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Biomass Storage and Carbon Sequestration in Priority Bamboo Species in Relation to Village Physiography

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ABSTRACT

The necessity to enhance biotic carbon sink is one of the significance areas of research under the current scenario of anthropogenic climate change. Bamboos being managed in the rural landscape over the years could be an important strategy to promote carbon sink. Bamboos growing under natural conditions have been studied worldwide for their role in vegetation and soil carbon storage. However, village bamboos have received little attention. The present study was undertaken in Hailakandi district of Assam with the specific objectives: (i) to identify priority bamboo species in relation to village physiography, and (ii) to estimate biomass storage and carbon sequestration potential under at different ages of priority bamboo species in relation to village physiography. On the basis of village physiography, villagers have evolved their own priority species. The study shows that older clumps dominates over younger clump. The aboveground standing biomass stock was higher (0.25-24 Mg ha^{-1}) in flood unaffected villages than flood affected (0.14-15.75 Mg ha^{-1}) and riverside (0.38-15.44 Mg ha^{-1}) villages. Across different priority bamboo species, clump ages and village physiography, the estimated carbon sequestration rate ranges from 0.2 to 0.74 Mg ha^{-1} yr^{-1}. Although low in carbon sequestration rate, management of village bamboos can provide opportunity for long term carbon sink management. We suggest future studies to explore belowground biomass and soil organic carbon stock to represent the ecosystem carbon stock of village bamboos for better representation of such systems in carbon sink management.

Key Words: Carbon Sink; Biomass Models; Culm Density; Bamboo Flowering

INTRODUCTION

Combating greenhouse gas emission through reducing sources or enhancing sinks has been the priority theme of global research since mid-1990s. Since, direct CO_2 emission from land use change (LUC) alone contributes ~10% of total anthropogenic emission (Le Quere et al. 2016); it is one of the most important human-driven anthropogenic sources of atmospheric CO_2 (IPCC 2014). Anthropogenic activities such as burning of fossil fuels, land-use changes, and forestry activities are accelerating the rate of increase in atmospheric CO_2 concentration resulting in global warming and climate change during the recent times (Brahma et al. 2018). With a view to recognize the importance of agricultural soil in mitigating the greenhouse effect, role of managed agro-ecosystems in soil carbon sink management has been prioritized in COP 21 (Le Foll 2015). Increase in the concentration of greenhouse gases in the atmosphere and its hostile effects associated with climate change have increased the need for identification of systems with high carbon sink as a mitigation strategy. Tree-based systems such as farm forestry or agroforestry systems have the potential to sequester carbon in a short period of time (Nath et al. 2018a).

Recently, the carbon cycle has become an important global issue, and plants serve an important function in carbon storage. Numerous studies have been made on the role of woody trees species in carbon sequestration, but our knowledge of the potential of bamboos in biomass production and terrestrial carbon sequestration is very limited (Ly et al. 2012, Nath et al. 2015, 2018b, Thokcham and Yadav 29015, Yuen et al. 2017) as only a few out of about 1250 species (Scurlock et al. 2000) have been studied yet.

Bamboo being one of the most important forest species in the tropical and subtropical regions of the world (Scurlock et al. 2000, Zhang et al. 2014), provides wood and food for human life, as well as economic and ecological benefits (Scurlock et al. 2000, Nath et al. 2015). Bamboos have become globally important biomass resources in many regions of the world in recent decades (Scurlock et al. 2000, Darabant et al. 2014, Yuen et al. 2017). The recognition of bamboos to volunteer carbon finance mechanisms increased its attractiveness as plantation species (Darabant et al. 2014). Recent studies have highlighted the potential role of bamboo in carbon trading and carbon farming (Nath et al. 2015, Nath et al. 2018b). In comparison to wild bamboos, those grown and managed in village landscape has been little researched in terms of exploring their role in biomass storage and carbon sequestration potential. In India thick walled bamboos are mainly composed of *Bambusa* species. *Bambusa* is a large genus of clumping bamboos and most species are tall and thick (Banik 2000). This species is widely grown in home gardens in India and Bangladesh (Banik 2000) forming family forest. In India, the genus *Bambusa* are represented by 37 species (representing 26% of the bamboo species), and are predominantly arborescent bamboos growing in diverse regions and habitats (Sharma and Nirmala 2015). Further, little has been studied on the bamboo biomass storage and carbon sequestration in relation to village physiography. In general village grown bamboos are taller and thicker than those grow naturally in wild conditions (Nath et al. 2015). Therefore, village bamboos due to its thick culm wall nature might store more biomass carbon and could be an important village grown plant to be explored for its role in carbon sink management. In this paper we have attempted to estimate the above ground biomass (AGB) storage and carbon sequestration potential of the priority village bamboos in relation to village physiography. The specific objectives of this article are: (i) to identify priority bamboo species in relation to village physiography, and (ii) to estimate biomass storage and carbon sequestration potential under age chronosequence of priority bamboo species in relation to village physiography.

