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Importance Value Index and Assessment of Carbon Stocks in Western Bhutan Himalaya (Thimphu)

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

This study assessed the importance value index to determine the importance of each tree species in relation to carbon stocks. The assessment was based on woody stem ≥10 cm diameter at breast height (DBH) and tree height. Biomass was estimated using volumetric equations and carbon stock by multiplying constant factor 0.5 to the biomass. The results showed biomass and carbon stock varied in different territorial forest ranges. Maximum biomass recorded from Thimphu forest range with 62.306 $Mgha^{-1}$ followed by Khasadrapchu forest range 55.503 $Mgha^{-1}$, Chamgang forest range 41.556 $Mgha^{-1}$ and Gidakom forest range 32.133 $Mgha^{-1}$ with carbon stock of 31.153 $MgCha^{-1}$, 27.752 $MgCha^{-1}$, 20.778 $MgCh^{-1}$ and 16.066 $MgCha^{-1}$ respectively. Total respective biomass and carbon stock of Thimphu conifer forest from sampling plots were 191.501 $Mgha^{-1}$and 95.740 $MgCha^{-1}$. All forests range had a similar tree size with dominant DBH class at ≥10-40 cm contributing greater biomass and carbon stock. Carbon storage potential in plant biomass using non-destructive method was never conducted before in the present study area. To reduce research gaps, present study used non-destructive methods and concludes that Thimphu conifer forest has enormous potential to accumulate biomass and carbon stock.

Keywords: Carbon stock; biomass; conifer forest; importance value index (IVI); biodiversity index; volumetric equation.

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1. INTRODUCTION

Bhutan currently has a forest cover of 72.5% reinforced by a constitutional mandate that a minimum of 60% of country's total land be maintained under forest cover for all times to come [1]. Forests are uniquely placed as it can act either as sink or source of carbon (C) depending upon its health. In addition, forests are one of the vital components in socio-economic system especially for the forest-dependent households [2,3]. Assessment of biomass is crucial for understanding the sustainable forest management and its role in C cycle and also useful in assessing forest structure and condition [4,5]. Importance of forest has attracted attention as it provides services as C sink [6] and has led to an estimate of C stocks [7].

Above ground biomass (AGB), below ground biomass (BGB), dead wood, litter and soil organic matter (SOM) are five carbon pools in forest ecosystem. Biomass can be measured either in terms of fresh weight or dry weight and it can be both dead and living components. Amount of C sequestrated by conifer forest can be inferred from biomass accumulation since approximately 50% of forest dry biomass is C [8, 9,10,11,12]. AGB accounts for the greatest fraction of total living biomass in a forest as it includes all living biomass above the soil. Biomass estimation to infer CO_2 capture and C storage in plant biomass and soil attracted considerable attention in recent past especially after inception of Kyoto Protocol [13].

During Conference of Party (COP) 15 in Copenhagen and COP 21 in Paris, Bhutan pledged to remain C neutral. As it stands, Bhutan is not simply C neutral it is C negative, one of the most rarity amongst many countries in the world. Though Bhutan generates 2.2 million tons of CO_2, the present forest has capability to sequestrate almost three times of that amount. Today global climate change is seen as an emerging interest to tackle the problems associated with increasing levels of CO_2 and other GHG concentration. In the whole scenario of global climate, forest ecosystem covering about 4.1 billion hectares globally [14] play vital role by storing about 80% of aboveground terrestrial C and 40% of below-ground C playing great potential to mitigate global climate change due to its woody nature [15,2,6]. The current concentration of CO_2 in atmosphere is 399 ppm and it is the main component which causes warming of earth and global climate change [15].

To understand the provisioning of ecosystem service by Thimphu conifer forest (TCF) as C storage [16] volumetric equations with variables DBH and tree height were used to calculate biomass accumulation and then to estimate C stock. TCF play vital role as C sink and source depending upon its management practices, disturbance, age and composition of forests [17]. Present study was conducted following non-destructive methods to assess status of biomass accumulation and C stock potential of territorial forest ranges of Thimphu District.

