Selecting Tree Species with High Carbon Stock Potency from Tropical Upland Forest of Bedugul-Bali, Indonesia

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ABSTRACT

Vegetation studies to reveal tree diversity and its contribution to carbon stock were conducted in three different sites of upland forest in Bali, Indonesia. The sites were located approximately 60 km north of the Bali Province capital city of Denpasar in an area named Bedugul. Those three sites were Mt. Mangu (forest area east of Beratan lake), forest area west of Buyan lake and forest area south of Tamblingan lake. There were 44, 29, and 21 tree species of 14, 19, 14 families with Shannon Diversity Index (H') of 2.87, 2.64 and 1.69 respectively. Carbon stock average of above ground tree biomass from these sites were 214.2, 693.0 and 749.1 ton.ha^{-1} respectively. Tree species with top Summed Dominance Ratio (SDR) in each of those sites were *Platea latifolia* in Mt. Mangu, *Planchonella* sp. in Buyan, and *Tabernaemontana macrocarpa* in Tamblingan. Average carbon content of these three species were 493.25, 12,876.26 and 40.35 kg.ha^{-1} respectively.

Keywords: *carbon stock, tree diversity, upland forest*

INTRODUCTION

Forest ecosystem is a fundamental component in life system. It provides many ecosystem services that most of it is intangible. At present however, deforestation are happening at an alarming rate. Indonesia has now supersede Brazil in terms of deforestation rate [1]. Large areas of lowland forest in Sumatera, Borneo and Java has been cleared for many anthropogenic reasons [2]. Consequently highland or upland forests are the last resort for biodiversity and ecosystem services [3].

Upland forests are important component of ecosystems since they serve as protector of watershed systems and since there have been continuous destruction of lowland forests, they are also maintaining species diversity [4]. Additionally, in the context of climate change, forests can act as carbon sink. Forest degradation causes carbon emission whereas afforestation makes it functions as carbon sink and storage [5]. In accordance with climate change mitigation, carbon stock monitoring in a variety of ecosystems types is a fundamental step [6]. On the other hand, achieving basis data of native species for restoration programs is an additional advantage of conducting carbon stock monitoring [7].

There have been a variety of studies related to carbon stock of various types of forest ecosystems in Indonesia, especially for upland forest. The most prominent one is studies which have been carried out in Cibodas biosphere reserve or also known as Mt. Gede-Pangrango national park [8]. Tree species diversity, environmental factors such as altitude, and also wood density were considered to affect carbon stock. In tree based ecosystems, tree component contributes to about 70% of its total carbon stock [9]. Moreover, study by [10] concluded that more than 80% total biomass from five forest types was located on tree layer. In Indonesia, carbon stock of approximately 300 ton.ha^{-1} was recorded in an undisturbed lowland forest and 190 ton.ha^{-1} for undisturbed peat land forests. For a tree with diameter more than 100 cm, its carbon contents can be as much as 40 ton individually [9]. A similar study by [11] revealed that there were 11 species in a secondary forest of Mount Batur Bali, with tree density 408 individuals.ha^{-1} and carbon stock of 108 ton.ha^{-1}. As a comparison, [10] reported that total carbon stock of an old growth forest can be as high as 651.1 ton.ha^{-1}.

From the previous studies, it can be inferred that

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monitoring carbon stock is an important task to be carried out. This may also be true for forest areas in Bedugul, Bali. This area is characterized by presence of three lakes, namely Beratan, Buyan and Tamblingan surrounded by hilly regions. Mt. Mangu is located east of Beratan lake, whereas Mt. Tapak and Mt. Lesung are south of Buyan and Tamblingan respectively. Most of the land use in the hilly region are natural upland forest, whereas the foothill are functioned as horticultural farms and settlements. The natural forest in this area is conserved by Natural Resource Conservation Bureau and well known as Batukahu Natural Reserve. These sites serve as in-situ plant conservation, whereas Bali Botanic Garden, which is located on eastern slope of Mt. Tapak, serves as ex-situ plant conservation. This research aimed to reveal tree diversity and to select tree species which have high capacity of carbon stock in three different locations of upland forest in Bedugul, Bali, Indonesia under study.

MATERIALS AND METHODS

Vegetation analysis was conducted in 3 upland forest area of Bedugul, namely Mt. Mangu (east of Beratan Lake), forest area west of Buyan Lake, and forest area south of Tamblingan lake on April 09-19, 2013. Study sites were located within the area of 115°05'00"-115°11'30" E and 08°14'30" - 08°17'00" S. Plots of 20 m x 20 m were laid across transects with distance between plots 50 m − 100 m [12]. There were 17 plots in Mt. Mangu (1,305 − 1,506 m asl) and 10 plots each in Buyan (1,219 − 1,298 m asl) and Tamblingan (1,226 − 1,243 m asl). On each plot, all trees with diameter at breast height (dbh) at least 10 cm were recorded. Dbh was calculated with a measuring tape. Environmental factors namely soil pH, soil moisture content, light intensity, air temperature and relative humidity were also recorded. Soil pH and its moisture content were measured on-site using a Demetra DM-5 soil tester. Light intensity was measured with a digital lux meter. A Hanna HI9565 thermohigrometer was used to measure air temperature and relative humidity. Coordinate points of each plot and the altitude were determined with a Garmin 76CSXi GPS. Data of dbh for each tree species then converted to above ground biomass by allometric equations [8]; namely Brown (Br), Ketterings (Kt), Chave (Cv) and Basuki (Bs). Data of wood density (g.cm^{-3}) to predict carbon stock using Kt and Cv equations were obtained from [13]. The data from those 3 locations and 4 different methods then subjected to analysis of variance (ANOVA) and duncan's test (α=0.05) in order to achieve comparisons.