STUDY AREA

The study was carried out in the villages of Hailakandi District of Barak valley, Assam in NE India which is situated between $24^0 41'$ and $24^0 68'$ North latitudes and between $92^0 34'$ and $92^0 57'$ East longitudes. The Hailakandi district is bounded by River Barak and Cachar district in the North and East, Mizoram State in the South and East and Karimganj district in the West. The geographical area of Hailakandi district is 1327 sq.kms. The district consists of plains and hilly areas and two reserve forests viz. Katakhal and Innerline. There are two main rivers Katakhal and Dhaleshwari running from south to north through the middle of the district meeting the river Barak at Panchgram. There are two small rivers also named Pola and Jita (http://hailakandi.gov.in/profile.htm).

The average annual rainfall of the district is 2388.54 mm with an average of 117 rainy days on the basis of record of last 10 years (2006-2015). During this period, the annual rainfall ranged from 1145 to 3975 mm. High rainfall occurred during the months of May to September. The annual mean maximum temperature ranges between 28.4 and 36.7°C and annual minimum temperature ranges from 10.0 to 24.4 °C (District Irrigation Plan, Hailakandi 2016-2021). The average annual humidity of the district is 85% (http://hailakandi.gov.in/profile.htm). The soil varies from sandy type to clay type with pH ranging from 4.5 to 5.9. The major soil classes prevalent in the district are old riverine alluvial, old mountain alluvial, non-laterite red soil and pit soil. Old riverine alluvial soil is mainly confined to the banks of the river Katakhal and Dhalaeswari. The soil texture varies from sandy to silty loam (http://hailakandi.gov.in/profile.htm).

According to India State of Forest Report (FSI 2017), 58.25 % of the total geographical area (1327 km^2) of the district, i.e., 773 km^2 is under forest cover of which 1.68% (13 km^2) is very dense forest, 47.35% (366 km^2) is moderate dense forest and 50.97% (394 km^2) is open forests. Major forest type in these reserve forests of Hailakandi are Cachar tropical wet evergreen forest with small patches of semi evergreen forests and some tropical deciduous forest (Champion and Seth 2005).

A reconnaissance survey was carried out randomly in 20 villages of Hailakandi district to understand the physiography and vulnerability to flood, and on the basis of which the villages were categorized into three categories as follows:

1. Flood affected villages- These villages are located on low-lying floodplain and are affected by flood every year.
2. Flood unaffected villages - These villages are

situated on uplands and are least affected by flood.

3. Riverside villages- Those villages which are situated on the river bank and are affected by flood when river overflows.

METHODS

Selection of Households

Fifteen villages from each of the three physiographic conditions were studied. The selected 45 villages represent 12.5 % of the total villages (361) of Hailakandi district. In each village, 10 bamboo growing homegardens were selected randomly for the present study. Thus a total of 450 homegardens were covered in the present study.

Sampling of Priority Bamboo Species

A detailed and well-structured questionnaire (Annexure I) was followed (Chambers et al. 1989, Vogl et al. 2004) to generate data on homegarden size, age of the culm and clump, and management aspect (Banik 2000, Nath et al. 2015). Selected home gardens from all the three village physiography were surveyed for presence of different bamboo species. All the bamboo clumps for different bamboo species in each homegarden were noted. Number of culms per clump were counted and measured for diameter at breast height (DBH). Relative importance value (RIV) for all the bamboo species occurring in home garden was calculated to obtain priority bamboo species of the study site.

