Estimation Procedures of Indicators and Variables of the Bangladesh Forest Inventory

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The Forest Department of Bangladesh leads actions to improve forest management and conservation, adopting forward thinking, innovative approaches in its management of approximately 1.55 million hectares of land across the country.

In 2015, the Forest Department began a process to establish a National Forest Inventory and Satellite Land Monitoring System for improved forest and natural resource management. The process supports national objectives related to climate change mitigation and provides information in support of the UN REDD programme aimed at Reducing Emissions from Deforestation and Forest Degradation (REDD+). The process also addresses domestic information needs and supports national policy processes related to forests and the multitude of interconnected human and environmental systems that forests support.

The activities implemented under the Bangladesh Forest Inventory process are collaboration between several national and international institutions and stakeholders. National partners from multiple government departments and agencies assist in providing a nationally coordinated approach to land management. International partners, including the United Stated Agency for International Development (USAID), the Food and Agriculture Organization of the United Nations (FAO) and SilvaCarbon are supporting the development of technical and financial resources that will assist in institutionalizing the process.

The results will allow the Forest Department to provide regular, updated information about the status of trees and forests for a multitude of purposes including for assessment of role of trees for firewood, medicines, timber, climate change mitigation.

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DISCLAIMER

This document is designed to reflect the activities related to the Bangladesh Forest Inventory process. It does not reflect the official position of the supporting international agencies including USAID, FAO or SilvaCarbon and should not be used for official purposes. Should readers find any errors in the document or would like to provide comments for improving its quality they are encouraged to contact one of above contacts.

Contents

List of Acronyms

AE	Allometric Equation
AGB	Above Ground Biomass
BD	Bulk Density
FD	Forest Department
BFI	Bangladesh Forest Inventory
BFIS	Bangladesh Forest Information System
BGB	Below Ground Biomass
CAGB	Carbon in AGB
CBGB	Carbon in BGB
CDWM	Carbon Down Woody Matter
CWD	Coarse Woody Debris
DBH	Diameter at Breast Height
DGPS	Differential Global Positioning System
DWM	Down Woody Matter
FAO	Food and Agriculture Organization of the United Nations
FGD	Focus Group Discussion
FRA 2020	Global Forestry Resource Assessment 2020
FWD	Fine Woody Debris
GS	Growing stock
HH	Household
NLRS	National land class representation system
QAQC	Quality Assurance and Quality Checking
RFID	Radio-frequency Identification
SFM	Sustainable Forest Management
SOC	Soil Organic Carbon
SP	Subplot
TC	Tree Cover
WD	Wood Density

Estimation Procedures of Indicators and Variables of the Bangladesh Forest Inventory

1 Introduction

Historically, forest inventories have been commodity oriented with more emphasis on estimating the commercial aspects of forests such as area, timber volume etc. Over time the conceptual basis of the national forest inventories has been changed. Now-a-days forest inventory data focuses on broader ecological, social and environmental issues such as biodiversity, forest restoration, recreation and aesthetics, ecosystem services, livelihoods, disturbances and vulnerabilities.

The Bangladesh Forest Inventory (BFI) was implemented from 2016 to 2019 by the Forest Department (FD) with technical support from Food and Agriculture Organization of the United Nations with cross-disciplinary collaboration from affiliated government agencies, academic institutions, non-government organizations, private industry and development partners. It's a multi-purpose process and the centerpiece of forest monitoring system with approaches to socio-economic, forest resources and tree cover monitoring. The ultimate goal is to support the Government's activities towards sustainable forest management (SFM) by producing reliable datasets on forests, trees and livelihoods which inform planning, interventions, and national and international frameworks such as Sustainable Development Goals (SDG's).

In order to better manage the interactions between people and natural resources for SFM, the BFI is integrated with field inventory, remote sensing and socio-economic survey information. Through field inventory biophysical data has been collected from pre-designed sample plots whereas socio-economic data has been collected from households across the country. Remote sensing technology was applied for land cover classification and mapping through collaborative efforts of different expert agencies. The wide ranges of data produced through these surveys are the basis for estimation of the criteria, indicators and variables outlined in GoB (2017a).

Criteria and indicators are the key for monitoring the achievements or process towards sustainable forest management whereas variables are established by data that enhances the specificity of an indicator. C&I framework delineated in GoB (2017a) was developed under BFI for sustainable management of trees and forest resources, fulfilling the national and international reporting requirements as well as policy makers' data needs.

This document describes the methods for estimating the BFI indicators. It also outlines the integration techniques of selected socio-economic information to the biophysical ones. Ratio to size estimators were used for uncertainty estimation across the strata and subpopulations. The document references a number of supplementary documents which provide details about all aspects of the BFI design, enumeration methods, data management, relevant trainings and sample-based estimation systems. The primary intended audience for this document is the BFI program itself with purposes to ensure sustainability, adoptability, adaptability and feasibility of the estimation process considering the manpower and organizational setup of FD. Nevertheless, other user and stakeholder will find it useful for understanding technical details and statistical techniques of the BFI indicator and variables estimation as well as the integration process.

2 An overview of the BFI

The BFI is a constant and comprehensive process that assesses, evaluates, interprets and reports on the status of trees and forest resources nationally. Field implementation of BFI is completed in three sessions (2016-17, 2017-18 and 2018-19) starting with biophysical survey from November 2016 and completed in April 2019. On the other hand, households' interviews of socio-economic survey were conducted during 2017-18. The characteristic features of BFI are-

- Integration of remote sensing, biophysical and socio-economic survey for relating trees and forest to society and environment,
- Dissemination of knowledge on forestry technologies by using latest equipment and open sourced tools for data management,
- Quality assurance and quality control through hot and cold check of 10% sample plots of biophysical survey and hot checking 5% household interviews in socio-economic survey,
- Establishment of a Bangladesh Forest Information System (BFIS) for providing user access to the information.

In both surveys, field data collection, data cleaning, quality control, and data archiving were part of a simultaneous process performed both in the field and in the central office (BFD, 2016b, 2016e, 2017b; M. F. Kumar, Costello, Mahamud, Henry, & Johnson, 2017). Biophysical estimation were done in R statistical software version 3.5.0, while socio-economic estimations were done using Stata statistical software. The R-scipts are be found in the BFIS e-library (Section 2.4) (M. A. Hossain, 2017; M.A. Hossain, Laurent, & Birigazzi, 2017; M.A. Hossain, Laurent, Sola, Birigazzi, & Aziz, 2017; Laurent & Hossain, 2017). Figure 1 shows an overview of the process and more details that are specific to the surveys are presented below.