Vegetation and Environmental data were tabulated in MS-Excel for further analysis. Summed Dominance Ratio (SDR) was calculated according to [14], which based on relative density, frequency and dominance. Calculated carbon stock (kg.tree^{-1}), instead of basal area, was used as dominance component in this SDR determination. In addition, to compare species richness among sites, Shannon diversity index (H') and estimated species richness using bootstrap method was determined for each site by using BiodiversityR package [15] in R ver. 3.0.2 [16]. Bray-Curtis similarity index (IS$_{BC}$) was used in comparison of vegetation composition among sites [17]. Selection of species with high carbon stock potency was carried out by choosing species with highest SDR which composed about 50% cumulative SDR.

RESULTS AND DISCUSSION

The results of duncan's test of measured environmental data from this study is presented in Table 1A. It can be seen that altitude, air temperature and slope are significantly different between plots in Mt. Mangu and two other locations. The plots in Mt. Mangu were higher than in Buyan and Tamblingan, therefore the air temperature was lower. The sloppiness of plots in Tamblingan were much more plain compared to situations in Mt. Mangu and Buyan. On the other hand, the magnitude of relative humidity, light intensity and soil pH were similar in those three locations. Diversity and structure-composition can be use as reflectance of forest stability and furthermore, forest health [18]. The calculation of IS$_{BC}$ revealed that vegetation composition varies considerably among sites (Table 1B). It can be interpreted that most of tree species were different between Mt. Mangu and Buyan, Mt. Mangu and Tamblingan, with IS$_{BC}$ 22.3% and 20.24% respectively. However, vegetation in Buyan and Tamblingan seems to be more similar rather than previous pairs, with IS$_{BC}$ 43.51%. The same table also showed each site's species richness and Shannon Diversity Index. Forty four species that belong to 14 families were recorded from Mt. Mangu, 29 species that belong to 19 families in Buyan and 21 species of 14 families in Tamblingan, with expected species richness 51, 32, and 26 respectively. H' clarifies that the sequence of sites with highest to lowest species richness is Mt. Mangu, Buyan and Tamblingan.

Table 1. **A.** Duncan's test of environmental factors in study areas, **B.** Matrix of Bray-Curtis Index of similarity (IS$_{BC}$), Species Richness and Shannon Index, **C.** Duncan's test of Carbon stock and its components

Site	Mean altitude (m asl)	Air Temperature (°C)	Relative Humidity (%)	Light Intensity (lux)	Slope (%)	Soil pH
Mt. Mangu	1417 a	20.4 b	91.3 a	1024 a	14.3 a	6.08 a
Buyan	1246 b	21.3 a	86.8 a	763 a	11.8 a	6.09 a
Tamblingan	1245 b	22.0 a	87.4 a	1187 a	6.4 b	6.10 a

Remark: On the same column, values with same letter are not significantly different (duncan's test α=0.05)

A

Site	IS$_{BC}$ (%)			Species Richness		Shannon Diversity Index (H')
	Mt. Mangu	Buyan	Tamblingan	Observed	Expected	
Mt. Mangu	-	22.03	20.24	44	51	2.87
Buyan		-	43.51	29	32	2.64
Tamblingan			-	21	26	1.69

B

Site	Average of tree dbh (cm)	tree density (individuals.ha^{-1})	% tree density from [8]	carbon stock (tonnes.ha^{-1})	% C stock average from [8]
Mt. Mangu	30.74 b	550 a	180.3	214.2 b	60.4
Buyan	38.97 ab	446 a	146.2	693.0 a	195.4
Tamblingan	41.75 a	443 a	145.2	749.1 a	211.1

Remark: On the same column, values with same letter are not significantly different (duncan's test α=0.05)

C

Based on duncan's test of carbon stock in each plot (not shown), 3 methods (Kt, Cv and Bs) gave similar results whereas Br gave much higher value. By considering this result, calculation of carbon stock by Ketterings' method had been chosen. Next, differences among sites in the form of average tree dbh, tree density per hectare and carbon stock per hectare are displayed on Table 1C. Despite of being the richest site in term of species, carbon stock in Mt. Mangu is the lowest compared to Buyan and Tamblingan. Since there was no significant difference of tree density, average of tree dbh had been the primary reason which explains the higher of carbon stock in Buyan and Tamblingan.