Biomass and Carbon Sequestration

The power-law function (($H=407.4D^{0.62}$, H is culm height (cm) and D is DBH (cm)) of H-D model for thick walled bamboo species proposed from similar geographical area of Barak Valley, Assam (Nath et al. 2018b) was used to estimate the height of the culm for different bamboo species of the study area. We selected this model because, among the H-D models compared by Nath et al. (2018b), the power-law function had 40% likelihood of being the best model for culm height estimation in the absence of measured culm height. Nath et al. (2018b) developed the allometric relationship between culm height, D and above ground biomass (AGB) in thick walled bamboo in Barak Valley and suggested biomass model including culm volume to be more appropriate for biomass prediction. We therefore used the biomass prediction model of the form:

$$\ln(\text{AGB}) = \ln(a)+b\ln(\text{HD}^2),$$

where AGB is above ground biomass, H is total height, D is diameter at breast height, a (-7.5) is the normalization (proportionality) constant, and b(0.91) is the exponent. Using this recommended biomass model culm biomass was estimated and expanded to hectare basis. 47% of the total biomass stock was considered as total carbon stock.

We estimated the carbon accumulation rates (Mg $\text{ha}^{-1}\ \text{yr}^{-1}$) by dividing the potential carbon sequestration by the accumulation time (age of the clump) for each species.

RESULTS

Priority Bamboo Species

Evaluation of villager's priority bamboo species revealed *B. vulgaris* schrad. as the dominant species (RIV=60%) in riverside villages. In contrast, *B. cacharensis* R.B.Majumdar was the dominant species in flood unaffected (RIV=62%) and flood affected (RIV=60%) villages (Figure 1). The co-dominant species in riverside, flood unaffected, and flood affected villages were *B. cacharensis*, *B. balcooa* Roxb. and *B. vulgaris* respectively (Figure 1). Data compilation on priority bamboo species irrespective of the village physiography have shown *B. cacharensis* as the highest priority species followed by *B. vulgaris*, *B. balcooa*, *B. nutans* Wall. ex Munro, *B. polymorpha* Munro, and *B. jaintiana* R.B. Majumdar (Figure 2).

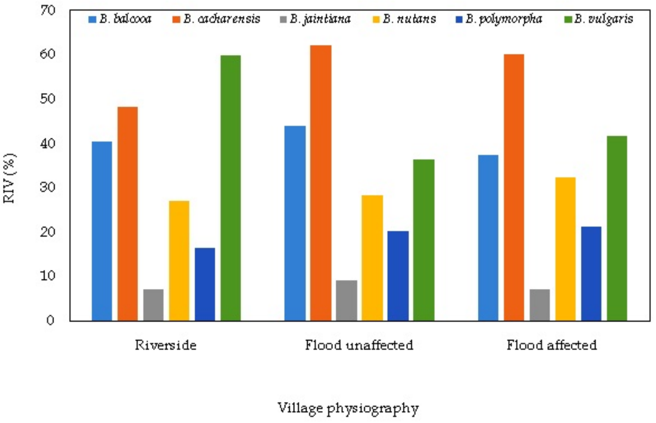

Figure 1. Priority bamboo species with respect to village physiography in Hailakandi district

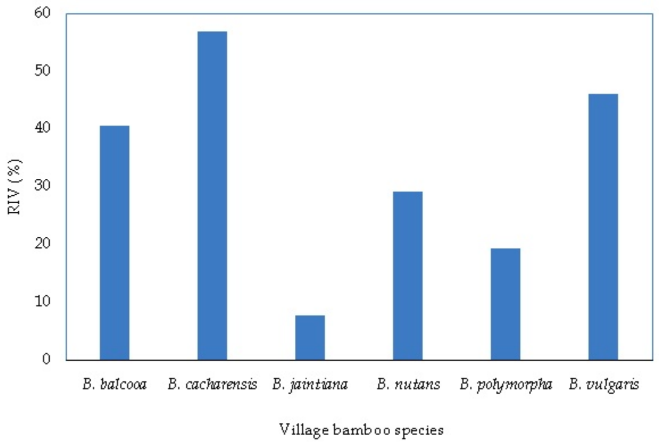

Figure 2. Priority bamboo species (irrespective of village physiography) in Hailakandi district

