig. 5**).

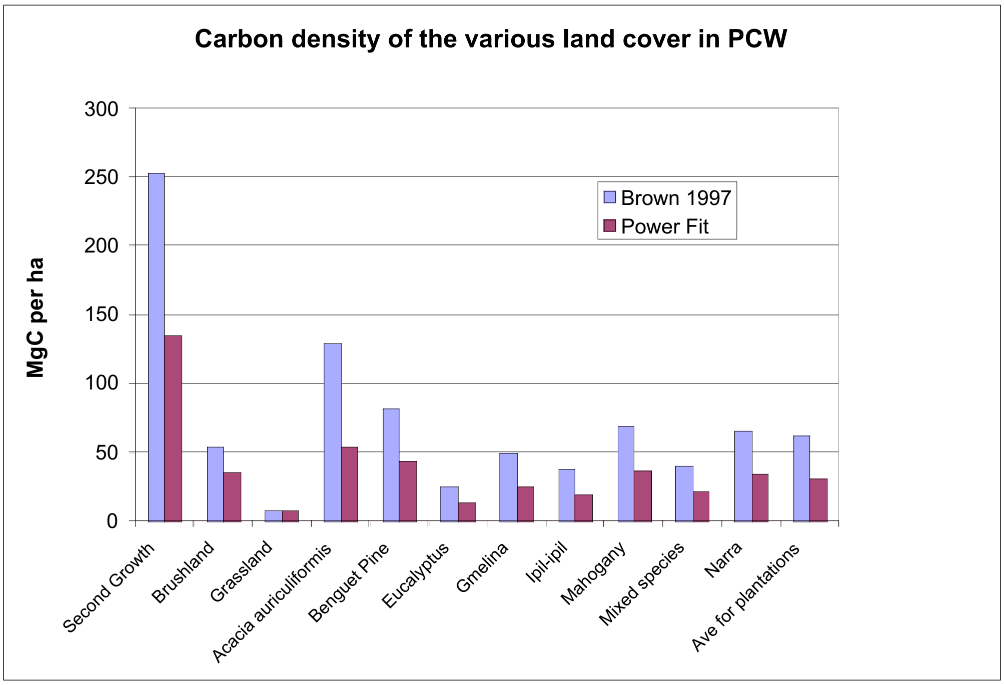

Fig. 4. Carbon density of land cover types in Pantabangan-Carranglan Watershed, Philippines
(Note: carbon content of biomass= 44%)

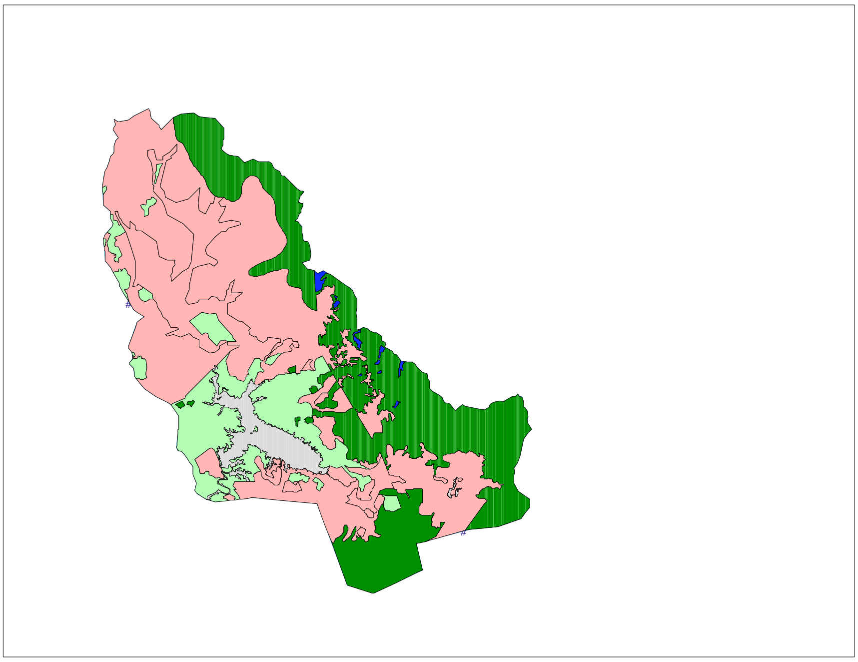

Fig. 5. Distribution of carbon density of the Pantabangan-Carranglan Watershed, Philippines

On the basis of the carbon density values, the entire watershed is estimated to contain 4,878 GgC (Power Fit) to 8,870 GgC (Brown) in above-ground biomass and necromass. As expected, most of these are contained in the natural forests (**Fig. 6**).