2. MATERIALS AND METHODS

2.1 Study Area

The present study sites were four territorial forest ranges of Thimphu District which is situated in western Himalaya. Thimphu District is in the western part of Bhutan and shares an international boundary with China in the north. Total area of study site is about 1,617 sq. km. The area is geographically located at 27.5959°N latitude and 89.5875°E longitude. Mean annual precipitation is 1599 mm while the mean annual temperature is 11.6°C.Thimphu conifer forest (TCF) is divided into four territorial forest ranges namely Thimphu forest range (TFR), Khasadrapchu forest range (KFR), Chamgang forest range (CFR) and Gidakom forest range (GFR). Study region consists pure conifer forests, mixed conifer forests and also broadleaf in some areas. Dominant tree species found in sampled plots are *Pinus wallichiana, Quercus griffithii, Quercus semecarpifolia* and *Rhododendron arboretum.* In this study, non-conifer tree species that falls in sampled plots were also included to get the total biomass accumulation and infer total C stock.

2.2 Direct Measurement of Tree Height and DBH

To measure tree height and DBH, we followed [18] to lay nested quadrate size of 31.62 m x 31.62 m using ropes and tree poles in 56 sampling plots. Tree trunk having ≥10 cm diameter at breast height (DBH: 1.37 m above ground) were considered as trees [19,20,13]. The total of 1187 plant taxa belonging to six families and 12 species were recorded from sampled plots. We measured the heights of standing trees using Forestry 550/Hypsometer and DBH of each tree using diameter tapes following non-destructive methods [9,21] and these two inputs were used for calculation of biomass accumulation and carbon stocks [22].

2.3 Vegetation Analysis of Thimphu Conifer Forest

To calculate the importance value index (IVI) of Thimphu conifer forest (TCF), three main parameters were used (frequency, density and dominance). In this present study, frequency is referred to the measurement of commonness and spatial distribution of species in an area and it also means the chance of finding the species in an area. It is calculated using given formula:

$$\text{Relative frequency} = \frac{\text{Frequency of a species in quadrat sampled}}{\text{Frequency of all species in quadrat sampled}}\ x\ 100$$

Whereas density is the number of individuals of species in any unit area indicating standing biomass and productivity of an area and is calculated using the formula:

$$\text{Relative density} = \frac{\text{Total no. of individuals of a species in quadrat sampled}}{\text{Total no. of individuals of all species in quadrat sapmpled}}\ x\ 100$$

Equally to frequency and density, dominance is also one of the most important parameters in estimating standing biomass in an area that in turn can be used as measure of productivity.

$$\text{Relative dominance} = \frac{\text{Total basal area of a species}}{\text{Total basal area of all species}}\ x\ 100$$

These three parameters were calculated to obtain IVI. Generally IVI was defined as statistical quantity which gives overall picture of importance of a species in a plant community. In present study, this biodiversity index (IVI) was used to determine importance of each tree species of conifer forest in relation to carbon stock. All the parameters (frequency, density and dominance) were calculated accordingly to obtain IVI using given formula and then their values were summed up to provide total importance value of Thimphu conifer forest. Average basal area (ABA) was also calculated to obtain average amount of an area occupied by tree stems.

IVI = Relative Density + Relative Frequency + Relative Dominance

2.4 Calculation of Biomass

Due to lack of specific volumetric equations for most of the tree species in Bhutan, selected volumetric equations from other countries based on similarity to the species type were used. Most of the volumetric equations developed by FSI [23], FSI [18] were used based on similarity of geographical distribution of sampled trees. For species which have no specific tree species' volumetric equations, the general volumetric equations were applied. Majority of wood density values of tree species were also selected from FSI [18] and for those species with unknown wood density, the general constant factor was used [23]. Bole biomass (BB: $Mgha^{-1}$) was calculated by multiplying volume of trees (v: $m^3\ tree^{-1}$) with respective wood density (WD: Mgm^{-3}) [24,25].

BB = V x WD

Above ground biomass (AGB: $Mgha^{-1}$) was derived by multiplying BB with biomass extension factor (BEF: 1.59) as prescribed by Khan et al. [26], Mandal and Joshi [24].