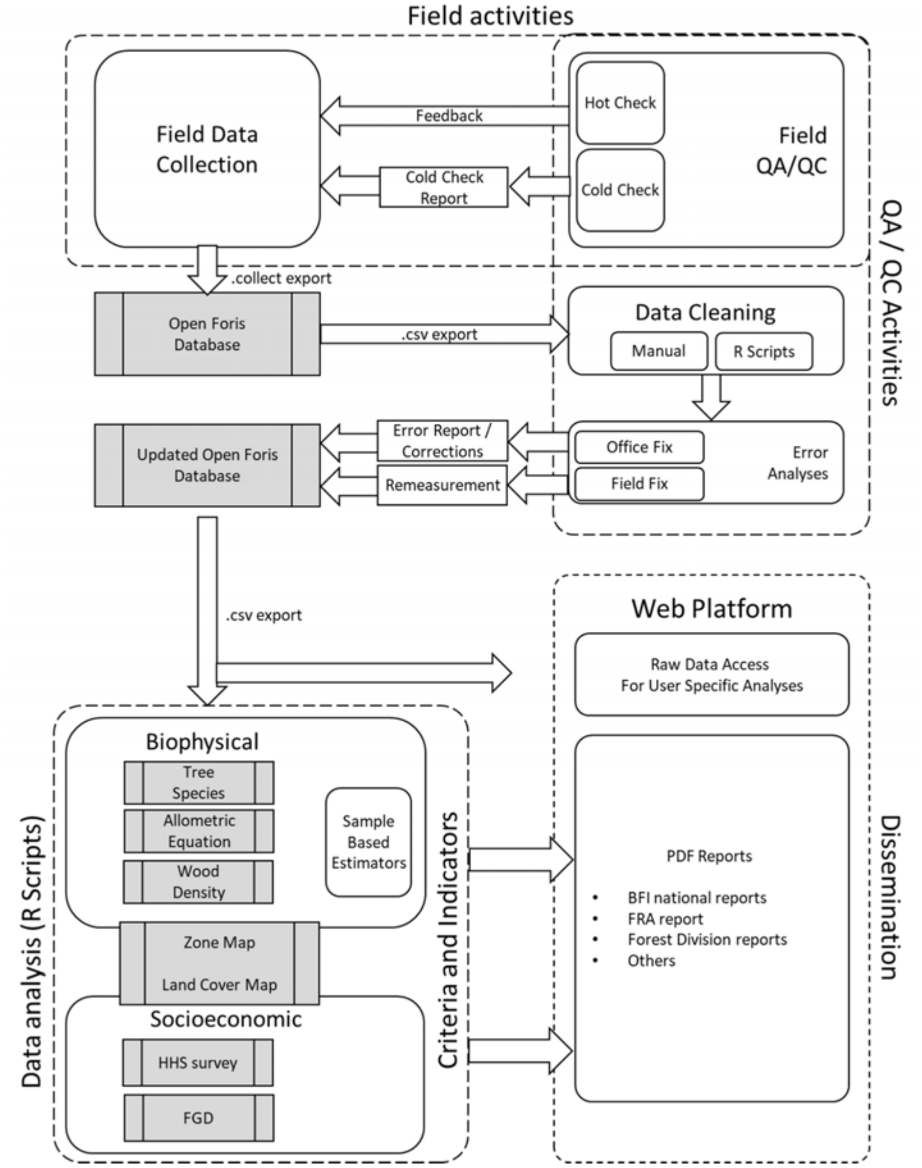

Figure 1: Flow diagram of the data management, data cleaning, QA/QC and estimation processes used in the biophysical and socio-economic surveys

2.1 Biophysical inventory

The biophysical inventory follows a stratified systematic random sample design (Iqbal et al., 2016) consisting of five zones based on the climatic and geophysical properties of Bangladesh (BFD, 2016f). The design of BFI is a pre-stratified systematic sampling with specified sampling intensities for each zone. In order to capture the national level data within an acceptable range of error with relatively low sampling intensity, a total of 1858 permanent sample plots were fixed for field survey. Neyman allocation was followed for allocation of plots at different ecozones (Cochran, 1977). The principle was to measure each plot in one day and which were consisted of 3 and 5 subplots of 19m radius in Sundarbans and the other zones respectively. The measurement of the field plots was performed by 13 field inventory teams and five quality assurance and quality control (QAQC) teams were responsible for verification of data by ensuring the implementation of the 7% hot and 3% cold checks provided that the budget is available (Iqbal et al., 2016). Moreover, to record the precise location of the samples plots another manual on Differential Global Positioning System (DGPS) use and Radio-frequency Identification (RFID) chip installation was prepared for the respective team. The inventory teams including the field and quality checking teams were trained on the species identification and recording, calibration and use of the instrument, using field forms for data input, land feature and issues identification.

2.1.1 Overview of the collected data

Two versions of Open Foris were used in the BFI program whereas Open Foris Collect Mobile was installed in handheld electronic tablets for data collection and Open Foris Collect was installed in centralized desktop computer for data receiving and processing. The data collected through biophysical survey relate to plot and subplot location, land feature, trees and sapling details, seedlings, down woody debris, soil and litter measurement, bamboo etc. Trees with DBH ≥ 30 cm were measured in 19m plot whereas trees with DBH ≥ 10 and DBH ≥ 2 cm were measured in 8 m and 2.5 m radius plots respectively. The trees were categorized as live, dead standing, live stump and dead stump status. Soil samples were collected at 8m at 270° bearing from the subplot center. Moreover, from each plot detail data were collected on the plot location, land feature, land ownership, down woody debris, bamboo and seedlings. Description and technical details of data collection are presented in BFD (2016) and Iqbal et al. (2016). Table 1 presents more detailed documentation of survey design, field instructions, soil sampling, data management and trainings.

Table 1: List of Bio-physical manuals, trainings, and R-scripts provided to the field teams for smooth and consistent data collection, recording and management.

Manuals
BFD (2016). Field Instructions for the Bangladesh Forest Inventory (Version 1.2). Forest Department and Food and Agricultural Organization of the United Nations, Dhaka, Bangladesh.
BFD. (2016). Manual for Soil Measurements for The Bangladesh Forest Inventory. Bangladesh Forest Department and Food and Agricultural Organization of the United Nations. Dhaka, Bangladesh. ISBN: 978-984-34-2714-4
BFD (2016). Quality assurance and quality control for the Bangladesh Forest Inventory. Bangladesh Forest Department and Food and Agricultural Organization of the United Nations, Dhaka, Bangladesh. ISBN 978-984-34-2713-7
Kumar, M. F., Costello, L., Mahamud, R., Henry, M., Johnson, K. (2017) Bangladesh Forest Inventory Data Management Protocol. Bangladesh Forest Department and Food and Agricultural Organization of the United Nations. ISBN: 978-984-34-4275-8
Kumar, M. F., Mahamud, R., Costello, L., Sarkar, N., Johnson, K., Hossain, A.M., Henry, M. (2017). Field Manual on DGPS and RFID chip for Bangladesh Forest Inventory. Forest Department and Food and Agricultural Organization of the United Nations. Dhaka, Bangladesh. ISBN 978-984-34-4276-5
BFD. 2016. Protocol for Describing Land Features in Bangladesh, Data Collection Field Manual. Bangladesh Forest Department and Food and Agriculture Organization of the United Nations, Dhaka, Bangladesh.