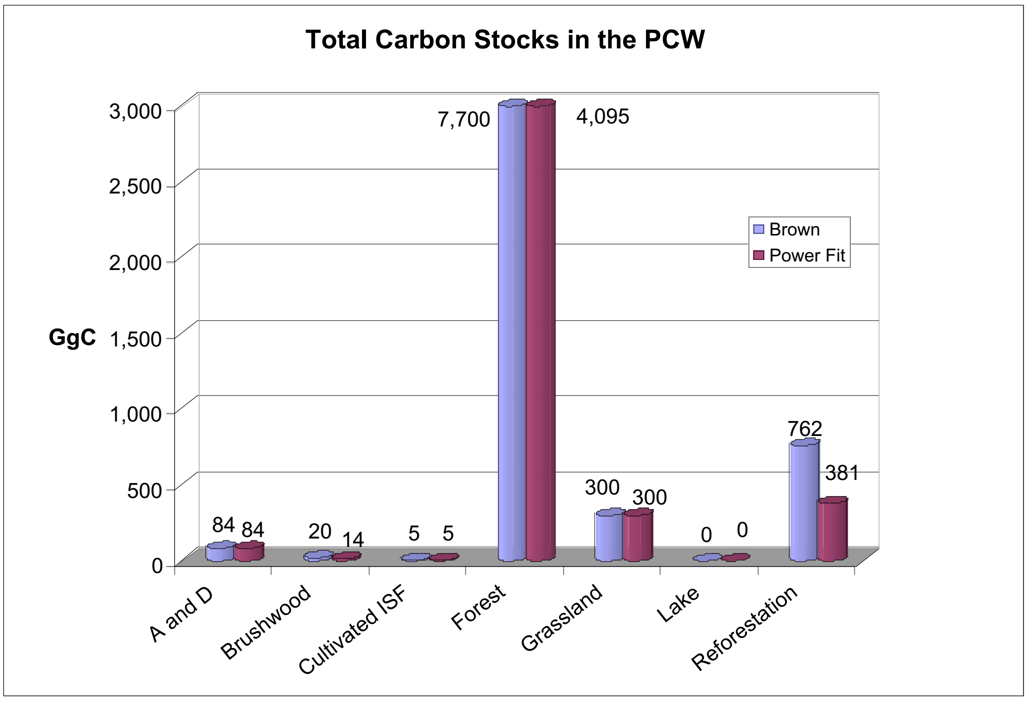

Fig. 6 Total carbon stocks of the Pantabangan-Carangglan Watershed, Philippines

3.2 Simulation of carbon budgets using CO_2-Fix v2.0

Three modules in the CO_2 Fix v.2.0 were parameterized using local data where available, viz., general, biomass, and soil parameters. Since there was no harvesting, the products module was not used.

The following are the values input to the model:

1. General parameters

- Simulation length= 100 years
- Maximum biomass= 400 Mg (roughly the average of the high and low estimate in Tables 1 and 2)
- Cohorts: Upper storey, understorey
- Cohorts age= 20 years

2. Biomass parameters

Upperstorey:

- Carbon content= 45% (from Lasco and Pulhin 2003)
- Wood density= 0.57 (Brown 1997)
- Initial carbon= 100 MgC/ha
- Stem growth rate:

The stem growth rate of the forest was estimated using the following logistic equation of a dipterocarp plantation in the Philippines:

Logistic Model: y=a/(1+b*exp(cx))

Where:

a = 260.9623

b = 204.2171

c = 0.14702

r= 0.998 R^2= 0.996

Equation generated using Curve Expert 1.3

The estimated total biomass and CAI are shown in **Tables 6** and **7**.