Culm and Clump Characteristics

Analysis of culm and clump characteristics showed culm DBH and culm density did not vary significantly with village physiography. However, clump density and number of culms/clump varied significantly with village physiography (Table 1). Irrespective of the bamboo species, river side villages have highest clump density. Similarly, flood affected villages have highest number of culms/clump (Table 1).

Culm density under clump age chronosequence revealed in riverside villages 15-yr old clumps have highest contribution over other clump ages. On the contrary, in flood unaffected villages dominant clump age group was 25 yr old, while in flood affected villages 20yr, 25yr, and 30 yr old clumps were the dominant age group (Figure 3).

Table 1. Culm and clump characteristics as affected by village physiography in Hailakandi district Assam

Village physiography	Species	Culm DBH (cm)	Culm Density no. ha^{-1}	Clump density no. ha^{-1}	Culms/clump
	Bambusa balcooa	10.38	270.37	5.22	51.20
	B. cacharensis	7.90	331.84	5.41	60.74
Flood unaffected	*B. jaintiana*	3.23	876.86	5.86	142.95
	B. nutans	7.48	318.28	5.14	61.57
	B. polymorpha	7.75	340.90	4.99	67.08
	B. vulgaris	9.68	267.69	4.71	54.88
	Average	7.74	400.99	5.22	73.07
	B. balcooa	10.51	254.64	5.02	53.61
	B. cacharensis	7.91	451.72	5.93	85.26
Flood affected	*B. jaintiana*	3.28	490.11	4.27	129.76
	B. nutans	7.55	380.27	5.48	71.68
	B. polymorpha	7.82	342.20	5.95	63.99
	B. vulgaris	9.60	356.63	5.55	67.61
	Average	7.78	379.26	5.37	78.65
	B.balcooa	10.46	415.75	7.00	55.21
	B. cacharensis	7.90	466.76	6.49	69.17
Riverside	*B. jaintiana*	4.68	482.29	6.25	78.70
	B. nutans	7.60	636.06	8.72	69.49
	B. polymorpha	8.41	443.53	7.76	56.69
	B. vulgaris	7.55	354.90	7.11	49.97
	Average	7.77	466.55	7.22	63.21
		F= 0.0004 p= 0.994	F= 1.353 p= 0.1077	F= 11.69 **p= 0.0027**	F= 28.75 **p= 0.0025**

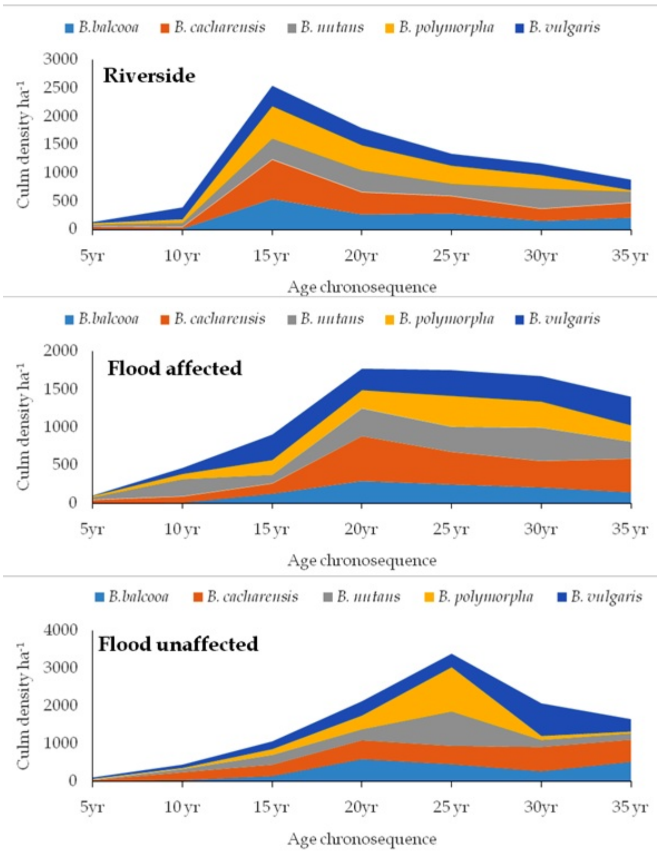

Figure 3. Age class distribution of different bamboo species with respect to village landscape in Hailakandi district