Trainings
Akhter, M. and L. Costello (2016). Proceedings of the Equipment training for the implementation of BFI, Bangladesh Forest Department and Food and Agriculture Organization of the United Nations.
Akhter, M. & Costello, L. 2016. Proceedings of the Training on Bangladesh Forest Inventory. 6-12 October 2016, BRAC CDM, Gazipur, Forest Department and Food and Agriculture Organization of the United Nations.
Chakma, N. (2016). Proceedings of the Information sharing meeting on Bangladesh Forest Inventory implementation in the Chittagong Hill Tracts (Rangamati, Khagrachari and Bandarban hill district), Bangladesh Forest Department and Food and Agriculture Organization of the United Nations.
Falgoonee, K. M. & Henry, M. 2016. Proceedings of the Training of Trainers for the Bangladesh forest inventory. 02-08 October 2016, Dhaka, Bangladesh Forest Department and Food and Agricultural Organization of the United Nations.
Kumar, M. F., Iqbal, M. Z., Mahmood, H., Costello, L., Henry, M., Rahman, L. M., Jalal, R., Das, S., Sidik, F., Hayden, H., Birigazzi, L., Uddin, M., Uddin, N., Akhter, M., Newaz, Y., Siddiqui, B, N., Sola, G., Ahmed, I., Nishad, H, M., Salahuddin, M., Rahman, M., Chowdhury, R, M., Hossain, B., Siddique, A, B., Rashed, A, Z, M, M., Misbahuzzaman, K., Siddique, M. R. H., Hoque, S., Hasan, M. N. (2017), Training materials for the biophysical component survey of the Bangladesh Forest Inventory – concepts, planning and procedures, Forest Department, Ministry of Environment and Forests, Government of the People's Republic of Bangladesh. ISBN: 978-984-34-2716-8
Mahamud, R., et al. (2017). Proceedings of Second DGPS training for the Bangladesh Forest Inventory, Bangladesh Forest Department and Food and Agriculture Organization of the United Nations.
Kumar, M. F., et al. (2017). Proceedings of The Bangladesh Forest Inventory field teams Refresher training, Bangladesh Forest Department and Food and Agricultural Organization of the United Nations.
Uddin, N. (2016). Proceedings for the training on tree species identification. Bangladesh Forest Department and Food and Agriculture Organization of the United Nations. Dhaka, Bangladesh.
R-scripts
Hossain, M. A. 2017. R-Script for Quality Assurance and Quality Checking of Bangladesh Forest Inventory Soil and Litter Data. Food and Agriculture Organization of the United Nations, Dhaka, Bangladesh.
Hossain, M. A., Laurent, S. & Birigazzi, L. 2017. R-Script for Bangladesh Forest Inventory Data Analysis. Food and Agriculture Organization of the United Nations, Dhaka, Bangladesh.
Hossain, M. A., Laurent, S., Sola, G., Birigazzi, L. & Aziz, T. 2017. R-Script for Bangladesh Forest Inventory Data Quality Assurance and Quality Checking. Food and Agriculture Organization of the United Nations, Dhaka, Bangladesh.

Field data collection concluded by visiting 1781 out of 1858 plots (1480 accessible, 301 partially accessible), or 96% of the total. Among those plots which were not visited were 42 inaccessible plots (2.3%) and 35 non-sampled plots (1.9%) (Figure 2). Partially accessible plots were cases where at least one subplot could be measured but other subplots were not possible to measure due to water (44%), hazardous condition such as steep slopes (25%), wall or building (21%), or other reasons such as denied access, restricted areas or border areas (10%). In the case of inaccessible plots, a visit was attempted but tree measurements were not possible, most commonly due to the plot center falling inside hazardous conditions such as steep slopes (52%), water (33%), or other reasons such as denied access, restricted areas, or wall or building (15%). Still, some information could be collected from inaccessible plots such as parameters for assigning land cover classes. Finally, a non-sampled plot status means that no parameter was measured on any subplot, usually due to plot falling in an extremely remote location (69%), restricted area (20%), or other reason such as water or border area (11%). The effect of inaccessible and non-sampled plots is not expected to substantially bias national or zone level estimates because they were relatively few (12% of the Hill zone plots; 4% of the total) and mostly randomly distributed.

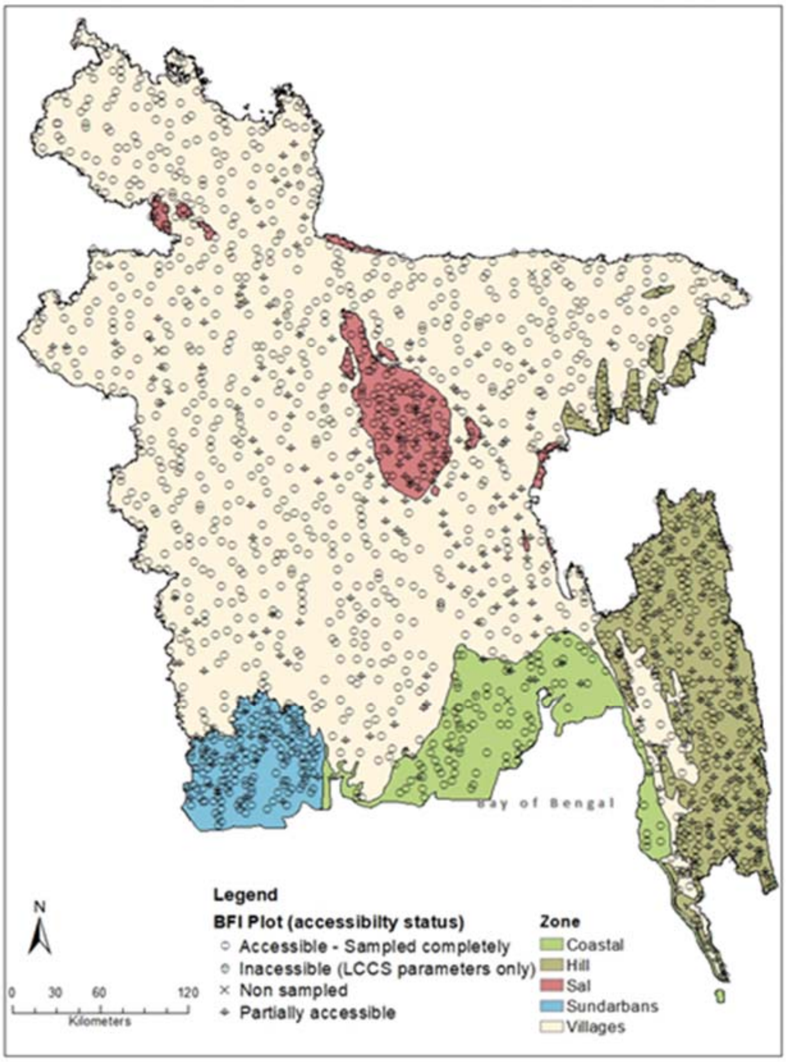

Figure 2: The distribution of plots according to the accessibility status

2.1.1.1 Data management and cleaning

The data collected though Open Foris Collect Mobile are is exported to a Dropbox folder in '.collect-data' files and then imported to the Open Foris desktop version every day for conversion to other data formats (e.g. .csv, .xml). At this point, the data are used for analysis. In cases of unavailability of communication networks or other problems, field teams submit data to BFI unit through USB toolkits (i.e. pen drive etc.) or email. After importing, the data is archived into the mass storage for future backup. MS Access and R code were used for updating the database regularly by doing necessary queries. For data cleaning and cold checking individual plot reports were prepared as .pdf from MS Access. Preliminarily, data cleaning was done in the Open Foris platform manually based on the errors identified in the plot report. After cleaning data in Open Foris platform they were then extracted in .csv form for identifying the inconsistencies or outliers through customized R-scripts. Then, based on the QC reports from R-scripts, data cleaning is done for 2nd time in Open Foris. After the cleaning is completed, cleaned data is then exported in the.csv format for analysis using customized R-script.