AGB = BB x BEF

Belowground biomass (BGB: $Mgha^{-1}$) was calculated by multiplying the total value of AGB with a constant root-shoot ratio of 0.26 [27,24,2].

BGB = AGB x 0.26

Dead organic matter (DOM: $Mgha^{-1}$) was calculated by adding AGB and BGB and then by multiplying the sum with default factor 0.11 [2].

DOM = (AGB+BGB) x 0.11

The total biomass (TB: $Mgha^{-1}$) was obtained by adding AGB, BGB and DOM.

TB = AGB + BGB + DOM

2.5 Carbon Stock Calculation

Total C stock ($CMgha^{-1}$) of TCF was calculated from total biomass obtained [28]. Constant conversion factor 0.5 was used to convert biomass to C stock. This constant factor has been used widely in many papers [29,24, 25,26].

C = TB x 0.5

3. RESULTS AND DISCUSSION

3.1 Floristic Composition

The total of 1187 plant taxa belonging to six families and 12 species were recorded from sampled plots using 31.62 m x 31.62 m plot size. Family-wise distribution revealed that Pinaceae with five species followed by Fagaceae with three species were dominant and others had a single species each. Dominant species according to IVI was *Pinus wallichiana (*160.778) followed by *Quercus semecarpifolia* (35.740) (Table 1). Margalej's index also indicated that Pinaceae and Fagaceae were dominant in the study area with species richness R=0.869 and R=0.434 respectively. Pinaceae dominate montane forests with examples such as montane forests of North America, Europe, China, Korea, Japan and Mexico. The present study is in agreement with Waring [30] that Pines (*Pinus*) are the most widely distributed conifers in montane forests. Non-conifer tree species were also included in present study to obtain total biomass accumulation and carbon stock of the study site. Species such as *Quercus griffithii, Juglans regia, Pinus wallichiana* and *Quercus lanata* were common in all four forest ranges of the Thimphu District. However, species having DBH <10 cm were not considered as trees so excluded in this study.

The dominant tree DBH class at >4.5-20 cm from Thong PhaPhum National Forest, Thailand was reported [31]. In contrary to above study, DBH class 20–30 cm was highest followed by DBH class 30–40 cm from Thimphu montane conifer forest and lowest 90–100 cm and > 100 cm. This difference might be due to habitat variability and species composition. Tree density of 27.885 tree count %ha^{-1} followed by 27.211 tree count %ha^{-1} showed highest in two respective high DBH classes (20-30 and 30-40 cm). Lowest were at DBH class 90–100 cm and > 100 cm (0.168 tree count %ha^{-1} each). The distribution of DBH classes showed right-skewed trend indicating that most of the trees both conifer and non-conifer species are young stands in the study area. A study also reported similar results showing right-skewed trend at protected forest of the International Centre for Integrated Mountain Development (ICIMOD) Knowledge Park indicating young trees [32].

3.2 Biodiversity Index of Thimphu Conifer Forest

Thimphu conifer forest was dominated by *Pinus wallichiana* with 705 individuals of the total 1187 trees in sampled plots. *Pinus wallichiana* had highest estimated ABA of 1281.085 cm^{2}ha^{-1}, relative dominance 73.625, and relative frequency of 27.840 with IVI value 160.778 of the total 300.000, whereas lowest was reported in *Eucalyptus robusta* with IVI 1.014 (Table 1). The dominance and diversity indices of mangrove forests of Mahanadi Mangrove Wetland, East Coast of India were based

Table 1. Floristic composition of Thimphu conifer forest

S. No.	Tree species	ABA (cm^{2}ha^{-1})	Relative dominance	Relative density	Relative frequency	IVI	Rank
1	Pw	1281.085	73.625	59.313	27.840	160.778	I
2	QL	372.266	1.820	3.271	5.394	10.485	VI
3	Qg	834.198	5.778	7.431	11.932	25.141	III
4	Qs	1186.787	11.026	9.374	15.340	35.740	II
5	Cd	235.005	0.804	2.323	2.486	5.613	IX
6	Sb	43.497	2.088	2.104	7.516	11.708	VI
7	Ps	775.803	1.391	5.209	10.699	17.299	IV
8	Tb	687.428	1.232	5.615	6.690	13.537	V
9	Er	156.847	0.391	0.062	0.561	1.014	XII
10	Jr	253.608	0.868	2.801	2.899	6.568	IX
11	J sp.	242.252	0.552	1.093	2.273	3.918	X
12	Ra	371.342	0.425	1.404	6.370	8.199	VIII
	Total	**6440.118**	**100.000**	**100.000**	**100.000**	**300.000**	