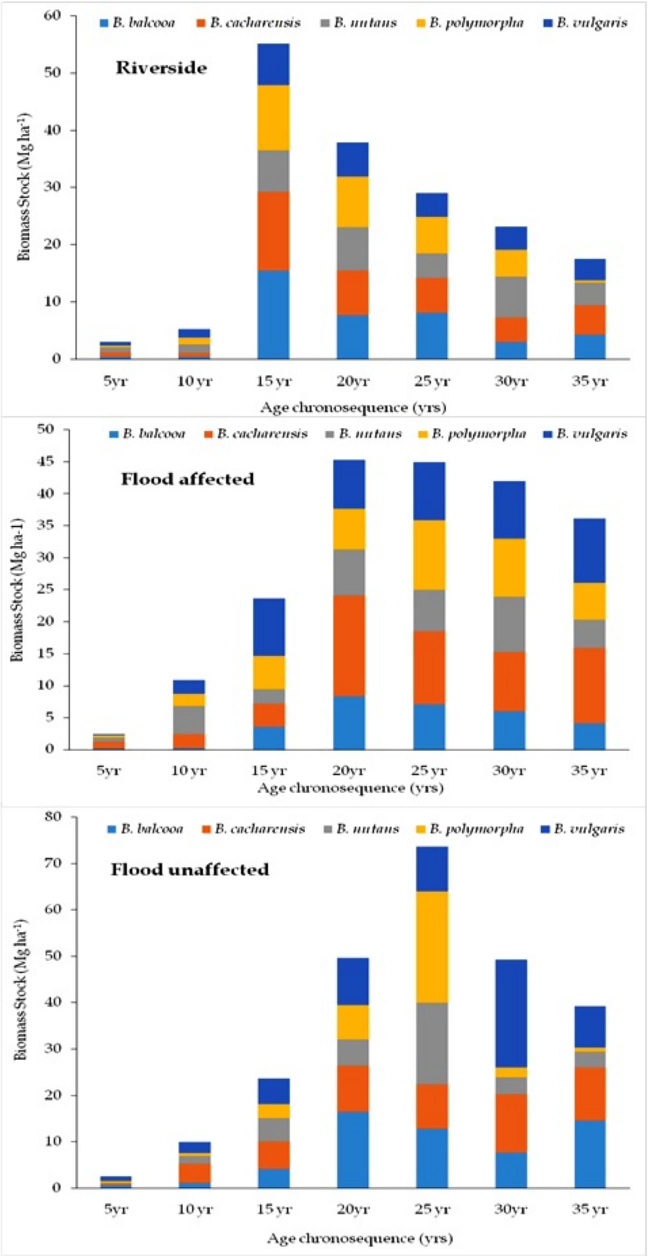

Figure 4. Biomass stock under age chronosequence of village bamboo clumps

Biomass Carbon Stock in Relation to Village Physiography

In riverside villages maximum biomass stock was stored in 15 yr old clumps with highest contribution by *B. balcooa* followed by *B. cacharensis* and *B. polymorpha* (Figure 4). In flood unaffected villages highest biomass was stored in 25 yr old clumps. *B. polymorpha* contributed highest biomass followed by *B. nutans*, and *B. balcooa*. Highest biomass stock was consistent under 20 yr and 25 yr old clumps in flood affected villages. Among the 20-yr old clumps, *B. cacharensis* contributed the maximum biomass followed by *B. balcooa*. Similarly, in 25 yr old clumps *B. cacharensis* contributed the highest biomass followed by *B. polymorpha* (Figure 4). The changes in biomass stock under age chronosequence irrespective of the bamboo species and village physiography revealed younger clumps (5 yr and 10 yr) contributed least to the standing biomass stock (Figure 5). In flood-unaffected and flood-affected villages, an exponential form best explained ($R^2 = 0.6646$ and $R^2 = 0.6726$ respectively) the changes in biomass stock with age chronosequence. In contrast, a polynomial form best explained the changes in biomass stock in relation to age chronosequence in riverside villages ($R^2=0.5852$) (Figure 5).