2.1.1.2 Allometric models

Volume and biomass were the two most important variables as revealed in different stakeholder consultations. Species or site specific Allometric Equations (AE) that represent as much as possible ecological conditions are essential for the estimation of biomass. Under the BFI program, the existing 517 allometric equations were considered and reviewed based on statistical credibility, applicability, operational and conceptual validity (Table 2). A total of 222 models belonging to 39 plant species were reported valid among which were 189 species specific tree allometric equations (representing 35 tree species). These equations were suitable to use in the calculation of parameter of interest (i.e. volume, biomass etc.) at different levels but still the number of AE was insufficient considering the diversity of tree species and ecosystems in Bangladesh (M. Hossain, 2016; M Hossain, Siddique, & Akhter, 2016). The details of model validation process is described in M. Hossain (2016) along with the list of all 222 varied models.

Table 2:Number allometric equations according to tree forms and nature of equation (Mahmood et al. 2016) [here, T = total number of equations, V= Number of verified equations]

Tree forms	Number of equations based on their nature													
	Volume		Green biomass		Oven-dried biomass		Air-dried biomass		Carbon		Nutrients		Length of split leaf	
	T	V	T	V	T	V	T	V	T	V	T	V	T	V
Tree	360	138	78	44	11	10	0	0	25	1	3	3	0	0
Palm	0	0	2	0	0	0	0	0	0	0	0	0	1	0
Bamboo	0	0	3	0	0	0	3	0	0	0	0	0	0	0
Total	360	138	83	44	11	10	3	0	25	1	3	3	1	0

2.1.1.3 Development of new allometric models

Among the validated models, there were 20% green-biomass equations, 12% oven-dry biomass equations, and 62% were volume equations which were not deemed suitable to apply to the more than 300 tree species found in the inventory. Therefore, to meet this need, five initiatives were taken to develop four zone specific allometric equations and six major tree species-specific equations (Akhter, Hossain, & Birigazzi, 2013; M Hossain et al., 2016). Several training programs were organized for capacity development of the national stakeholders for developing the equations. Then, field work was conducted to collect tree data using semi-destructive methods including, wood density, biomass and carbon expansion factors (Table 3). The list of newly developed allometric equation that are not in M. Hossain (2016) are provided in Table 7.

2.1.1.4 Decision tree for selection of allometric equation

A decision tree for selecting allometric equation is designed that is divided into two parts i) Route A and ii) Route B (Figure 3**)**. In route A, there are 7 levels based on the area of consideration i.e. species, genus, diameter range and zone. Since there is no country specific equation, so Pan-tropical equations will be considered if there is no equation, for any species, upto level VI. According to this route if, for a species, equation is available at species level then following levels will be ignored. If, for any species, equation is not available at species level then equations at immediately next, "genus", level will be searched if no equation is available at that level also then equation under the next level "species without diameter range" will be looked for and this procedure will be followed upto "zone equation without diameter range" level. If no equation is found at that level also then pantropical equation will be used for tree biomass calculation. Route B is to be followed after the levels, at which equation is available, being selected. This route is same for all levels.

In route B there are four ways for each level which are mainly consisted of forest zone, tree forms (palms, bamboos and other trees) and diameter range. Ways situated hierarchically in upper positions and with more options is given priority. However, after following any of the ways, in case of multiple equations for a certain species, the criteria at the right corner of route B will be followed in order to select one final equation for biomass calculation of that species. Among the criteria, extent of biomass calculation (total or partial), greater diameter range, vastness of sample size, higher coefficient of determination will be given priority based on the hierarchical positions as shown in the Route B (Figure 3). The decision tree is expected to fit the Bangladesh perspective for accurate assessment of tree biomass.

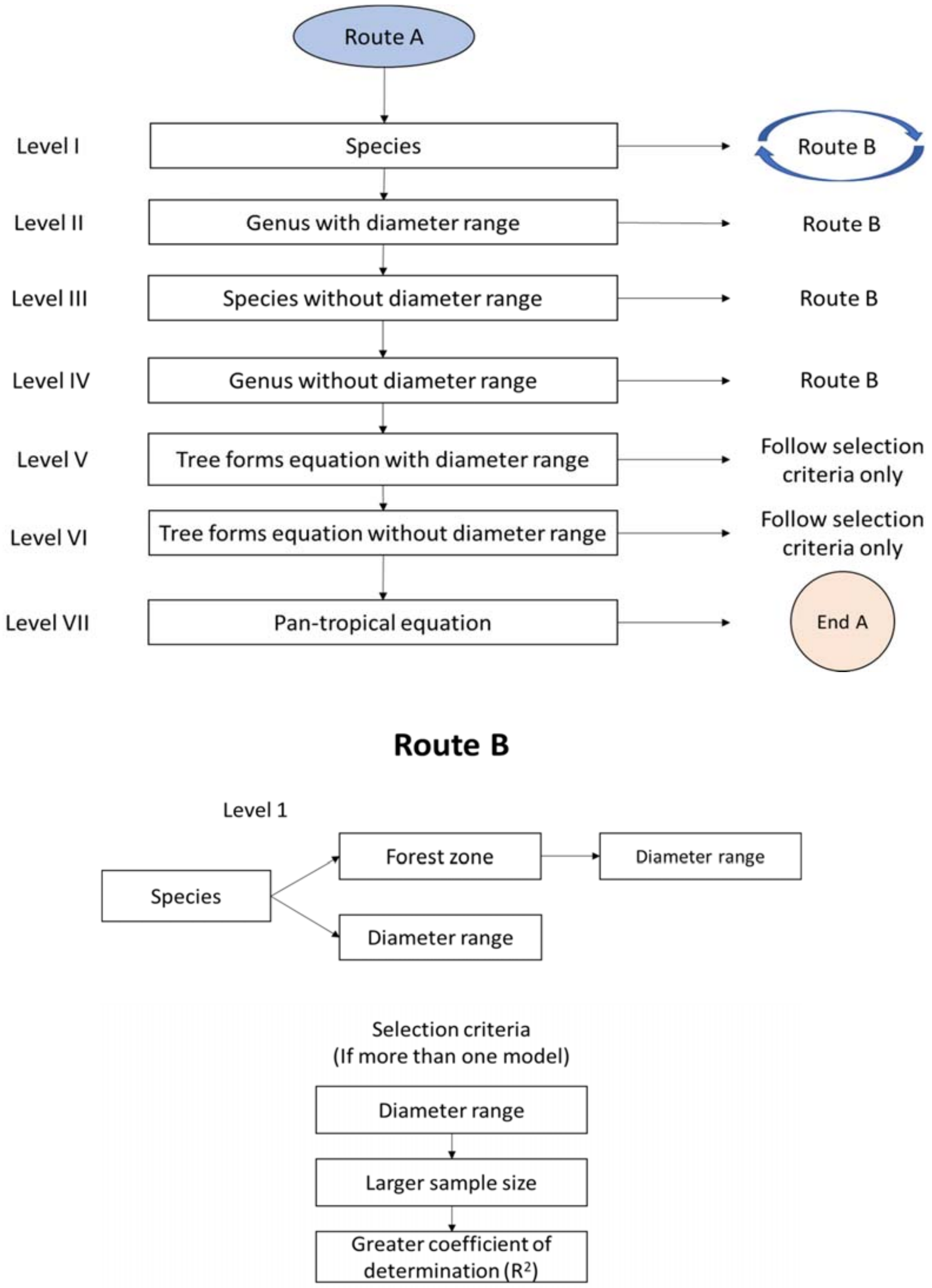

Figure 3: Decision tree for selecting allometric equation to estimate tree biomass

