Research article

Ecosystem Carbon Stock Assessment in Upland Forest: A Case Study in Koh Kong, Mondulkiri, Preah Vihear, and Siem Reap Provinces

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Abstract The climate change problem is caused by human-induced increases in the stock of greenhouse gases (GHGs) in the atmosphere. In Cambodia, forests provide many important ecosystem services to local people such as food production, natural medicine, water supply, and wind/storm protection. Additionally, Cambodian forests sequester a considerable amount of carbon, contributing to the mitigation of greenhouse gas-induced climate change on a global level. However, the amount of carbon stored in forests differs according to spatial and temporal factors such as forest type, size, age, stand structure, associated vegetation, and ecological zonation, among other things. The current research aimed to i) conduct forest inventory of upland forest area in the Koh Kong, Mondulkiri, Preah Viher, and Siem Reap provinces of Cambodia, and ii) assess carbon stock at the target sites across different provinces. The study applied the carbon stock assessment methodology as outlined in the National Forest Inventory and the Field Manual for the National Forestry Inventory of Cambodia issued by the Food and Agriculture Organization (FAO) in 2018, applied across different types of forest at several pilot project sites. In addition, the study conducted an assessment of carbon stock in soil and ground litter carbon pools. The research studied five carbon pools: aboveground biomass pool (AGB), belowground biomass pool (BGB), litter biomass pool, dead wood biomass pool, and soil organic carbon pool (SOC). The results indicated total carbon stock in Koh Kong Province at 200.04 tonnes C/ha for evergreen forest, in Mondulkiri Province at 246.18 tonnes C/ha for deciduous forest, in Preah Vihear Province at 185.06 tonnes C/ha for deciduous forest, and in Siem Reap Province at 207.67 tones C/ha for deciduous forest and 414.13 tones C/ha for evergreen forest

Keywords aboveground biomass, belowground biomass, carbon stock, dead wood, litter, soil organic carbon

INTRODUCTION

Many plant species, especially the native species are essential to understand the plant communities in Cambodia. The country is predominantly rich in biodiversity and other natural resources for socio-economic development, food, livelihoods, and well-being. Most of them are threatened with extinction through human activity. Most of the flora species, especially the native species are key to the plant communities in the country. The forest area of Cambodia is managed by three government institutions: Forestry Administration (FA) of the Ministry of Agriculture, Forestry and Fisheries (MAFF), the General Directorate of Administration for Nature Conservation and Protection (GDANCP) of the Ministry of Environment (MoE). FA is the government agency under MAFF, and its mandate is to manage forest and forest resources of the Permanent Forest Estate (PFE), including naturally growing and planted state forest resources and is subdivided into the Permanent Forest Reserve (PFR) and Private Forest. The PFR consists of production forest, protection forest, and conversion forestland. According to the Forestry Law (2002), Private Forests shall be maintained by owners with interesting rights to manage, develop harvest, use, sell, and distribute the product by themselves. Reducing Emission from Deforestation and Forest Degradation (REDD); and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries (REDD+) is a mechanism to use financial incentives to reduce greenhouse gases emitted by deforestation and forest degradation.

OBJECTIVE

The research aims i) to conduct forest inventory of upland forest area in the four provinces, and ii) to assess carbon stock in different provinces of the target sites.

METHODOLOGY

The study was conducted in four provinces such as Koh Kong (KK), Mondulkiri (MDK), Preah Viher (PVH), and Siem Reap (SR) province. There were 8 clusters or 24 permanent plots conducted forest inventory survey, and the case study was implemented from September 2021 until June 2022.

The overall procedure of this survey followed the National Forest Inventory (NFI) sampling design and Field Manual for the National Forestry Inventory of Cambodia issued by the Food and Agriculture Organization (FAO, 2018). The tool is used for producing information on the state of forests and forest resources for land use policy at the national and regional levels.

Carbon Stock Estimation

Aboveground biomass was estimated using different allometric equations for different types of forest. The allometric equation developed by Chave et al. (2014) was applied to evergreen forests and the equation developed by Kim et al. (2019) was used for semi-evergreen and deciduous forests.