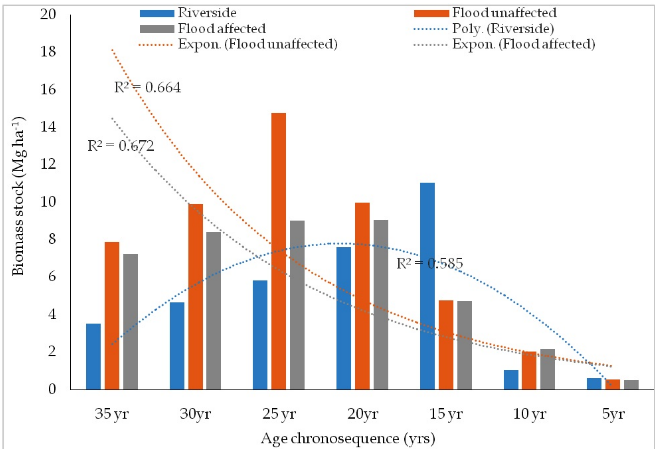

Figure 5. Changes in biomass stock in village bamboo clumps (irrespective of species)

Carbon Sequestration in Relation to Village Physiography

In all physiographic conditions carbon sequestration rate was higher under older clumps than in younger ones and varied significantly with the physiography (Table 2). In 15 yr old clumps carbon sequestration rate was higher in riverside villages (0.74 Mg ha^{-1} yr^{-1}). However, in 20 yr, 25 yr, and 30 yr old clumps carbon sequestration rate was higher in flood unaffected villages than in riverside and flood affected villages (Table 2). Across all the clump age group when carbon sequestration rate was computed *B. vulgaris* exhibited highest carbon sequestration rate in flood unaffected villages (0.39 Mg ha^{-1} yr^{-1}) over other species. Similarly, in flood affected and river-

Table 2. Carbon sequestration rate (Mg ha^{-1} yr^{-1}) under chronosequence of priority bamboo species in relation to village physiography

Village physiography	Species	5yr	10 yr	15 yr	20yr	25 yr	30yr	35 yr
Flood unaffected	*B. balcooa*	0.14	0.12	0.29	0.83	0.52	0.26	0.42
	B. cacharensis	0.07	0.42	0.39	0.49	0.38	0.42	0.33
	B. nutans	0.05	0.16	0.33	0.28	0.70	0.12	0.10
	B. polymorpha	0.06	0.06	0.20	0.37	0.96	0.07	0.03
	B. vulgaris	0.20	0.24	0.37	0.51	0.39	0.78	0.25
	Average	0.10	0.20	0.32	0.50	0.59	0.33	0.22
Flood affected	*B. balcooa*	0.03	0.02	0.24	0.42	0.28	0.20	0.12
	B. cacharensis	0.22	0.22	0.24	0.79	0.46	0.31	0.34
	B. nutans	0.12	0.44	0.15	0.36	0.26	0.29	0.13
	B. polymorpha	0.08	0.19	0.35	0.32	0.43	0.31	0.16
	B. vulgaris	0.04	0.21	0.60	0.38	0.36	0.30	0.29
	Average	0.10	0.22	0.31	0.45	0.36	0.28	0.21
River side	*B. balcooa*	0.08	0.05	1.03	0.38	0.32	0.10	0.12
	B. cacharensis	0.16	0.06	0.92	0.39	0.24	0.14	0.15
	B. nutans	0.16	0.15	0.48	0.38	0.17	0.24	0.11
	B. polymorpha	0.08	0.12	0.77	0.44	0.25	0.16	0.01
	B. vulgaris	0.12	0.15	0.48	0.30	0.17	0.14	0.11
	Average	0.12	0.10	0.74	0.38	0.23	0.15	0.10
		F= 0.205 p= 0.818	F= 1.872 p= 0.230	F= 5.895 **p= 0.034**	F= 6.895 **p= 0.024**	F= 6.964 **p= 0.021**	F= 7.639 **p= 0.016**	F= 2.882 p= 0.124

side villages the highest carbon sequester species was *B. cacharensis* (0.37 Mg ha^{-1} yr^{-1}) and *B. balcooa* (0.30 Mg ha^{-1} yr^{-1}) respectively.