Table 3: List of Allometric Equaltion manuals, protocols, trainings proceedings, and other publications

SN	List of manuals, protocols and training proceedings on allometric equation development
1	Hossain, M. (2016). Improved National Tree Allometric Equation Database to Support Forest monitoring and Assessment of Bangladesh. Bangladesh Forest Department, Food and Agricultural Organization of the United Nations, Dhaka and Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh.
2	Hossain, M. (2016). Proceedings of the training on tree allometric equation development and use, Dhaka, Bangladesh Forest Department and Food and Agriculture Organization of the United Nations.
3	Hossain, M. (2016). Proceedings of the National Consultation Workshop on Tree Allometric Equations in Bangladesh, Dhaka, Bangladesh Forest Department and Food and Agriculture Organization of the United Nations and Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh.
4	Hossain, M. (2016). Proceedings of the Training on Sample Processing and Laboratory Analysis for the Development of Allometric Equation, Bangladesh Forest Department, Food and Agriculture Organization of the United Nations, and Forestry and Wood Technology Discipline, Khulna University, Bangladesh.
5	Mahmood, H., Siddique, M.R.H., Abdullah, S.M.R., Akhter, M. and Islam, S.M.Z. (2016). Manual for Building Tree Volume and Biomass Allometric Equation for Bangladesh. Bangladesh Forest Department and Food and Agricultural Organization of the United Nations, Dhaka, Bangladesh. ISBN 978-984-34-2711-3
6	Mahmood, H., Siddique, M.R.H., Abdullah, S.M.R., Matieu, H (2016). Training Manual: Sample Processing and Laboratory Analysis for the Development of Allometric Equation. Bangladesh Forest Department and Food and Agricultural Organization of the United Nations, Dhaka, Bangladesh. ISBN 978-984-34-2710-6
7	Mahmood, H., Siddique, M.R.H., Abdullah, S.M.R., Akhter, M., Islam, S.M.Z. 2016. Field measurement protocol on tree allometric equations for estimating above-ground biomass and volume in Bangladesh. Food & Agriculture Organization of the United Nations, Rome, Italy and Forest Department, Government of the People's Republic of Bangladesh, 95 pp.
8	Mahmood, H. (2018). Common tree allometric equations for the Sundarbans, Coastal and Village zone of Bangladesh, 52 pp.
9	Mahmood, H. (2018). Proceedings of the training on- Data and sample analysis for the hill zone allometric equation development. 17 pp.

2.2 Socio-economic survey

The socio-economic survey is designed to provide information about the interactions between people and tree and forest resources as well as the valuation of tree and forest ecosystem services. Specifically, the design aimed to achieve both national estimates of and also the spatial comparisons between areas of greater versus lower impact or dependence on tree and forests. The survey was designed by multiple partners and approved by Bangladesh Bureau of Statistics (GoB 2017b).

2.2.1 Overview of the survey design

A multi-stage random sample was used for the stratification of the survey (GoB 2017b). The assumption was made that tree and forest ecosystem services and their relationship with local households depends on the quantity of tree and forest resources and tree cover per household. Tree cover was obtained from remotely sensed Landsat data from 2014 (Potapov et al., 2017), and household data from the 'Population and Household Census - 2011' dataset (BBS, 2016). The variable Household Tree Availability or percent tree cover per household (%TC HH-1) was calculated for each union or ward:

Household Tree Availability = ((TC area)/(Union area))/(Number HH's)=(%TC)/HH.

This metric was then defined into four Household Tree Availability Classes (HTAC) within each zone by quartiles. The unions were classified using those four HTAC classes. Thus, the total sub-strata were 4 classes * 5 zones = 20 strata. The first quartile represents lowest %TC but highest number of HH's per union. In other words, strata 1 represents the lowest availability of tree and forest resources, or the highest impact of the people on their resources, and strata 4 may represent the highest availability due to lowest impact. Once the strata were defined, and to give the equal allocation of union to each stratum, 16 unions (or wards) were randomly sampled from each strata (GoB 2017b).

To select which households would be surveyed within the pre-selected unions, 10 GPS points (five first option and five second option) were placed randomly within the Rural Settlement land cover class (Figure 4). Interviewers then navigated to five GPS points and chose the nearest four households to interview so that 20 households were visited in each union. A total of 6400 household from 320 unions were surveyed (20 strata * 16 unions * 20 households = 6400 total households). The 2015 Land Cover Map was used by enumerators to ask respondents from which land cover certain primary products were collected (BFD, 2017). The full questionnaire can be found in the Appendix 2.62.

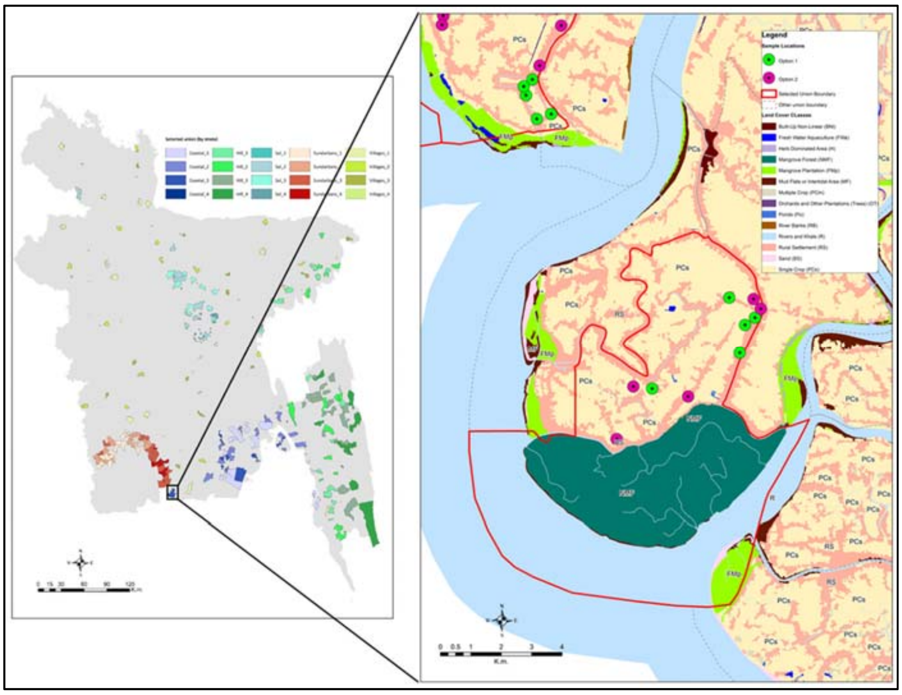

Figure 4:Left: Map of 320 unions selected for socio-economic field data collection stratified by 20 HTAC's. Right: Map of a single union indicating 10 GPS points where field teams chose to visit either even or odd numbers, but not both, for a total

In addition, 100 a qualitative survey was conducted through conducting 100 FGDs (Focus Group Discussion) across the zones (20 in each zone) where 8-10 participants including community leader and special forest user groups participated. In FGDs the location specific forest and socio-economic attributes were focused in the discussion (GOB, 2017b).