Table 1 Allometric equations used to determine tree mass and each carbon pool of the forest types encountered in the study areas

Forest types / Pools	Equation	References
Evergreen forest	AGB = 0.0673* (DBH^2* H* WD) ^0.976	Chave et al. 2014
Semi-evergreen forest	AGB = 0.0607* DBH^2.2692* H^0.5122 WD^0.3183	Kim, et al. 2019
Deciduous forest	AGB = 0.0607* DBH^2.2692* H^0.5122 WD^0.3183	Kim, et al. 2019
Standing Dead trees	Mass = V * WD decomposition class V = A * L * 100	Chao et al. 2008
Stump	Mass = V * WD decomposition class V = A * L * 100 A = (d1/2) * (d2/2) * π	Chao et al. 2008
Fallen Dead Wood	Mass = V * WD decomposition class $V = L\left[\frac{\pi\left(\frac{D_1}{2}\right)^2 + \pi\left(\frac{D_2}{2}\right)^2}{2}\right]$	Chao et al. 2008

Note: AGB = Aboveground biomass (kg); BGB = Belowground biomass (kg); DBH = Diameter at breast height (cm); WD= wood density (g/cm³)

Trees aboveground biomass was summed to plot level and converted to ton per hectare. A 95 % confidence interval was calculated with the forest types in average aboveground biomass. The carbon stocks were finally calculated as the sum of aboveground and belowground biomass multiplied by conversion factors see Eq. 1.

Equation Conversion from AGB to Carbon Stock:

$$C\,stock = AGB * (1+RS) * CF * 44/12 \qquad (1)$$

Where RS is the Root-to-shoot ratio. Different root-to-shoot ratios were applied to the different forest types: 0.37 for evergreen forest (IPCC 2006) and 0.2 for all other types (IPCC 2006). CF is carbon fraction, using the carbon fraction value 0.47 (IPCC 2006), and 44/12 is atomic mass conversion from carbon to CO_2.

Table 2 Main species in each forest type and province

Species Name	KK1	MDK1	MDK2	MDK3	MDK4	PVH1	SR1	SR2	Total	FRE	%
	Semi-evergreen	Deciduous						Evergreen			
Shorea obtusa	0	0	1	23	4	1	18	0	47	5	62.5
Terminalia alata	0	8	4	9	4	0	2	0	27	5	62.5
Xylia xylocarpa	0	9	1	4	0	0	2	0	16	4	50.0
Terminalia mucronate	0	0	4	1	7	0	1	0	13	4	50.0
Careya arborea	0	2	2	2	0	0	2	0	8	4	50.0
Shorea siamensis	0	4	85	0	0	0	11	0	100	3	37.5
Syzygium cumini	0	0	0	0	0	4	1	2	7	3	37.5
Irvingia malayana	0	0	0	0	0	2	1	2	5	3	37.5
Knema corticosa	0	0	1	1	0	3	0	0	5	3	37.5
Catunaregam tomentosa	0	0	4	0	0	0	9	0	13	2	25.0
Dipterocarpus tuberculatus	0	0	0	12	1	0	0	0	13	2	25.0
Melodorum fruticosum	0	0	0	0	0	1	0	11	12	2	25.0
Aporosa ficifolia	0	1	0	0	0	0	9	0	10	2	25.0
Cratoxylum cochinchinense	0	0	0	0	4	0	0	2	6	2	25.0
Shorea roxburgshii	0	0	2	0	4	0	0	0	6	2	25.0
Haldina cordifolia	0	0	1	3	0	0	0	0	4	2	25.0
Mitragyna sp.	0	0	0	1	0	0	3	0	4	2	25.0
Spondias pinnata	0	1	0	3	0	0	0	0	4	2	25.0
Syzygium lineatum	0	3	0	0	1	0	0	0	4	2	25.0
Antidesma ghaesembilla	0	0	2	1	0	0	0	0	3	2	25.0
Cinnamomum litseifolium	1	0	0	0	0	2	0	0	3	2	25.0
Grewia eriocarpa	1	0	0	0	0	0	0	2	3	2	25.0
Vatica odorata	0	0	0	0	0	2	0	1	3	2	25.0
Microcos paniculata	1	0	0	0	0	1	0	0	2	2	25.0

Wood density was added to the tree-level data based on species and genus averages from the Global Wood Density (GDW) database (Jerome Chave et al., 2009; Zanne et al., 2009). The data from Southeast Asia and Southeast Asia Tropical were selected, and averages were calculated for each species and genus. Wood density for each tree was based on species if available in the GWD, genus if species were not available, or a default value of 0.57 g/cm^3 if both species and genus were unknown, not recorded, or not in the data. The default value was based on a wood density average for Tropical Asia by Reyes et al. (1992). To estimate dead wood mass, it was initially calculated the volume of each dead wood piece. Then, converted the volume to dry mass using wood densities based on decomposition class, the wood density of class 1 was 0.55, class 2 was 0.41, and class 3 was 0.23. Some literature values are useful to adopt estimation of dead wood mass. For example, wood densities in three decomposition classes are estimated in Amazonian forests, in Peru (Chao et al., 2008).