DISCUSSION

Bamboo is an important agroforestry and forest plant managed and used by the rural communities in several countries of the Asia-Pacific region for generating diverse economic and socio-environmental needs (Nath et al. 2015). The rural lives in Hailakandi district, Barak Valley are also intricately linked with the village bamboos. Evaluation of villager's priority village bamboo species revealed the highest priority species changes with the village physiography. Such changes may be attributed to community living and managing the bamboo and their choice for a particular species for their requirement. Overall dominance of *B. cacharensis* in Hailakandi district resembles the findings of Nath and Das (2008) where *B. cacharensis* was the highest priority species in home gardens of Cachar district. The greater dominance of *B. cacharensis* in home gardens of Barak valley is due its high preference for household requirements, its wider adaptability, straight culms and short culm growth period (Nath and Das 2012).

Influence of soil physical and chemical properties on characteristics of *B. balcooa*, *Teinostachyum wightii, Melocanna baccifera,* and *Dendrocalamus giganteus* have been reported from North Eastern Himalayan region (Venkatesh et al. 2005). Therefore, different soil characteristics under diverse village physiographic condition might have triggered the differences in culm and clump characteristics between the species and village physiography.

An age chronosequence study on different village bamboo species in relation to village physiography illustrates that younger clump ages are least distributed. However, in comparison to riverside and flood unaffected villages, 5 yr and 10 yr old clumps were more in flood affected villages. Sparse distribution of younger clumps could be due to limited availability of space in home gardens. Bamboo cultivation is an age old practice in Barak Valley and over the period villagers have planted and managed such resources (Nath and Das 2012) leading to saturation of land: plant ratio in homegardens.

Comparatively the distribution of above ground standing biomass stock was higher in flood unaffected villages than flood affected and riverside villages. Higher standing biomass stock in flood unaffected villages is attributed better management systems like selective felling, and manuring (litter residue) that are being practiced by the villagers for sustainable harvest and production system. In contrast, the primary objective of bamboo management in riverside and flood affected villages is to promote adaptive and mitigative strategy against flood and erosion loss. In the absence of better management systems village bamboos being grown in riverside and flood affected villages contributed comparatively less standing biomass stock than flood unaffected villages. The estimated biomass stock of the present study (0.14-24 Mg ha^{-1}) is comparable with corresponding reported values of 23.7 Mg ha^{-1}for *Fargesia spathacea* (Taylor and Zisheng 1987), but lies at the lower end of the other reported values like 138 Mg ha^{-1} for *Phyllostachys pubescens* (Isagi et al. 1997); 110 Mgha^{-1} for *Yushania alpine* (Embaye et al. 2005), 286 Mg ha^{-1} for *Bambusa bambos* (Shanmughavel and Francis 1996); 170.8-257.3 Mg ha^{-1} for *B. bambos* (Das and Chaturvedi 2006); 44.7 Mg ha^{-1} for *Schizostachyum dullooa*, 43.0 Mg ha^{-1} for *Pseudostachyum polymorphum,* and 118 Mg ha^{-1} for *Melocanna baccifera* (Singnar et al. 2017). The reduced biomass stock in the bamboo species of the present study is due to: (i) in the homegarden, bamboos are grown as one of the constituent of the multi species tree based system and hence the stand density of the bamboo is low, and (ii) low culm density contributed to reduced biomass stock. In the present study highest culm density was estimated at 1177 culms ha^{-1} by *B. polymorpha* in flood unaffected villages, 590 culms ha^{-1} by *B. cacharensis* in flood affected villages, and 694 culms ha^{-1} by *B. cacharensis* in riverside villages. In comparison to culm density of the present study, culm density of the bamboo forests in North East India was reported at 32376, 43000, and 39075 culms ha^{-1} for *S. dullooa*, *P. polymorpha*, and *M. baccifera* respectively (Singnar et al. 2017). Therefore, standing culm density in any system (forest/homegarden) is one of the important drivers for determination of biomass stock.