2.2.2 Data collection, management, and cleaning

A questionnaire including all the variables meeting the objective of the socioeconomic survey was designed, pretested in the field and then used for interviewing the selected households (Rahman & Jashimuddin, 2017). Enumerator manual and Open Foris form were developed for data collection and 5 days intensive training were provided to the enumerators and QAQC experts for accurate and quality data collection from the field. After being trained, the 5 enumerator teams (5 enumerators in each team) collected data across the country. The household survey data were collected by household interview using Samsung Tablet while the FGD community surveys used printed forms for recording the responses to specific queries. The procedure of data gathering and organization for developing a database was done following M. F. Kumar, Costello, L., Mahamud, R., Henry, M., Johnson, K (2017) which is also similar to that of biophysical survey.

For verification of household interviews and ensuring consistent field data collection, QAQC was conducted in the 5% interviews (BFD, 2017). The process involved 7 experts from relevant universities, government and non-government organizations. Quality controlling activities was also conducted indoor after receiving the data through cleaning in Open Foris platform and checking inconsistencies or errors through customized R-script. The whole process is well documented all the design materials, manuals, field instructions, training proceedings as listed in Table 4.

Table 4: List of manuals, trainings, R-scripts and maps related to socio-economic survey design, training on household interview and field instructions

Manuals
BFD (2017). Socioeconomic Field Instructions for the Enumerators of Bangladesh Forest Inventory. Bangladesh Forest Department and Food and Agriculture Organization of the United Nations. Dhaka, Bangladesh. ISBN: 978-984-34-4271-0
BFD (2017). Quality Assurance and Quality Control for the Socio-economic component of Bangladesh Forest Inventory. Bangladesh Forest Department and Food and Agricultural Organization of the United Nations, Dhaka, Bangladesh. ISBN: 978-984-34-4274-1
Chakma, N. (2017). Proceeding of National Consultation on Socioeconomic Survey Design of the Bangladesh Forest Inventory, Dhaka, Bangladesh Forest Department and Food and Agriculture Organization of the United Nations.
GOB (2017). The socio-economic survey of the Bangladesh Forest Inventory, Bangladesh Forest Department, Ministry of Environment and Forests, Government of the People's Republic of Bangladesh.
Rahman, M. and M. Jashimuddin (2017). Field Test Report on Socioeconomic Survey, Bangladesh Forest Department.
Trainings
Chakma, N., et al. (2017). Proceedings of the training of survey enumerators, and quality assurance and quality control team members for the socio-economic component of the

Bangladesh Forest Inventory, Bangladesh Forest Department and Food and Agriculture Organization of the United Nations.
Chakma, N., Barua, S. K, Kumar, M. F., Mahamud, R., Akhter, M., Jalal, R., Hira, S., Islam, A., Miah, A. K., Haque, E., Rahman, L. M., Johnson, K., and Henry, M. (2018). Training materials for the socio-economic component survey of the Bangladesh Forest Inventory-concepts, planning and procedures. Bangladesh Forest Department, Ministry of Environment, Forest and Climate Change, Government of the people's republic of Bangladesh.
R-scripts
Hossain, M.A. 2019. Socio-economic data quality assurance and quality check script. Dhaka, Bangladesh, Food and Agriculture Organization of the United Nations.
Maps
Hira, S. and R. Jalal (2017). Land cover maps of 320 selected unions for the socioeconomic survey of Bangladesh Forest Inventory. Food and Agriculture Organization of the United Nations, Dhaka, Bangladesh: These maps are based on the land cover 2015 data.
Hira, S. and R. Jalal (2017). Basemaps of 320 selected unions for the socioeconomic survey of Bangladesh Forest Inventory. Food and Agriculture Organization of the United Nations, Dhaka, Bangladesh: These maps are based on the administrative boundary, road, river, etc.
Jalal, R. (2017). Selected unions for the socioeconomic survey of the BFI. Food and Agriculture Organization of the United Nations, Dhaka, Bangladesh: Unions were selected based on stratified random sampling based on tree cover, household density and union area data.

2.3 Integration of biophysical, socio-economic and remote sensing data

Application of both natural and social sciences is required for sustainable natural resource management through development of common indicators as they are interrelated and interdependent (De Lange, Wise, Forsyth, & Nahman, 2010). An integrated approach is required for making decisions concerning the management of the natural resources, development of socio-economic condition of forest dependent communities, strengthening forest co-management, reducing conflicts with stakeholder, and ensuring local knowledge-based planning (Conley & Moote, 2003; Curtis, Byron, & MacKay, 2005; Lockwood, 2000).

Particular attention was put in the sampling design of socio-economic survey to ensure that the results are compatible and consistent with the data collected through the surveys in order to facilitate the socio-economic and biophysical integration. A total of 79 indicators were identified under eight criteria for the BFI where a significant number of these indicators require information coming from both socio-economic and biophysical components. The purpose is to know the interactions between socio-economic status and the dynamics of trees and forest status. The integration will eventually support the development of national policies, strategy processes and forestry planning. The integration process is described with examples in GoB (2017a). However, some of the indicators that integrate both the biophysical and socio-economic information are-

- Fuel wood demand and supply,

- Average income from primary tree and forests products collected by households from different forest cover classes,
- Average value of tree and forest products collected by HHs
- Total value of the primary tree and forest products collected by households
- Extent and impact of natural and human made disturbances

3 Statistical methodologies for biophysical data analysis

3.1 Estimations of plot level forest attributes

This section describes the estimation procedures of the important forest attributes such as biomass, carbon, volume, basal area and stem density at plot level. The tree distribution by diameter and height classes were estimated at zone level. Forest area is estimated from both map and field survey at different levels including plot, zone, forest type etc.

3.2 Area estimations

3.2.1 Extent of trees and forests

The 2015 Land Cover Map is used to determine the extent and distribution of land cover classes, including forest and Trees Outside Forest (TOF). The legend classes were derived from the National Land Representation System (NLRS) of Bangladesh based on the distinction of classes from satellite image interpretation, availability of ancillary data, and expert knowledge. Land cover classes can be further categorized into Forest and Other Land following the FRA definitions (FAO 2018). Other Land also defines the area to be used in TOF. The determination of which classes to include in either class was the decision of the FD and are outlined in Table 5. Also included are the land cover classes used in land cover changes estimates for the years 2000, 2005, and 2010 used for Forest Reference Levels (FRL).

