Comparing Carbon Stock and Increment Estimation using Destructive Sampling and Inventory Guideline of *Acacia Catechu, Dalbergia Sissoo, Eucalyptus Camaldulensis* and *Pylunthus emblica* Plantations, Mahottary Nepal

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Abstract— *This research was objectively carried out to compare the forest carbon stock estimation and increment applying destructive sampling and community forest inventory guideline (CFIG). Plantation of Acacia catechu, Dalbergia sissoo, Eucalyptus camaldulensis and Pylunthus emblica at Pragatinagar community forest, Mahottary Nepal was selected for this study. Altogether 62 random points were distributed to select the plant applying stratified random sampling for harvesting purpose. The diameter and height of plants were recorded and these were uprooted. Total 192 discs were slashed each from stem and branches and eight discs cut from the root of plants. The samples were dried in lab. The carbon stock and mean annual carbon increment (MACI) were calculated using both methods to compare the values statistically. The moisture content was about 45.34% in leaves of Eucalyptus camaldulensis and there was about 51 – 58% contribution of stem in total carbon of Pylunthus emblica. Total carbon stock was 3.61±1.32 t/plant of Acacia catechu applying destructive sampling which was 5.37±0.88 t/plant using CFIG and the MACI was 0.72 t/plant of same species using destructive sampling which was 1.07 t/plant using CFIG. The t-test showed significance difference in values of carbon stocks and MACIs at 95% confidence level employing the methods.*

Keywords— Destructive, Inventory, Carbon, Increment, REDD+, Volume.

I. INTRODUCTION

Reducing emission from deforestation and forest degradation (REDD+) is worldwide accepted mechanism to address the issues of climate change [1,2]. The Forest Carbon Partnership Facility (FCPF) has been working as a pool between developed countries (Donors) and developing nations aiming to mitigate and adapt the impacts of climate change [3]. Thus 47 developing countries including Nepal have been participated to REDD+ mechanism and 17 financial contributors have been supporting since 2008. In this context, the financial contributors expect a guarantee of satisfactory, standard and precise methods to measure and monitor the carbon credit [4].

The uncertainty in carbon credit depends up on application of database, techniques, technologies of carbon estimation and applied methods [5,6]. The tier 3 is the most efficient level of precise carbon measurement and monitoring approach in REDD+ mechanism which considers high scale of models, equations and data of carbon quantification, monitoring, reporting and verification [7] (Westfall, 2012). Meanwhile, the carbon credit is the differences between carbon increment and reference level [8]. These technical preparations are essential for carbon trading [9]. It is obvious that the countries which can demonstrate tier 3 level of precision; these will be highly benefitted financially, technically and socially.

Nepal is approaching to tier 2 level precision under the REDD+ mechanism. REDD+ pilot projects demonstrated by International Centre for Integrated Mountain Development (ICIMOD) and World Wildlife Fund, Nepal are maintaining some level of precision [10]. If additional technological and technical advance preparation can be demonstrated, Nepal will be able to upgrade to tier 3 level. Nepal has already database of community managed forests.

At the same time some of the community forests users have been initiated to incorporate the records of carbon as well applying the community forestry inventory guideline. In this context, often question raised, can carbon estimated using community forestry inventory guideline provide precise result? This paper tried to find the answer of this question comparing the forest carbon estimation employing community forest inventory guideline and destructive sampling techniques.

II. MATERIALS AND METHOD

Site selection

The plantation of *Acaccia catechu*, *Dalbergia sisoo*, *Pylenthus emblica* and *Eucalyptus camaldulensis* of Jagriti community forest in Mahottari district, Nepal was selected as the research site which was planted in 2011. The main reason of selection of this community forest was users were agreed to carry out the experiment that was harvesting of some plants. The geographical location of this district is 26° 36' to 28° 10' N and 85° 41' to 85° 57' E (Figure 1). The temperature of this district ranges between 20-45 ºC and average annual rainfall has been recorded between1100-3500 mm. Some equipments like saw, digital weighing machine, simple tape, D-paint, scissor and plastics bags were used to carry out the sample.