Table 6 Estimated total biomass of a dipterocarp plantation in a good site in the Philippines

Age	Merchantable Volume[1] (m^3)	Biomass (kg)	MAI Biomass (kg/ha/yr)
20	8	5	3
25	60	34	18
30	111	63	10
35	165	94	8
40	223	127	8
45	271	154	6
50	308	176	4
55	330	188	2
60	348	198	3
70[2]		199	0
80		200	0
90		200	0
100		200	0

[1]Merchantable volume data for ages 20 to 60 from PCARDD (1985)
[2]Biomass for ages 70 to 100 were extrapolated from the logistic equation

Table 7. CAI used for stem in the CO2 Fix Model (estimated based on the logistic equation)

Biomass/Maximum Biomass	**CAI (m3/ha/yr)**
0.10	0.7
0.20	3.5
0.30	9.2
0.40	12.2
0.50	12.7
0.60	10.8
0.70	7.6
0.80	4.5
0.90	1.6
1.00	0.5

- Default values were used for foliage, branches and roots.
- Mortality and competition were assumed to be zero.

Understorey

- Carbon content= 45%
- Wood density= 0.57
- Initial carbon= 10 MgC/ha

- Default values for potential species were used in the other parameters.

3. Soil Parameters

- Annual mean temperature = 27.6°C for Cabanatuan station (www.worldclimate.com)
- Precipitation in growing season = 2000 mm
- PET in growing season = 1848 from (mean monthly temperature from www.worldclimate.com)

Calibration of initial soil carbon

Total litter fall= 10 t/ha/yr (8 upper; 2 under)
Upper (3 leaves; 2 stems; 1 branch; 2 roots)
Under (0.5 leaves; 0.5 stems; 0.5 branch; 0.5 roots

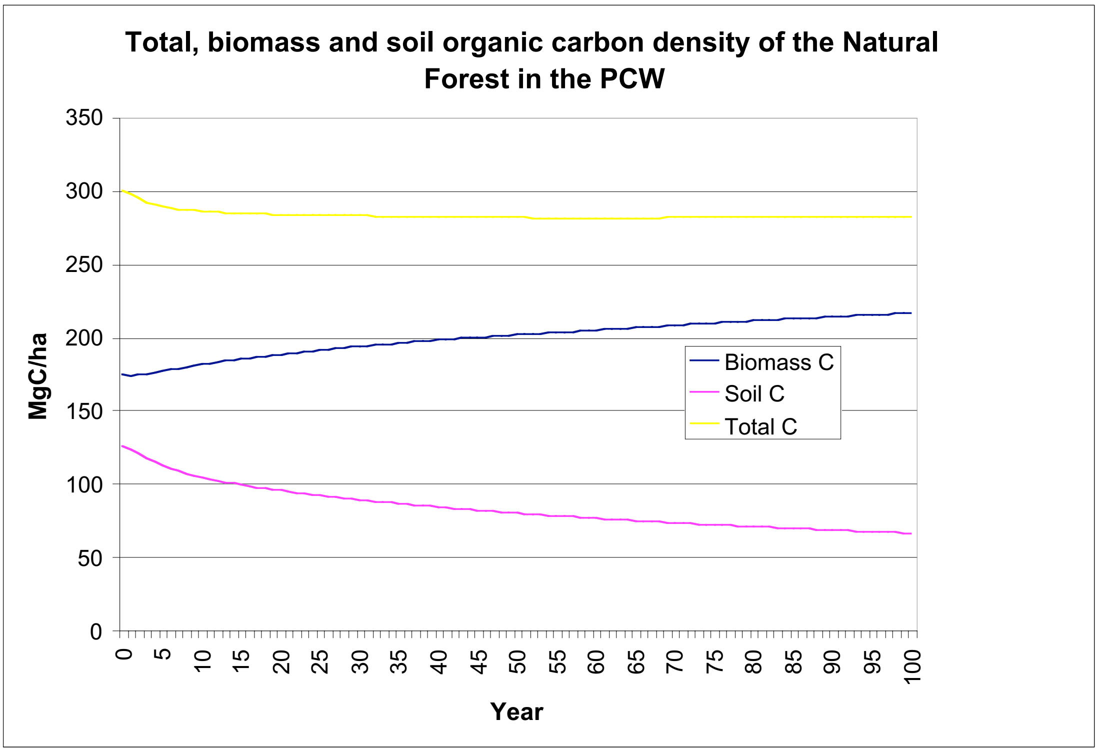

Fig. 7. Total, biomass and soil carbon density in the natural forest of PCW for 100 years as simulated by CO2 Fix v2.0