Table 5: Land cover assignments to FRA categories and previous land covers

Land Cover 2015	**FRA class**	**Land Cover (2000, 2005 and 2010)**
Bamboo Forest	Forest	Forest Tree Dominated Area (Terrestrial) and Cultivated Trees (Hill Forest, Bamboo Forest, Forest Plantation)
Forest Plantation	Forest	Forest Tree Dominated Area (Terrestrial) and Cultivated Trees (Hill Forest, Bamboo Forest, Forest Plantation)
Hill Forest	Forest	Forest Tree Dominated Area (Terrestrial) and Cultivated Trees (Hill Forest, Bamboo Forest, Forest Plantation)
Mangrove Forest	Forest	Mangrove Forest
Mangrove Plantation	Forest	Mangrove Plantation
Plain Land Forest (Sal Forest)	Forest	Plain Land Forest (Sal Forest)
Rubber Plantation	Forest	Rubber Plantation
Shrubs with scattered trees	Forest	Shrub Dominated Area (Terrestrial) (Orchards and Other Plantations (Shrub), Shifting Cultivation)
Swamp Forest	Forest	Forest Tree Dominated Area (Aquatic/ Regularly Flooded) (Swamp Forest, Swamp Plantation)
Airport	Other Land	Artificial Surfaces (Airport, Built-Up Non-Linear and Dump Sites / Extraction Sites)
Baor	Other Land	Baor
Brackish Water Aquaculture	Other Land	Aquaculture

Brickfield	Other Land	Brickfield
Built-Up Non-Linear	Other Land	Artificial Surfaces (Airport, Built-Up Non-Linear and Dump Sites / Extraction Sites)
Dump Sites/ Extraction Sites	Other Land	Artificial Surfaces (Airport, Built-Up Non-Linear and Dump Sites / Extraction Sites)
Fresh Water Aquaculture	Other Land	Aquaculture
Herb Dominated Area	Other Land	Herb Dominated Area
Lake	Other Land	Lake
Mud Flats or Intertidal Area	Other Land	Mud Flats or Intertidal Area
Multiple Crop	Other Land	Permanent crop
Orchards and Other Plantations (Shrub)	Other Land	Shrub Dominated Area (Terrestrial) (Orchards and Other Plantations (Shrub), Shifting Cultivation)
Orchards and Other Plantations (Trees)	Other Land	Orchards and Other Plantations (Trees)
Perennial Beels/Haors	Other Land	Perennial Beels/Haors
Ponds	Other Land	Ponds
Riverbanks	Other Land	Sand
Rivers and Khals	Other Land	Rivers and Khals
Rural Settlement	Other Land	Rural Settlement
Salt Pans	Other Land	Salt Pans
Sand	Other Land	Sand
Shifting Cultivation	Other Land	Shrub Dominated Area (Terrestrial) (Orchards and Other Plantations (Shrub), Shifting Cultivation)
Single Crop	Other Land	Permanent crop
Swamp Reed Land	Other Land	Swamp Reed Land
Swamp Plantation	Other Land	Forest Tree Dominated Area (Aquatic/ Regularly Flooded) (Swamp Forest, Swamp Plantation)

3.2.2 Surveyed area estimations

Sampled area of the all accessible plots and subplots were used in the denominator of the ratios estimators of the attribute (e.g. for volume, biomass, carbon, etc). Partially accessible, inaccessible, or nonsampled plots were not used. In addition, subplots falling inside River and Khal and Lake land cover classes were excluded. Therefore, estimates were expanded using the *total land area*, not the total country that is sometimes used by BBS and other agencies (indicated in the table below).

Areas (ha)	Coastal	Hill	Sal	Sundarban	Village	Grand Total
TOTAL LAND AREA	*510,127*	*1,658,833*	*522,147*	*403,461*	*10,355,541*	*13,450,109*
TOTAL WATER AREA	476,491	57,316	12,284	229,218	531,582	1,306,891
TOTAL COUNTRY AREA	986,618	1,716,149	534,430	632,680	10,887,123	14,757,000

Importantly, for estimations involving land cover, the land cover assignments and sample land cover area were determined post hoc by overlaying the subplot boundaries on the 2015 Land Cover Map. The land cover boundaries, class designation, and areas were extracted to the subplot level to determine their proportions. DGPS coordinates were available for most of the plots to reduce errors related to the misalignment of the map and subplots (1387 out of 1858 plots). The result of this procedure achieves consistency in the way land cover is assigned to land features among all the plots and ensures consistency with the Land Cover Map. This was necessary because although field teams also delineated land features and assigned them land cover classes, they were found to be inconsistent (e.g. inconsistent land feature object information, land feature number, proportioning, size etc). Consequently, the area estimations using field survey information produced were substantially different from those of the land cover map, and this in turn was affecting attribute estimates that were summarized by land cover classes, including forest and TOF estimates.

3.3 Growing stock estimation

The growing stock (GS) is defined as “Volume over bark of all living trees with a minimum diameter of 10 cm at breast height (or above buttress if these are higher). Includes the stem from ground level up to a top diameter of 0 cm, excluding branches” following the definitions of FAO (2018b) for global Forest Resource Assessment (FRA) 2020. The GS is estimated differently for trees, bamboos and stumps (live) as described in the following paragraphs.

3.3.1 Tree volume

3.3.1.1 *Individual tree volume*

Similar individual tree volume computation method was used for both live and dead standing trees (DBH ≥ 10 cm) whereas live tree volume was considered as growing stock and dead standing tree volume was dead wood volume. Validated models as mentioned in paragraphs 2.1.2 were used for total volume estimation of individual trees. The associated features were considered to select equation for a certain species following the decision tree described in Figure 3. For a certain species the model to model features were compared to select the appropriate equation since there was no automatic method or software program based on the decision tree. In total 31 species-specific volume models for 30 species were selected and applied (Table 6). These species are most important in Bangladesh as they consisted most of the tree population. However, for the other species Huber’s volume equation associated with an average form factor of 0.693 for gross volume was used (Equation 1). The form factor was determined empirically from available data used for developing allometric equations. Though commercial volume of trees has significant values but total gross volume would also serve many purposes since the demand for the natural resources in Bangladesh is very high. From that consideration we focused only on the gross volume. The computation procedure can also be followed in Section 2.2 of analysis R-script.

$$V_g = \frac{D_{bh}^2}{4} \times \pi \times H_{tot} \times f_{gross} \text{-----------------------Equation 1}$$

Here,
V_g= Gross volume (m^3) of individual tree,
$D_{bh} = Tree\ diameter\ at\ breast\ height\ (m)$,
π = 3.1416,
H_{tot}= Tree total height (m),
f_{gross}= Average form factor of trees here 0.693.

