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1 author:

Wawan Sujarwo
Badan Riset dan Inovasi Nasional (BRIN)

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ORIGINAL PAPER

Stand biomass and carbon storage of bamboo forest in Penglipuran traditional village, Bali (Indonesia)

Wawan Sujarwo[1,2]

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Abstract Bamboo forest is an important land use in the traditional village of Penglipuran, Bali Indonesia. Bamboo growing in the rural areas can be a good choice for capturing CO_2. I harvested selected culms to determine biomass content, and 50 % of dry weight biomass was calculated as carbon content. The Penglipuran bamboo forest supported six bamboo species in a one hectare sampling plot, all of the genus *Gigantochloa*. The clump and culm densities were 339 and 7190 ha^{-1}, respectively. Total above- plus below-ground biomass was 87.35 Mg ha^{-1}, and carbon storage was 43.67 Mg ha^{-1}. Carbon storage estimated in the bamboo forest at Penglipuran offers insight into the opportunity for PES (payment for ecosystem services) through emission trading mechanisms.

Keywords Bali · Bamboo forest · Biomass · Carbon

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✉ Wawan Sujarwo
wawan.sujarwo@lipi.go.id

1 Bali Botanical Gardens, Indonesian Institute of Sciences (LIPI), Candikuning Baturiti, Tabanan, Bali 82191, Indonesia

2 Department of Science, University Roma Tre, Viale G. Marconi 446, 00146 Rome, Italy

Introduction

Bamboo forest is one of important forest types in tropical and sub-tropical areas. Although the total forest areas in many countries have drastically decreased, bamboo forest area has progressively increased (Lei 2001; Ben-zhi et al. 2005). Indonesia, with over 100 species, has rich bamboo diversity, third in the world only to China and India (Dransfield and Widjaja 1995).

Bamboo is known to be one of the fastest growing plants in the world, with a growth rate ranging from 30 to 100 cm per day in rainy season. Considering this characteristic, it is believed that bamboo is the highest yielding renewable natural resources on earth (Lessard and Chouinard 1980; Ben-zhi et al. 2005). Bamboo is not only utilized for many economic purposes but also has enormous potential for both ecological and social purposes. Its biological characteristics make it a good choice for solving environmental problems, such as erosion control and carbon sequestration.

Study of bamboo biomass was initiated in the tropics of South America in the 1980 s, and has continued over the years (Veblen et al. 1980; Isagi et al. 1997; Embaye et al. 2005; Nath et al. 2008). Most of these studies are carried out in natural stands. Although studies on bamboo biomass have been reported from tropical and sub-tropical areas, there is an absence of bamboo biomass studies in Balinese bamboo forests.

Global climate change has inspired the increasing interest of scientific communities in the study of global carbon storage (Landsberg et al. 1995; Nath et al. 2008). A focus of this climate change debate has been the role of the forests, and especially tropical forests in sequestering carbon. In bamboo forest ecosystems, through the mechanism of photosynthesis, bamboo turns carbon dioxide into organic carbon and then stores it in the form of the bamboo

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stem or culm. Considering the respiration of bamboo, the net primary production of bamboo forest is one of the key issues for mitigating climate change (Ben-zhi et al. 2005). Estimated carbon storage in the bamboo forests can be considered through emission trading mechanisms to earn payment for ecosystem services. Therefore, the main objective of this study was to estimate carbon storage in the well-known bamboo forest of the Indonesian island of Bali.

Materials and methods

Study area

The study was conducted in an indigenous community-managed bamboo forest in Penglipuran village, Bangli regency of Bali (08º25′10.6″ S; 115º21′37.9″ E; 700 m, a.s.l.). The bamboo forest was raised in the 11th century through natural regeneration of *Gigantochloa aya* Widjaja & Astuti and *Gigantochloa taluh* Widjaja & Astuti, and offset plantation of *Gigantochloa apus* (J.A. & J.H. Schult.) Kurz (Arinasa and Sujarwo 2015). The size of the bamboo forest in Penglipuran village varies between 40 and 50 hectares. The local community practices selective felling in order to maintain the sustainability of the bamboo forest (Arinasa and Peneng 2013).

The study area has a tropical climate with a bimodal seasonality (dry season from May to October and rainy season from November to April). The total annual rainfall can vary, ranging from around 2000 to around 2500 mm. The annual temperature range is from 18 to 30 °C (Badan Pusat Statistik 2014).

Study species

Gigantochloa apus is widely distributed and frequently cultivated bamboo species in the Indian, Indochinese, and Malesian regions (Takhtajan 1986; Dransfield and Widjaja 1995). Clumps are dense with up to 12 culms or sympodially branched rhizomes. The culm is erect about 15 m tall, 7.1–8.7 cm in diameter, greyish-green to bright, shiny, and covered by brown hairy sheaths that are caducous when mature. Internode length is 30–35 cm, the culm wall is about 15 mm thick and its top is curved. Young shoots are slender, with appressed blackish brown hairs, light green to grey-green.