The results of the simulation showed that while carbon in forest biomass is increasing over time by about 50 MgC per century in the PCW, the soil organic carbon was declining by roughly similar amount. Thus, overall, the total carbon density remains stable over time after an initial decrease.

3.4 Potential for Carbon Sequestration

Open areas in the watershed, mainly grasslands and brushwood, have some potential to sequester carbon through tree planting and agroforestry. Because of the harsh and sub-marginal conditions in grassland areas, the rate of carbon sequestration is estimated to be generally less than 4 Mg/ha/yr (**Table 6**). This is low compared to the IPCC default for tropical plantations (IPCC 1996) as well previous findings in other part of the country like the Makiling Forest Reserve and Leyte where conditions are much better (Lasco and Pulhin 2003; Lasco et al. 2002; Lasco et al. 2001). However, given the large open area in the watershed, there is some potential for carbon sequestration through natural and/or artificial regeneration.

Table 6. Biomass and C density and MAI in Nueva Ecija, Philippines (from Lasco 2001)

Species	Age (yr)	Ave dbh (cm)	Biomass Mg/ha	MAI Mg/ha/yr	C density Mg/ha	MAI Mg/ha/yr
Acacia auriculiformis 1	6	5.68	7.39	1.23	3.33	0.55
A. auriculiformis 2	6	6.46	9.97	1.66	4.49	0.75
A. auriculiformis 3	9	9.62	42.51	4.72	19.13	2.13
A. auriculiformis 4	9	8.71	32.00	3.56	14.40	1.60

A. auriculiformis 5	9	10.47	46.11	5.12	20.75	2.31
A. auriculiformis 6	9	8.73	39.73	4.41	17.88	1.99
Tectona grandis 1	13	5.50	8.70	0.67	3.92	0.30
T. grandis 2	13	7.36	22.30	1.72	10.04	0.77
Gmelina arborea 1	6	7.33	17.22	2.87	7.75	1.29
G. arborea 2	6	6.80	7.71	1.29	3.47	0.58
Pinus kesiya	13	12.53	107.83	8.29	48.52	3.73
P. kesiya + broadleaf spp.	13	10.10	83.24	6.40	37.46	2.88

Note: age and dbh data from Sakurai et al. 1994; biomass computed using the equation Biomass/tree in kg = 21.297-6.953*dbh+0.74dbh^2 for broadleaf species and Biomass/tree= EXP-1.17+ 2.119*LN(dbh) for conifers (from Brown 1997); %C in biomass= 45% (based on Lasco and Pulhin 2000)

4. CONCLUSIONS AND RECOMMENDATIONS

The study shows that natural forests have a carbon density of 300 (using the Powerfit equation) and 563 MgC/ha (using the Brown (1997) equation) in aboveground biomass and necromass. Brushlands and tree plantations have lower carbon densities (generally less than 200 MgC/ha), while grasslands have less than 20 MgC/ha. Total above-ground carbon stocks of the whole watershed are estimated to range from 4,800 to 8,900 MgC depending on the biomass allometric equation used.

The results of simulation using CO_2 Fix model showed that while carbon in forest biomass is increasing over time by about 50 MgC per century in the PCW, the soil organic carbon was declining by roughly similar amount. Thus, overall, the total carbon density remains stable over time after an initial decrease.

The watershed has great potential for carbon sequestration through tree establishment in open areas.

Literature Cited

Bantayan, N. et al. 2000. Philippine Watershed Atlas. College of Forestry and Natural Resources, University of the Philippines, College, Laguna, Philippines.

Brown, S. 1997. Estimating biomass and biomass change of tropical forest: A primer. Forestry paper 134, FAO. Rome.

Gillespie, A.J.R., S. Brown and A.E. Lugo. 1992. Tropical forest biomass estimation from truncated stand tables. *For Ecol and Mgt* 48: 69-87.