In flood unaffected villages, carbon sequestration rate under older clumps (0.33-0.59 Mg ha^{-1} yr^{-1}) was higher than flood affected (0.28-0.45 Mg ha^{-1} yr^{-1}) and river side (0.15-.38 Mg ha^{-1} yr^{-1}) villages. Across the different bamboo species, clump ages and village physiography the estimated carbon sequestration rate ranges from 0.2-0.74 Mg ha^{-1} yr^{-1} is lower than earlier reports of 1–14 Mg ha^{-1} yr^{-1}(Yuen et al. 2017). The reduced carbon sequestration rate is due to observed reduced culm density in the homegardens of the study area. In spite of reduced carbon sequestration rate in the village bamboos they can be an important sink of carbon due to (i) village bamboos are selectively felled every year and therefore stored biomass carbon is a permanent sink, (ii) village bamboo under investigation flowers sporadically (Banik 2000) and therefore conserves carbon against the uncertainty of concomitant carbon loss through flowering and die back event.

CONCLUSIONS

Based on the village physiography villagers have evolved their own priority species depending on their species specific choices. Agroforestry expansion with emphasis on bamboo could enhance the growing stock of younger culms in the village landscapes. Further, intensification of bamboo management system in homegarden will increase the culm density and subsequently enhanced biomass carbon stock of such systems. We suggest future studies to explore the below ground biomass and soil organic carbon stock to represent the ecosystem carbon stock of such systems for better understanding their role in carbon management.

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Author contributions: AKD and AJN formulated the research work. AFM and AJN analyzed the data and wrote the first draft. All authors jointly discussed the results, drew conclusions and finalized the manuscript. All authors read and approved the final manuscript.

Competing interests: The authors declare that they have no competing interests.

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Annexure I

QUESTIONNAIRE

PART: A

Information about the village surveyed:

1. Name of the village:
2. Name of the block:
3. Physiography of village:
4. Infrastructural information:

- Schools present in the village:
- Hospitals/Health centers present:
- Transport and communication:
- Distance from the town:

PART: B

Information about the family, bamboo resources, management and utilization of bamboo:

1. Name of the villager/respondent:
2. Age of the respondent:
3. Size of the family:
4. Type of family: Nuclear / Joint
5. Literacy status: Below HSLC / HSLC / HS / Graduate / Post Graduate
6. Occupation:
7. Type of house:
8. Roofing pattern of the house:
9. Area of the homegarden:
10. Area of extended homegarden (if any):
11. Area under bamboo plantation:
12. Area of agricultural land:
13. Bamboo species grown :

Bamboo pecies	Clump number	Age of the clump	Current year	Girth	Number & girth of culms in each clump							
					1 yr old	Girth	2 yr old	Girth	3 yr old	Girth	4 yr old	Girth

14. Bamboo species preferred:
    1. 1st preference:
    2. 2nd preference:
    3. 3rd preference:
15. Why preferred?
16. Harvesting pattern: Selective / Clear felling
17. Time of harvesting:
18. Uses of bamboo:
    - Commercial use:
    - Non- commercial use:
19. Utilization of bamboo for bamboo crafts:

Sl. no.	Name of the product	Local name of the product	Utility	Bamboo species used	Market value per item.

20. Management practices:

- Yearly soiling:
- Application of fertilizer:
- Burning of litter:
- Weeding:
- Any other practices:
-

21. Interest for growing new bamboo plantation:

22. Method of propagation followed:

- Selection of mother plant:
- Age of the planting material:
- Length of the planting material:
- Selection of planting site:
- Time of planting:
- Pit preparation:
- Irrigation after planting:

23. Interest for knowing or learning the technical skills for making bamboo products