Abbreviations: *ABA- Average Basal area, IVI-Importance Value Index, Pw-Pinus wallichiana, QL-Quercus lanata, Qg-Quercus griffithii, Qs-Quercus semecarpifolia, Cd-Cedrus deodara, Sb- Salix babylonica, Ps-Picea spinulosa, Tb-Taxus baccata, Er- Eucalyptus robusta, Jr-Juglans regia, J sp- Juniper sp.,and Ra- Rhododendron arboreum* on Shannon–Weiner index (H'), Simpson's value, evenness value and Menhinick's species richness [33]. Analysis using vegetation richness and dominance based on total individual tree occurrence in undisturbed regenerating sal (*Shorea robusta*) forest of Goalpara district, Assam of northeast India was also conducted [13]. Similarly, dominance of *Pinus wallichiana* was derived based on its relative density, relative dominance, relative frequency, ABA, IVI value and total individual tree occurrence. Thimphu District was estimated to have average Shannon–Weiner index (H'**)** of species diversity 1.321±0.313 with an average Margalej's index value of R=1.176±0.372 and average Pielou species evenness at e=0.652±0.072 (Table 2).

3.3 Tree Basal Area, Biomass and Carbon

Average basal area (ABA) was recorded highest in *Pinus wallichina* (1281.085 cm^2 ha^{-1}) followed by *Quercus semecarpifolia* and *Quercus griffithii* with1186.787 cm^2ha^{-1} and 834.198 cm^2ha^-1 respectively. This proves that *Pinus wallichina* is more dominant in biomass accumulation and C stock potential as compared to other species. The least biomass accumulation and C stock was shown by *Eucalyptus robusta* and *Salix babylonica* with biomass 0.004 $Mgha^{-1}$ and carbon 0.002 $MgCha^{-1}$ each. IVI also showed similar results, where highest value for *Pinus wallichina* at 160.778 and also highest DBH mean 35.862±17.984 (cm). As ABA, biomass and carbon were strongly associated, *Pinus wallichina* was reported with highest biomass accumulation (171.699 $Mgha^{-1}$) of total 191.581 $Mgha^{-1}$and C sequestration (85.85 $MgCha^{-1}$) of the Thimphu District's total C 95.791 $MgCha^{-1}$at highest ABA (1281.085 cm^2 ha^{-1}) (Table 3). This proved that biomass and carbon were positively correlated to ABA in case of *Pinus wallichina* with r=.554 at p value <0.01. Biomass and C were also strongly correlated with $r=1.000^{**}$ at p value <0.01. Similar findings of positive correlation between basal area and biomass were reported by [26,34].

Some tree species like *Quercus griffithii, Quercus semecarpifolia, Taxus baccata, Picea spinulosa,* and *Quercus lanata* were found to have less biomass accumulation (0.07, 0.214, 0.026, 0.004 and 0.402 $Mgha^{-1}$ respectively) and less C sequestration potential (0.035, 0.107, 0.013, 0.018 and 0.201 $MgCha^{-1}$ respectively) contrary of high ABA (834.198, 1186.787, 687.428, 775.803 and 372.266 cm^2ha^{-1}). Pearson correlation statistical test also showed negative correlation with p value >0.05. It was also evidenced that *Cedrus deodara* and *Juglans regia* having ABA 235.005 cm^2ha^{-1} and 253.608 cm^2ha^{-1} respectively, stored biomass of 11.546 $Mgha^{-1}$ and 4.598 $MgCha^{-1}$ and sequestrated C 5.773 $MgCha^{-1}$ and 2.299 $MgCha^{-1}$ respectively which were much higher than species having high ABA like *Quercus griffithii* (834.198 cm^2ha^{-1}) and *Quercus semecarpifolia*