Houghton, J.T., Meira Filho, L.G., Lim, B., Treanton, K., Mamaty, I., Bonduki, Y., Griggs, D.J. and Callander, B.A. (eds). 1997, Greenhouse Gas Inventory Workbook, Intergovernmental Panel on Climate Change (IPCC), Organization for Economic Co-operation and Development (OECD) and the International Energy Agency (IEA), Paris, France, pp. 5.1-5.54.

IPCC. 2001. Climate Change 2001: Impacts, Adaptation and Vulnerability. Summary for Policy Makers and Technical Summary of the Working Group II Report.

World Meteorological Organization (WMO), Geneva, Switzerland and UN Environmental Programme (UNEP), Nairobi, Kenya. 89pp.

Kawahara, T. Y. Kanazawa and S. Sakurai. 1981. Biomass and net production of man-made forests in the Philippines. *J Jap For Sci* 63(9): 320-327.

Lasco, R.D. 2002. Forest carbon budgets in Southeast Asia following harvesting and land cover change. *Science in China* 45: 55-64.

Lasco, R.D. 1998. Management of tropical forests in the Philippines: implications to global warming. *World Resource Review* 10(3): 410-418.

Lasco, R.D. and F.B. Pulhin. 2003. Philippine forest ecosystems and climate change: Carbon stocks, rate of sequestration and the Kyoto Protocol. *Annals of Tropical Research* (in press).

Lasco, R.D. and F.B. Pulhin. 2000. Forest land-use change in the Philippines and climate change mitigation. *Mitigation and Adaptation Strategies to Global Change Journal* 5: 81-97.

Mueller-Dombois, P. and H. Ellenberg. 1974. Aims and methods of vegetation Ecology. New York: John Wiley and sons. 547 pp.

Lasco, R.D., J.S. Lales, M.T. Arnuevo, I.Q. Guillermo, A.C. de Jesus, R. Medrano, O.F. Bajar, and C.V. Mendoza. 2002. Carbon dioxide (CO_2) storage and sequstration of land cover in the Leyte Geothermal Reservation. *Renewable Energy* 25: 307-315.

Lasco, R.D., I.Q. Guillermo, R.V.O. Cruz, N.C. Bantayan, and F.B. Pulhin. 2001a. Carbon stocks assessment of a tropical secondary forest in Mt. Makiling, Philippines. *J of Tropical Forest Sci*. (in press).

Nabuurs, G.J., J.F. Garza-Caligaris, M. Kanninen, T. Karjalainen, T. Lapvetelainen, J. Liski, O. Masera, G.M.J. Mohren, A. Pussinen, M.J. Schelhaas. 2001. CO2FIX V2.0 – manual of a model for quantifying carbon sequestration in forest ecosystems and wood products. ALTERRA Report Wageningen The Netherlands 64pp.

The Philippines Recommends for Dipeterocarp Production. 1985. PCARDD Technical Bulletin Series No. 58. Philippine Council for Agriculture and Resources Research and Development. Los Baños, Laguna, Philippines. 96 pp.

Sakurai, S., R.S.B. Ragil and L.U. de la Cruz. 1994. Tree growth and productivity in degraded forest land. In Rehabilitation of Degraded Lands in the Tropics. JIRCAS International Symposium Series No. 1, Japan International Research Center for Agricultural Sciences (JIRCAS), Tsukuba, Japan, pp.64- 71.

Schimmel, D., Enting, I.G., Heimann, M., Wigley, T.M.L., Rayneud, D., Alves, D. and Seigenthler, U.: 1996, 'CO2 and the carbon cycle', in J.T. Houghton, L.G. Meira Filho, J. Bruce, H. Lee, B.A. Callander, E. Haites, N. Harris, and K.

Maskell (eds), Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emision Scenarios, Published for the IPCC, Cambridge University Press, pp. 35-71.

Watson, R.T., I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verado and D.J. Dokken (eds): 2000, Land Use, Land-use Change, and Forestry, Published for the Intergovermental Panel for Climate Change, Cambridge University Press, 377pp.

CarbonBudgetPanta\rdl