Calculation of Soil and Litter Carbon Pools

Soil Sample was taken from a field survey at the General Directorate of Agriculture (GDA) laboratory. Soil samples were dried in the oven and recorded timely. The laboratory processing for soil samples was to explore the following parameters: Organic matter, Nitrogen, pH, total carbon, and Hydrogen. The liter sample was taken and put in a plastic bag and then dried in the dry oven or solar dryer. Follow-up and weigh the samples every day until constant drying.

RESULTS AND DISCUSSION

Main Tree Species for Each Forest Type

According to the field inventory survey in the study site, the tree species were found 98 species, including unknown Species 4 species in 8 clusters, 24 plots. It also described on number of species in each forest type and cluster ID in each province. The main tree species in the study site such as *Shorea obtusa*, *Terminalia alata, Xylia xylocarpa*, *Terminalia mucronate,* and *Careya arborea*.

Comparison of Height and Diameter of Height Breast by Each Cluster ID (Provinces)

Depending on the study on comparison of height, the maximum tree height in the research site is about 36 meters, where the highest Cluster ID is in SR2, located in Kulen mountain, Siem Reap province. DBH maximum cluster is MDK1 which is rich in *Terminalia alata* and *Xylia xylocarpa*.

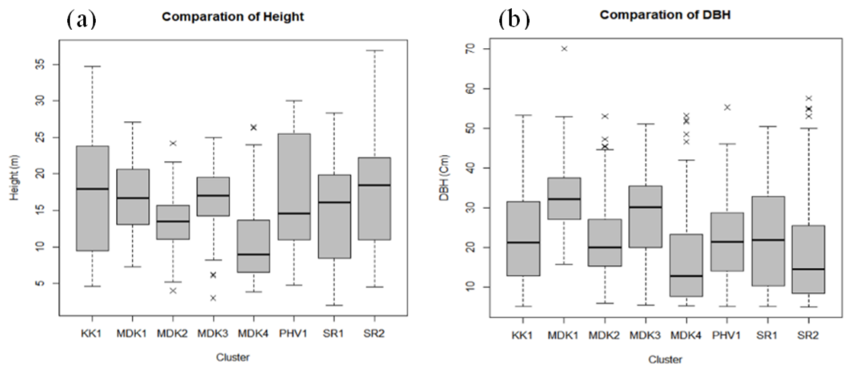

Fig. 1 Comparisons of height by cluster ID (a) and of DBH by cluster ID (b)

Carbon Pool (AGB, BGB, and Deadwood)

As a result, the aboveground tree (AGB) biomass in each plot was different depending on the number of trees present in the plot and forest types, too. The total aboveground biomass in this study excluded bamboo. Therefore, the estimated value of total aboveground biomass was higher than the Cambodia FRL, which excluded bamboo in aboveground biomass. The total aboveground biomass in the deciduous forest was 98.24 t/ha or 46.17 Ct/ha, semi-evergreen forest was 183.20 t/ha or 86.11 Ct/ha, while evergreen forest was 336.07 t/ha or 157.95 Ct/ha, and other was 75.92 t/ha or 35.68 Ct/ha.

Deadwood was defined as one of the carbon pools in terms of the calculation of carbon stock. In this study, the average biomass from deadwood in deciduous forests, semi-evergreen forests, and evergreen forests was a bit different (11.58 t/ha, 10.74 t/ha, and 6.79 t/ha, respectively). The result was similar to (USAID, 2014) which estimated the biomass from deadwood in Cambodia. By including the biomass from deadwood in the estimation, the total carbon stock in the research location will be increased.

Table 3 Aboveground biomass, belowground biomass, and dead wood biomass

Cluster ID	Plots	Forest Type	AGB	BGB	SD	CI95%	Dead Wood	SD	CI95%
KK1	2	Semi-evergreen	96.76	19.35	11.11	15.40	3.33	2.59	3.58
MDK1-4	12	Deciduous	119.07	23.81	58.79	33.26	3.30	2.14	1.21
PVH1	3	Deciduous	61.98	12.40	48.33	54.69	0.55	0.96	1.08
SR1	3	Deciduous	114.90	22.98	35.52	40.20	2.54	2.22	2.51
SR2	2	Evergreen	222.57	82.35	161.45	223.75	4.30	2.04	2.83

Soil Organic Carbon and Litter Carbon Pools

According to the manual of the National Forest inventory, the size of take soil sample was 40 x 40 cm, with three levels of soil layer (SL) (sampling position deep was 5 cm, 15 cm, 25 cm). The study showed that soil carbon pool as well as the C stocks in each of the three layers. Soil depths were 40 cm respectively. The mean of carbon in the soil was 80.06 C t/ha for the semi-evergreen forest in Koh Kong, the deciduous forest in Mondulkiri was 99.35 C t/ha, deciduous forest in Preah Vihear was 109.37 C t/ha, and deciduous forest in Siem Reap was 65.95 C t/ha and evergreen forest in Siem Reap was 104.09 C t/ha.