Table 2. Calculation of vegetation analysis of Thimphu district

Vegetation analysis of Thimphu district									
S. No.	**Species**	**TNI**	**Pi**	**LnPi**	**PiLnPi**	**(H')**	**(R)**	**(e)**	**(S Do)**
1	*Pw*	705	0.594	-0.521	-0.309	x	x	x	X
2	*QL*	60	0.051	-2.985	-0.151	x	x	x	x
3	*Qg*	85	0.072	-2.637	-0.189	x	x	x	x
4	*Qs*	114	0.096	-2.343	-0.225	x	x	x	x
5	*Cd*	42	0.035	-3.342	-0.118	x	x	x	x
6	*Sb*	12	0.010	-4.594	-0.046	x	x	x	x
7	*Ps*	22	0.019	-3.988	-0.074	x	x	x	x
8	*Tb*	22	0.019	-3.988	-0.074	x	x	x	x
9	*Er*	2	0.002	-6.386	-0.011	x	x	x	x
10	*Jr*	41	0.035	-3.366	-0.116	x	x	x	x
11	*J sp.*	13	0.011	-4.514	-0.049	x	x	x	x
12	*Ra*	69	0.058	-2.845	-0.165	x	x	x	x
Total		**1187**	x	x	**-1.528**	**1.528**	**1.554**	**0.615**	**-0.376**
Mean		x	x	x	x	**1.321**	**1.176**	**0.652**	**-0.413**
SD		x	x	x	x	**±0.313**	**±0.372**	**±0.072**	**±0.104**

Abbreviations: *Species abbreviation as indicated in Table 1. TNI- Total number of individuals, (H') -Shanon-Weiner index of species diversity, (R) - Margalej's index for species richness, (e) - Pielou index for species evenness, (S Do) - Species dominance and (SD) - Standard deviation*

Table 3. Descriptive analysis of tree basal area, biomass and carbon

Sl. No	TNI	Trees species	ABA (cm^2ha^{-1})	DBH (cm) mean±SD	IVI	Biomass ($Mgha^{-1}$)	Carbon ($MgCha^{-1}$)
1	705	Pw	1281.085	35.862±17.984	160.778	171.699	85.85
2	60	QL	372.266	20.427±7.093	10.485	0.402	0.201
3	85	Qg	834.198	30.059±12.009	25.141	0.07	0.035
4	114	Qs	1186.787	34.920±16.468	35.74	0.214	0.107
5	42	Cd	235.005	16.595±4.446	5.613	11.546	5.773
6	12	Sb	43.497	22.333±6.896	11.708	0.004	0.002
7	22	Ps	775.803	30.045±8.466	17.299	0.036	0.018
8	22	Tb	687.428	28.5±7.153	13.537	0.026	0.013
9	2	Er	156.847	14±1	1.014	0.004	0.002
10	41	Jr	253.608	17.233±4.642	6.568	4.598	2.299
11	13	J sp.	242.252	24.225±12.274	3.918	0.005	0.002
12	69	Ra	371.342	20.232±7.554	8.199	2.977	1.489
				Total	**300.000**	**191.581**	**95.791**

(1186.787 cm^2ha^{-1}). Variability in biomass and C sequestration potential of tree species was not only depended on tree density but also on the size of the tree, rates of productivity, human disturbances and right forest management [13, 31,24,25].

4. CONCLUSIONS

Carbon stocks estimation was based on DBH and tree height. Biomass accumulation and carbon sequestration potential varied in all the four territorial forest ranges as it completely relied on importance value index, tree sizes and forest management practices. It also showed that area having more anthropogenic disturbance such as developmental activities, fuel wood harvest, illegal cutting of trees, forest fire and clearing of forests for housing structures are the main factors to less biomass accumulation and ultimately to a reduced amount of carbon sequestration potential. Results of the present study might assist the policy-makers, respective conservation organizations and institutes to find most efficient solutions to increase the biomass accumulation and carbon sequestration potential of ecologically fragile regions of forest of Bhutan.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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