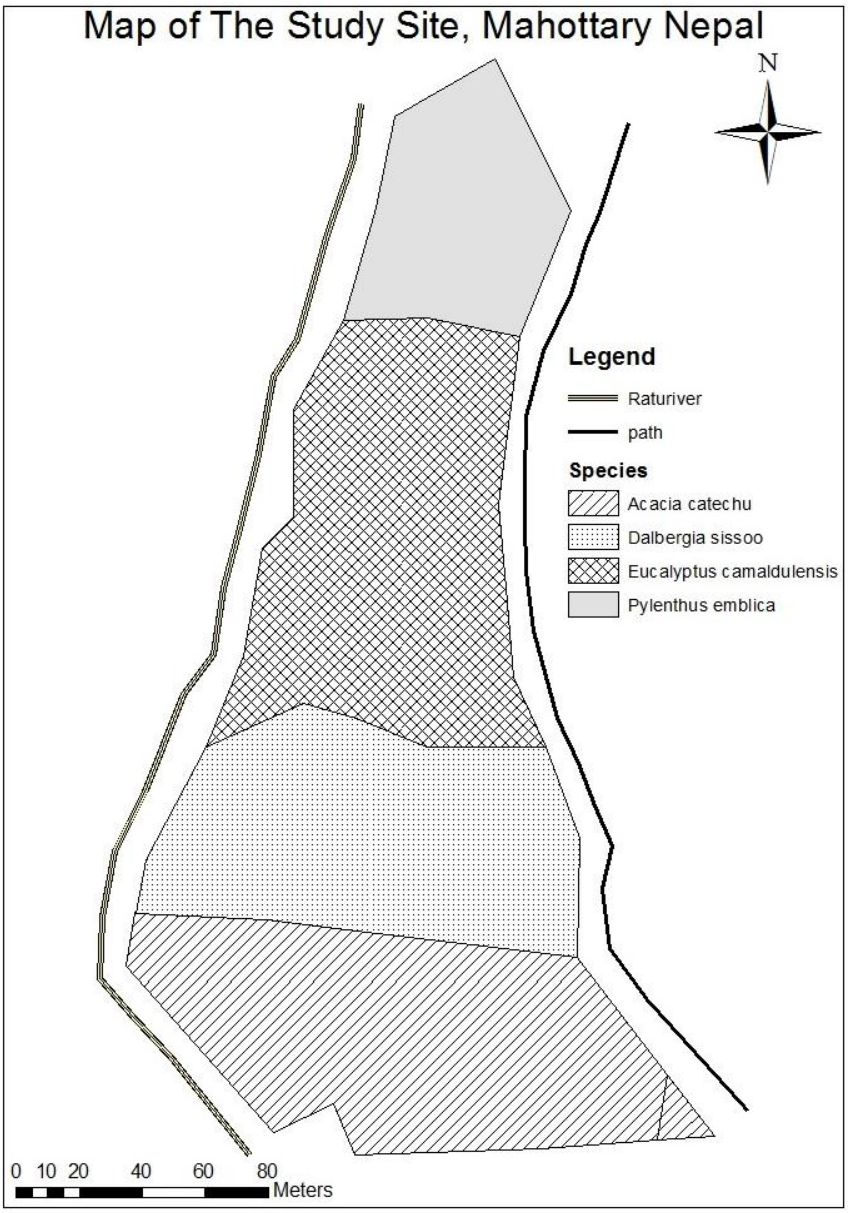

Fig.1: Map of the Study area of

Experimental design and sampling

The map of the plantation was prepared and these were stratified according to the species. Altogether sixty two points were distributed randomly on the map to select the plants for destructive purposes. The whole forest was considered as one block and species wise stratum was assumed as sub-block [11,12]. There were four blocks namely *Dalbergia sissoo, Acacia catechu, Eucalyptus camaldulensis* and *Pylenthus emblica*. So, randomized block experimental design was set and stratified random sampling was applied. Then, the plants were selected randomly from each stratum representing the species.

Harvesting and recording

Selected plants were uprooted to determine the actual carbon of whole plants. Specifically there were 15 plants from each *Pylanthus imblica* and *Eucalyptus camaldulensis* strata as well as 17 plants from each *Dalbergia sissoo* and *Acacia catechu* strata. Inaddition, samplings of all parts of plant specifically stem, branch, leaf and root were also collected.

The total length (height) and diameter at breast height of felled plant were measured and recorded. In the meantime, three discs were cut from first and last ends as well as midpoint of the stem. Next, the branches were separated from the main stem and their fresh weight was recorded. The three discs were cut from selected largest branches of each plant. Moreover, the leaves were collected from each branch and their weight was noted. Apart from these, roots of harvested plant were also dug and their fresh weight was recorded. Then disc of stem, branch and root was weighted and their diameter and thickness was also recorded. Altogether 192 discs each from stem and branch were cut and eight discs cut from root (Table 1). Meanwhile 100 gram sample of leaf of all species was carried to dry in the lab.

Table.1: Number of harvested plant

Species	Area of Stratum ha	No. of plants uprooted	No of disc samples		
			Main stem	Branches	Roots
Pylanthus imblica	1.21	15	45	45	2
Dalbergia sissoo	3.71	17	51	51	2
Acacia catechu	4.21	17	51	51	2
Eucalyptus camaldulensis	3.21	15	45	45	2

Data Analysis

The biomass was calculated using two methods. They were biomass calculation using inventory guideline and destructive method. The results were compared statistically.

a. biomass calculation based on community forest inventory guideline

The biomass was calculated using following steps. The community forest inventory guideline recommended to apply the value of form factor 0.5 [13] to calculate volume of the plant to calculate the biomass.