If these results are compared to published data, for example [8] in Mt. Gede-Pangrango West Java and reported that tree density of 305 individuals.ha^{-1} and average C stock was 354.65 ton.ha^{-1}, it will be found that C stock in Mt. Mangu was lower, nevertheless C stock in Buyan and Tamblingan roughly twice higher (Table 1C). Additionally, carbon content of 152.3 ton.ha^{-1} with number of individuals 337 trees.ha^{-1} was reported by [19] from highland forest of Mt. Halimun-Salak West Java. From these two comparisons, it can be shown that carbon stock of upland forest in Bedugul areas is relative high, especially in Buyan and Tamblingan.

For species assemblage varied across sites, information about individual species characteristics related to its carbon content is inevitably needed (Table 2). For convenience, the list in that table was sorted by carbon average of each tree. It can be inferred that there was a difference in species evenness among sites. In order to compose cumulative SDR of about 50%, there were 6, 4 and 3 species for Mt. Mangu, Buyan and Tamblingan respectively. However, there was also differences in species dominance pattern among those three sites. *Platea latifolia* contributes 24.57% of SDR in Mt. Mangu, whereas 5 other species shares 27.01%. Similar SDR value of 24.66% was derived for *Tabernaemontana macrocarpa* in Tamblingan and other 2 species shared 27.27%. A more evenly distributed figure was occurred in Buyan with highest SDR of 16.01% for *Planchonella* sp. and 33.76% shared by other 3 species. Additionally, there was no species which always can be found in three sites. However, *Ficus drupacea* existed in Mt. Mangu and Tamblingan whereas *Tabernaemontana macrocarpa* and *Dendrocnide stimulans* occurred in Buyan and Tamblingan.

Table 2. Summed Dominance Ratio (SDR), diameter at breast height (dbh) and average of carbon stock (kg.tree^{-1}) in Mt. Mangu, Buyan & Tamblingan

No	Species	Family	SDR (%)			dbh (cm)	Wood Density (g.cm^{-3})	Average of Carbon (kg.tree^{-1})
			Mt. Mangu	Buyan	Tamblingan			
1	*Planchonella sp.*	Sapotaceae	-	16.01	-	15->150	0.56	12,876.26
2	*Ficus drupacea*	Moraceae	5.65	-	11.52	30 - >150	0.44	11,524.47
3	*Dendrocnide peltata*	Urticaceae	-	12.37	15.75	10 - >150	0.20	2,232.57
4	*Vernonia arborea*	Asteraceae	4.41	-	-	20 - >150	0.38	790.48
5	*Macaranga tanarius*	Euphorbiaceae	4.02	-		25-65	0.50	635.79
6	*Platea latifolia*	Icacinaceae	24.57	-	-	15 - 85	0.43	493.25
7	*Dendrocnide stimulans*	Urticaceae	5.37	-	-	10 - >150	0.38	393.4
8	*Polyosma integrifolia*	Escalloniaceae	-	8.17	-	15 - 50	0.61	393.33
9	*Homalanthus giganteus*	Euphorbiaceae	7.56	-	-	15 - 45	0.36	108.09
10	*Tabernaemontana macrocarpa*	Apocynaceae	-	13.21	24.66	10 - 40	0.30	40.35
	Total		51.58	49.77	51.93			

List of species with highest SDR which were shown in the table were very dissimilar from those reported by [8] and [19]. There was only one species which also mentioned by [8] i.e. *Platea latifolia* and also one species by [19] i.e. *Vernonia arborea*. The values of carbon content per tree range from 40.35 kg.tree^{-1} for *Tabernaemontana macrocarpa* to 12.8 ton.tree^{-1} for *Planchonella* sp. Although the first has much lower carbon content than the second species, its SDR value is higher.

This data indicated that individual carbon stock capacity can not be solely functioned as an indicator to select tree species with high potency to stock carbon. It can be inferred from the frequency component in SDR calculation (not shown), species with low carbon stock individually such as *Tabernaemontana macrocarpa* were occurred very frequently in almost every plot. On the other hand, huge trees like *Planchonella* sp., *Ficus drupaceae* and some others with dbh over 150 cm can only be found occasionally in a small portion of the plots. These information were in accordance with previous study, as [14] pointed out that usually in forest across tropical areas in Southeast Asia tree number for each species is small and there had been no dominant species.

CONCLUSIONS

The species assemblage varies among sites, i.e. Mt. Mangu, Buyan and Tamblingan. Therefore, there were different species which characterized each site. Carbon stock in those three locations were measured 214.2, 693.0, and 749.1 ton.ha^{-1} respectively. *Platea latifolia*, *Planchonella* sp. and *Tabernaemontana macrocarpa* were three species with highest SDR in Mt. Mangu, Buyan and Tamblingan. Average carbon content of those trees individually were 493.25; 12,876.26; and 40.35 kg.tree^{-1} respectively.

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