Gigantochloa aya and *G. taluh* are endemic to Penglipuran bamboo forest in Bangli regency of Bali Indonesia (Widjaja et al. 2004). Both species are among the six bamboo species endemic to Bali (Arinasa and Sujarwo 2015). *G. aya* is a sympodial bamboo with dense clumps of up to 30 culms. The erect culm grows up to 15 m in height, 40–45 cm internode length, 8–10 cm in diameter, and green. *G. taluh* is also a sympodial bamboo with rather dense clumps of up to 7 culms, erect culms up to 10 m in height, 27.5–40 cm internode length, and with culm diameter up to 3.8 cm.

Sampling plot

A permanent sampling plot (100 × 100 m) with 25 nested subplots (20 × 20 m) was established in August 2011. Living clump and culm census, and measurement of stand characteristics were undertaken annually in each subplot. Dead culms were disregarded (Isagi et al. 1997; Embaye et al. 2005). The bamboos were collected, and then identified by the author and professional experts of the Bali Botanical Gardens. Scientific names of the bamboo were verified using online sources (e.g., The Plantlist 2015). Voucher specimens were deposited at the Herbarium Hortus Botanicus Balinese in the Bali Botanical Gardens.

Biomass and carbon determinations

Biomass was determined by harvesting selected culms (Nath et al. 2008). Aboveground litterfall was estimated by randomly placing three litter traps per subplot. The bamboo sub-samples (root, rhizome, culm, branch, and leaf) and litterfall were dried by open-air drying, and took about 2 weeks to achieve a constant dry weight. Dry weight is considered as biomass (Brown 1997), and 50 % of dry weight biomass is calculated as carbon (Bruce et al. 1996). Statistically no significant difference in carbon content has been documented in relation to different culm ages or bamboo species (Nath et al. 2008). Total biomass and carbon for the sampled bamboos were multiplied by their respective stand density to yield biomass and carbon on a per hectare basis.

Management system

Penglipuran bamboo forest is principally managed for ecological and tourism purposes i.e. for soil erosion control, water conservation, land rehabilitation, carbon sequestration, and cycling tour. *G. aya* is the most predominant species in the bamboo forest, followed by *G. apus*.

The study did not evaluate the dynamic changes over multiple years. I assumed the bamboo forest was not subject to felling within a year because selective felling of larger culms is typically practiced once a year and the younger culms are retained in the clump for re-growth. This means that the carbon storage in the forest as a whole is maintained at a reasonably constant amount over the year.

Results

Culm density and stand characteristics

The bamboo forest is composed of *Gigantochloa apus*, *Gigantochloa aya*, *Gigantochloa taluh*, *Gigantochloa* sp1, *Gigantochloa* sp2, and *Gigantochloa* sp3. The clump density of the stand was 339 clumps ha^{-1}, and 41.6 % of clumps were *G. aya*. The culm density of the stand was 7190 culms ha^{-1} during 2011 (Table 1). Stand characteristics are presented in Table 2.

Stand biomass and carbon storage

Total above- and below-ground biomass of Penglipuran bamboo forest was estimated to be 87.35 Mg ha^{-1} during 2011 (Table 1). Of the total stand biomass 63.46 % was contributed by culms, followed by branches (13.87 %), leaves (11.31 %), rhizomes (10.93 %), and roots (0.41 %). Total leaf litter production of the stand was 2.1–3.1 Mg ha^{-1} with a mean value of 2.5 Mg ha^{-1}.

Total carbon storage in the above- and below-ground biomass of the stand was 43.67 Mg ha^{-1} during 2011 (Table 1). Allocation of carbon was more in culm components than in branch, leaf, rhizome, and root. Of the total annual carbon production, 94.6 % was contributed by the stand, and 5.4 % by annual total leaf litter production.

Discussion

Stand biomass of the bamboo forest

The above- and below-ground standing biomass of 87.35 Mg ha^{-1} of this forest is lower than the corresponding values reported for bamboo grown in different parts of the world (Veblen et al. 1980; Difan 1985; Shanmughavel and Francis 1996; Isagi et al. 1997; Kleinhenz and Midmore 2001; Das and Chaturvedi 2006). But it is similar to the corresponding published values for *Fargesia spathacea* (Taylor and Zisheng 1987), *Dendrocalamus strictus* (Tripathi and Singh 1994; Singh and Singh 1999), *Gigantochloa atter* and *G. verticillata* (Christanty et al. 1996), *Phyllostachys pubescens* (Isagi et al. 1997), *D. latiflorus* (Yiming et al. 1998), *Yushania alpina* (Embaye et al. 2005), and *B. cacharensis*, *B. balcooa*, and *B. vulgaris* (Nath et al. 2008). The average biomass of the other species of bamboo stands is 95.36 Mg ha^{-1}, a figure that approaches the mean biomass of subtropical broadleaf evergreen plantations, i.e., Chinese fir forests and *Pinus massoniana* forests (Chen et al. 2009). The relatively low biomass productivity at Penglipuran was associated with low dry matter density compared to other reports (Rao and Ramakrishnan 1989; Shanmughavel et al. 2001). Thus, the hollow nature of the sampled culms and, consequently, low specific gravity compared to bamboo species with solid culms might be an important reason for the low biomass values reported here. Greater productivity of the bamboo forest can also be attributed to management of culm population structure with the dominance of one and 2 year old culms, as obtained in the present study. This is also evident from studies of Nath et al. (2006, 2007) where a culm population structure of five different ages was skewed toward younger culms, and it could optimize yield by producing more new culms with superior height and diameter.