Volume $=\pi r^2 \times L$

Whereas, r= radius of the plant at breast height and L is total length

Biomass= Volume × wood density

Then, according to Sharma and Pukala [14], biomass of branch and leaves was 45% and 11% respectively of stem biomass.

The root biomass was calculated multiplying by12.5% given by [15].

Total biomass = Biomass of (stem biomass+ branch+ leaves + root)

b. Destructive method:

Cross sections of felled plant were made a length of1.5 m but it was differed according to the tapering of the plant. The volume of harvested plants was calculated.

Volume calculation:

The volume was calculated using different equations. The i. stump volume (V_1) was estimated using cylindrical formula, ii. Volume of butt section (V_2) was calculated using Newton's formula, iii. Volume of sections between butt log and below the top section (V_3) was calculated using Smalian's formula and iv. The volume (V_4) of top section was calculated applying volume formula of cone.

i.$V_1 = S \times L$; ii. Volume of butt log (V_2)= $(S_1+4S_m+S_2) \times L /6$

iii. Volume of section between butt log and below the top of the plant (V_3)= $(S_1+S_2) \times L /2$

iv. Volume of top section (V_4)= $[\{S_1+S_2+\sqrt{(S_1*S_2)}\}/3]*L$

Whereas the S is basal area and L is the length of the log in above formulae [16.17].
Total volume (V)= V1+ V2+ V3 + V4
v. Biomass was calculated using following equation
Biomass = V × Species wise wood density

c. Lab work
Collected discs and samples of leaves were dried in the lab at 104 ^{0}C until the weight of these samples showed constant.
Moisture content %=(fresh weight –dry weight) of disc×100/fresh weight
Total dry weight= dry weight of (stem + branches + leaves + root)
Mean Annual Carbon Increment (MACI)= Total carbon stock/Age of the plant
The plantation was done in 2011 [18] and data was collected in 2016.

III. RESULTS AND DISCUSSION

Mean Basal Area and Volume of different species
The average DBH, height, basal area and volume were differed according to species. The average diameter was the lowest only 1.9 cm of *Pylenthus emblica* while it was the highest of *Acacia catechu* nearly 7.03 cm. Meanwhile, the average height of *Pylenthus emblica* was the lowest about 1.21 m whereas this was the highest about 5.46 m of *Eucalyptus camaldulensis*. The estimated highest basal area and volume were 409.38 cm^2 and 89341.96 cm^3 respectively of *Acacia catechu* (Table 2).The *Pylenthus emblica* is not so suitable species of riverine site in because of less fertile soil [19]. The riverain site is the most favorable area for growth of *Acacia catechu* and *Dalbergia sissoo* [20] therefore the growth performance of the riverine species were good [21].

Height growth of *Dalbergia sissoo* plant was recorded about 7.64 m and diameter of *Acacia catechu* was recorded about 14.7 cm of 5 years in Rajsthan state India [22].The values of height was quite similar but the diameter was differed in comparison to our study. The growth of the plant depends mainly up on its phenological characteristics, soil fertility, climatic condition and management options [23].

Table.2: Average Basal area and volume of Pylenthus emblica, Acacia catechu, Dalbergia sissoo and Eucalyptus camaldulensis.

Species	Average DBH cm	Average ht m	Average BA cm^2	Average volume cm^3
Pylenthus emblica	1.94	1.21	31.18	1891.67
Acacia catechu	7.03	4.36	409.38	89341.96
Dalbergia sissoo	6.26	5.14	325.16	83632.44
Eucalyptus camaldulensis	6.23	5.46	321.56	87787.21

Percentage contribution of different pools in total carbon
The moisture content was differed in different parts of plants [24]. This was also varied according to species. Particularly, there was the highest moisture content in leaves of the plant and followed by the stem and branch. The moisture content was about 45.34% in leaves of *Eucalyptus camaldulensis* (Table 3). Generally, the moisture content of the wood is from 12-40% [25] which showed quite similar result of our study.

Table.3: Moisture content of different parts of plants

Species	Percentage of moisture contents			
	Stem	Branch	Leaves	Root
Pylenthus emblica	35.32	32.67	37.21	29.44
Acacia catechu	31.43	25.47	38.21	28.34
Dalbergia sissoo	33.31	27.33	41.32	27.42
Eucalyptus camaldulensis	41.22	34.22	45.34	31.56

Percentage contribution of different parts in total carbon

The percentage contribution of different parts of the plant is differed in total carbon stock. Specifically, there was about 51 – 58% contribution of stem in total carbon while it was the lowest of root of *Pylenthus emblica*. This proportion was about 62 - 65.21 % of stem of *Eucalyptus camaldulensis* in total carbon stock. A study done by [26] showed that the carbon contribution of stems and large limbs was nearly 85% of the above ground biomass of *Dacrydium cupressinum* in natural forest which values was quite similar of *Eucalyptus camaldulensis* of our study (Table 4). A past study showed that rate of carbon sequestration of branches and stem together contributed to 74 % of the total accumulation rate from 4 to 6 years of age. The root biomass accumulation rate decreased from 17 to 11 % of the total for the same age intervals [27], the values were also close to our study.