Litter was defined as one of the carbon pools in terms of the calculation of ecosystem carbon stock. Based on forest type, the semi-evergreen forest in Koh Kong was 0.54 C t/ha, the deciduous forest in Mondulkiri was 0.65 C t/ha, the deciduous forest in Preah Vihear was 0.76 C t/ha, the deciduous forest in Siem Reap was 1.3 C t/ha and evergreen forest in Siem Reap was 0.82 C t/ha. The result was similar to (RUA, 2020) which estimated the biomass from turnover leaves in Cambodia.

Table 4 Carbon pool in soil organic matter and litter by different forest types and provinces

Cluster ID	Forest type	Soil C (t/ha)			Total C (t/ha)	CO_2	Litter C (t/ha)	CO_2
		SL1	SL2	SL3				
KK1	Semi-evergreen	33.42	24.22	22.43	80.06	293.57	0.54	1.96
MDK1-4	Deciduous	48.12	25.95	25.28	99.35	364.29	0.65	2.39
PV1	Deciduous	36.79	36.45	36.13	109.37	401.01	0.76	2.77
SR1	Deciduous	18.03	24.11	23.80	65.95	241.82	1.30	4.76
SR2	Evergreen	38.04	37.98	28.07	104.09	381.66	0.82	3.02

Table 5 Total carbon stock in each province by forest types

Provinces	Koh Kong	Mondulkiri	Preah Vihear	Siem Reap	Siem Reap
Forest Types	Semi-evergreen (C t/ha)	Deciduous (C t/ha)	Deciduous (C t/ha)	Deciduous (C t/ha)	Evergreen (C t/ha)
ABG	96.76	119.07	61.98	114.90	222.57
BGB	19.35	23.81	12.40	22.98	82.35
Deadwood	6.31	5.97	1.18	5.41	8.87
Litter	0.54	0.65	0.76	1.30	0.82
Soil	80.06	99.35	109.37	65.95	104.09
Total C stock	200.04	246.18	185.06	207.67	414.13

Total Carbon Stock in Four Provinces Based on Different Forest Types

Forest ecosystem carbon stock is the amount of carbon that has been sequestered from the atmosphere and is stored within the forest ecosystem, mainly within living biomass and soil, and dead wood and litter. Results of forest carbon stock in the study areas shown in Table 5, semi-evergreen in Koh Kong was 200.04 Ct/ha, deciduous forest in Mondulkiri was 246.18 Ct/ha, deciduous forest in Preah Vihear was 185.06 Ct/ha, deciduous forest in Siem Reap was 207.67 Ct/ha, and evergreen forest in Siem Reap was 414.13 Ct/ha.

CONCLUSION

This case study provides a current estimation of forest biomass and carbon stock in the different forest types by four provinces of Cambodia, which are important biophysical outcomes of the forest landscape. A total of 8 clusters or 24 permanent sample plots within different forest types in natural forests were assessed from September 2021 until June 2022. Vegetation parameters, along with the total carbon stock were calculated separately for different forest carbon pools. It can be concluded that the forest, on the third forest type, can sequester more carbon in the future as the trees have enough DBH values, which means a greater tendency to build biomass, and therefore carbon content. There are 98 species in the tree layer were recorded, and *Shorea obtusa, Terminalia alata, Xylia xylocarpa, Terminalia mucronate, Careya arborea* were the dominant tree species in the third forest type based on density. The carbon stock of semi-evergreen forest in Koh Kong (200.04 C tone/ha) was lower than that of deciduous forest in Mondulkiri (246.18 C tone/ha), deciduous forest in Preah Vihear (185.06 C tone/ha) was lower than Siem Reap (207.67 C tone/ha) and evergreen forest in Siem Reap (414.13 C tone/ha) was highest carbon stock, if compare with each province in this research. Finally, the result indicates that different carbon stocks in different provinces and forest types contribute to improving environmental quality, reducing greenhouse gas emissions, and supporting the government strategy in terms of sustainable management of the forestry sector in Cambodia.

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