Carbon storage in the bamboo forest

Mean above- and below-ground carbon storage of 43.67 Mg ha^{-1} in the present study is comparable to the reported above-ground carbon storage of 52.3 Mg ha^{-1} for *Phyllostachys pubescens* (Isagi et al. 1997), 38.3 Mg ha^{-1} for *Gigantochloa atter*, *G. verticillata*, *G. apus* (Christanty et al. 1996), and 50.03 Mg ha^{-1} for *Bambusa cacharensis*, *B. balcooa*, and *B. vulgaris* (Nath et al. 2008). But it is lower than total carbon storage of 83.3–103.8 Mg ha^{-1} for *B. bambos* (Das and Chaturvedi 2006). Carbon storage of

Table 1 Stand biomass (Mg ha^{-1}) and carbon storage (Mg ha^{-1}) of the bamboo species in Penglipuran bamboo forest, Bali (Indonesia)

Species	Dry weight (kg)					Biomass per culm (kg)	Carbon per culm (kg)	Number of clump	Number of Culm	Total biomass (Mg ha^{-1})	Total carbon (Mg ha^{-1})
	Roots	Rhizomes	Culms	Branches	Leaves						
Gigantochloa apus	0.01	0.60	4.23	0.73	0.90	6.47	3.23	140	1744	11.27	5.64 ± 0.60
Gigantochloa aya	0.05	2.13	8.25	2.80	2.00	15.23	7.61	141	4394	66.90	33.45 ± 0.43
Gigantochloa taluh	0.01	0.13	1.20	0.25	0.20	1.79	0.89	3	7	0.01	0.01 ± 0.00
Gigantochloa sp.1	0.08	0.78	6.93	0.98	1.35	10.11	5.06	24	688	6.96	3.48 ± 0.37
Gigantochloa sp.2	0.01	0.30	3.05	0.18	0.21	3.75	1.88	22	260	0.98	0.49 ± 0.08
Gigantochloa sp.3	0.05	1.54	8.10	2.00	1.00	12.69	6.35	9	97	1.23	0.62 ± 0.01

Table 2 Stand characteristics of the Penglipuran bamboo forest

Species	Culm thickness at breast height (cm)	Culm height (m)	Culm DBH (cm)	Culm internodes (cm)	Culm type
Gigantochloa apus	0.91	11.5	7.07	34–40	Hollow
Gigantochloa aya	1.3	13.6	8.34	37–48	Hollow
Gigantochloa taluh	0.48	8.5	4.25	39	Hollow
Gigantochloa sp.1	0.64	12.5	6.33	60	Hollow
Gigantochloa sp.2	0.85	12.2	4.93	40–45	Hollow
Gigantochloa sp.3	1.06	13.5	7.1	38–43	Hollow

DBH diameter at breast height

2.1–3.1 Mg ha^{-1} through leaf litter production reflects its importance as a carbon sink and its positive impact on environmental services. The consequences of increased litter mass can be increased soil fertility and land productivity for greater production, and prevention of land degradation (Nath et al. 2008).

The typically rapid culm growth of bamboos results in greater biomass productivity of the bamboo forest. As bamboo is known to reach maximum biomass within very short periods, it is inferred that bamboo forest compares very favorably with many different types of forests in its ability to quickly store large amounts of carbon (Chen et al. 2009). The findings of this study reveal that management of bamboo forest is an important tool for overall management of carbon sinks. Indigenous people in Penglipuran village practice selective felling and maintain a growing stock throughout the year that can provide long term carbon storage in the bamboo forest. The utilization pattern of bamboo forest in Penglipuran village is for ecological conservation and tourism. Thus it is not subject to intensive felling so it can maintain the carbon stock and sequester carbon due to the long lives of its culms. People living in the village will not over-harvest bamboo because they earn additional values from the standing bamboo forest through the tourism sector.

Conclusions

High density of culms results in high biomass productivity of the bamboo forest. Present findings reveal the potential of bamboo forest as an important sink for CO_2 storage. Bamboo is characterized by short periodicity of culm growth, and rapid culm elongation. This makes bamboo forest a prospective resource to mitigate climate change. Bamboo forests also have socio-economic and ecological values that can provide benefits for rural communities. Carbon storage estimated in the Penglipuran bamboo forest can be considered under emission trading mechanisms to earn PES (payment for ecosystem services).

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