Table.4: Contribution different parts in total carbon stock

Species	Carbon percentage			
	Stem	Branch	Leaves	Root
Pylenthus emblica	51-58	19-23	10-13	5-6
Acacia catechu	55-57.43	17-21.33	5.5-7.1	10-14.14
Dalbergia sissoo	48-58.27	19.2-24.63	6.1-7.1	7-10.03
Eucalyptus camaldulensis	62-65.21	10.1-12.21	11-15.5	6-7.09

Average carbon stock estimation based on destructive method and inventory guideline

The carbon stock different parts of the plant differed applying the estimation methods of destructive technique and community forest inventory guideline. Specifically, the estimated carbon stock of stem part of *Pylenthus emblica* was 0.44 t/plant using destructive method while it was less 0.31 t/plant applying community forest inventory guideline so the difference is 0.11 t/plant. The estimated carbon of stem of *Dalbergia sissoo* was nearly 2.16 t/plant applying destructive sampling while it was 1.87 t/plant using community forest inventory guideline (Table 5). The carbon stock, storage capacity and carbon sequestration depend up on the forest management option, forest composition, plants structure, their individual characteristics and applied methods [28, 29].

Table.5: Carbon stock variation using destructive sampling and CF inventory guideline

Species	Carbon estimated after harvesting t/plant				Carbon estimation by inventory guideline t/plant			
	Stem	Branch	Leaves	Root	Stem	Branch	Leaves	Root
Pylenthus emblica	0.44	0.20	0.08	0.04	0.31	0.14	0.03	0.04
Acacia catechu	2.07	0.88	0.29	0.36	3.19	1.43	0.35	0.40
Dalbergia sissoo	2.16	0.43	0.27	0.33	1.87	0.84	0.21	0.24
Eucalyptus camaldulensis	1.37	0.20	0.04	0.01	1.19	0.54	0.13	0.15

Statistical comparison of total carbon stock applying both methods

The total carbon stock was 3.61±1.32 t/plant applying destructive sampling but it was 5.37±0.88 using community forest inventory guideline of *Acacia catechu*. The difference was -1.76 t/plant which was significant differences at 95% level of confidence applying independent t-test. This was not significant differences in carbon stock t/plan of *Dalbergia sissoo* at 95% confidence level applying destructive method and CF inventory guideline (Table 6).

Table.6: Carbon stock differences per/plant applying destructive sampling and community forest inventory guideline

Species	Estimated total Carbon t /plant using		Difference	t-test
	Destructive method	CF Inventory guideline	C t/plant	(P- value)
Pylenthus emblica	0.76±0.19	0.53±0.28	0.23	0.04
Acacia catechu	3.61±1.32	5.37±0.88	-1.76	0.02
Dalbergia sissoo	3.19±1.28	3.15±1.30	0.04	0.96
Eucalyptus camaldulensis	1.61 ±0.21	2.01±0.17	-0.40	0.04

Meanwhile the independent t-test showed that there was significant difference in mean annual carbon increment (MACI) t/plant estimated using the destructive sampling and community forest inventory guideline at 5% level of significant (Table 7). The reason may be due to application of different estimation methods [30]. The calculated mean annual increment (MAI) of *Eucalyptus* plantation was about 12.2 t ha^{-1} $year^{-1}$ [28, 31], this value is quite differed from the value of our study.

Table.7: Comparing MACI of plants applying destructive method and community forest inventory guideline

Species	Estimated total MACI t /plant using		Difference	P- value,
	Destructive Method	CF Inventory guideline	MACI t/plant	Assuming equal variance
Pylenthus emblica	0.15	0.11	0.05	0.041
Acacia catechu	0.72	1.07	-0.35	0.022
Dalbergia sissoo	0.64	0.63	0.01	0.860
Eucalyptus camaldulensis	0.32	0.40	-0.08	0.031

IV. CONCLUSION AND RECOMMENDATIONS

The moisture content varied in different parts of the plants and it was the highest in leaves. There was significant difference in carbon stock of different parts of plant, total carbon stock and mean annual carbon increment of the plant estimated applying destructive sampling and community forest inventory guideline.

Therefore, it is essential to compare the carbon stock estimation based on applied different methods of other plant species too in Nepal.

CONFLICT OF INTEREST

All authors are agreed to publish the paper through International Journal of Forestry Research and there is no conflict of interest.

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