Table 6: List of models used for estimation of tree gross volume over bark [here, D = Diameter at Breast Height (cm), C = Girth at Breast Height (cm), H = Height (m), D_{in}= Diameter at Breast Height (inch), H_{ft} = Total height (ft), V = Volume (m3), V_{cft} = Volume (cft)]

SN	Species	Volume models	R^2	n	DBH range
1	*Acacia auriculiformis*	Log (V) = -11.506528 + 1.973377 × Log (C) + 0.623823 × Log (H)	0.979	124	25-125
2	*Acacia mangium*	Log (V) = -10.7488 + 2.2178 × Log (C)	0.98	132	16-79
3	*Acacia nilotica*	Log (V) = -11.875835 + 1.8823999 × Log (C) + 1.0819988 × Log (H)	0.91	128	25-115
4	*Albizia saman*	Log (V) = -11.37623 + 2.26924 × Log (C)	0.981	153	<15 to >180
5	*Albizia richardiana*	Log (V) = -10.996396 + 2.247808 × Log (C)	511	0.98	20->240
6	*Albizia procera*	Log (V) = -11.6632 + 1.941989 × Log (C) + 0.754839 × Log (H)	221	0.991	20-> 130
7	*Albizia* spp.	Log (V) = -11.19651 + 1.85690 × Log (C) + 0.67878 × Log (H)	140	0.979	<15-165
8	*Aphanamixis polystachya*	Log (V) = -11.25528 + 1.98544 × Log (C) + 0.47163 × Log (H)	105	0.987	<15-180
9	*Artocarpus chaplasha*	Log (V) = -8.9449526 + 1.82851 × Log (D) + 0.735381 × Log (H)	427	0.984	5-66
10	*Artocarpus heterophyllus*	Log (V) = -10.99533 + 1.80823 × Log (C) + 0.68951 × Log (H)	119	0.983	<15 to >180
11	*Avicennia officinalis*	V = 0.0089 + 0.0000264 × D^2 × H	308	0.859	10-28
12	*Azadirachta indica*	Log (V) = -11.42823 + 1.89235 × Log (C) + 0.71493 × Log (H)	36	0.985	15-105
13	*Breonia chinensis* *Neolamarckia cadamba*	Log (V) = -10.4647 + 2.3911 × Log (D) + 0.6373 × Log (H)	51	0.991	
14	*Dalbergia sissoo*	Log (V) = -12.5189939 + 1.9800535 × Log (C) + 1.0775148 × Log (H)	202	0.934	25-145
15	*Dipterocarpus turbinatus*	Log (V) = -8.5116354 + 2.35556 × Log (D)	436	0.979	8-58
16	*Eucalyptus camaldulensis*	Log (V) = -9.3520 + 1.8055 × Log (D) + 0.8590 × Log (H)	0.986	511	3 - 18
17	*Eucalyptus camaldulensis*	V = 0.076339 - 0.00058066 × H + 0.000016216 × C^2 + 0.0000032565 × C^2 × H	0.978	94	<60, >120
18	*Gmelina arborea*	Log (V) = -8.4687076 + 1.63502 × Log (D) + 0.784847 × Log (H)	0.966	486	8-76
19	*Hevea brasiliensis*	Log (V) = -11.2768 + 1.8795 × Log (C) + 0.6928 × Log (H)	0.97	583	40-240
20	*Lagerstroemia speciosa*	Log (V) = -9.6744 + 2.1065 × Log (D) + 0.6675 × Log (H)	0.986	74	
21	*Lannea coromandelica*	Log (V) = -11.519102 +2.01724 × Log (C) + 0.56356 × Log (H)	0.971	87	15-105
22	*Mangifera indica*	Log (V) = -11.25377 + 1.96697 × Log (C) + 0.52237 × Log (H)	0.981	343	<15 to >180
23	*Pinus caribaea*	Log (V) = -9.39412 + 1.867386 × Log (D) + 0.839034 × Log (H)	0.995	122	5 - >25
24	*Senna siamea*	Log (V) = -11.6557 + 1.871 × Log (C) + 0.897 × Log (H)	0.99	120	16-79
25	*Shorea robusta*	Log (V) = -12.0554 + 2.5178944 × Log (C)	0.967	499	31-189
26	*Sonneratia apetala*	Log (V) = -9.29715 + 1.70514 × Log (D) + 0.95088 × Log (H)	0.98	236	
27	*Swietenia macrophylla*	Log (V) = -11.27102 + 1.88064 × Log (C) + 0.64629 × Log (H)	0.99	105	<15-165
28	*Syzygium cumini*	Log (V) = -11.24854 + 2.24804 × Log (C)	0.966	99	<15-150
39	*Tectona grandis*	$V_{cft} = 0.000465 \times D_{in}^{1.58} \times H_{ft}^{1.603}$	0.92	645	7-62
30	*Terminalia arjuna*	Log (V) = -11.3794 + 1.896423 × Log (C) + 0.653558 × Log (H)	0.997	177	20 to 120
31	*Xylia xylocarpa*	Log (V) = -9.4303 + 2.0988 × Log (D) + 0.6042 × Log (H)	0.987	94	

3.3.1.2 *Stump volume*

For stumps (live or dead), total length, diameter and diameter measurement height point was collected. But, BFI data showed that, in some cases of stump total length (tree_total_lgt) was not filled but stump height measurement point (tree_htdmp) is collected and entered in the form. There may be some technical flaws in the form due to which the field teams couldn't entered the total length of stumps. In those cases, the stump height measurement point was assumed as total stump length. Stump volume is calculated assuming it as cylindrical shaped (Equation 2). The form factor for stump is ignored because of it's small size. The computation procedure can also be followed in Section 2.3.2 of analysis R-script.

$$S_v = S_{ba} \times H \text{ ------------------------- Equation 2}$$

Here, S_v= Stump volume (m^3), S_{ba} = Stump basal area (m^2), H = Stump height (m).

3.3.1.3 *Bamboo volume*

The Bamboo Culm Woody Volume has been calculated using the following Equation 3. The detail analysis procedure can also be explored from Section 2.2.2 of analysis R-script.

$$V_b = D_{bh}^2 \times \frac{(D_{bh} \times 7)^2}{4} \times \pi \times H_{length} \times f_{bamboo} \text{ ----------------------------------Equation 3}$$

Here,
V_b= Volume of bamboo culm (m^3)
D_{bh} = Diameter of bamboo at breast height (m)
H_{length} = Total height (m)
f_{bamboo} = Form factor of bamboo (0.80)

3.3.2 Dead wood volume

Dead wood volume includes the volume of dead standing tree, down woody debris and dead stump (Equation 4). The method varied with the type of dead wood volume. The detail analysis procedure of all the dead wood volume can be explored from section of 2.3 of data analysis r-scrip.

$$Y_{dv} = Y_{sdt} + Y_{cwd} + Y_{fwd} + Y_{ds} \text{ ------------------------------ Equation 4}$$

Here, Y_{dv} = Dead wood volume, Y_{sdt} = Standing dead tree volume, Y_{cwd} = Volume of Coarse Woody Debris, Y_{fwd} = Volume Fine Woody Debris and Y_{ds} = Volume of dead stump

3.3.2.1 *Standing dead tree*

In case of standing dead tree, the species names were recorded from the field. So, volume of standing dead tree volume is computed using the same procedure (paragraph 3.3.1.1) followed for trees. See section 2.2.1 of analysis R-script for r-codes of standing dead tree volume.

3.3.2.2 *Down Woody Material volume*

Down woody debris (DWD) are of two types, i) Coase Woody Debris (CWD) and ii) Fine Woody Debris. Volume computation process for each of the types at plot, subplot, land feature and transact level is same. The following equation 5 proposed by Marshall, Davis, and LeMay (2000) was used for computing the volume of both Coarse and Fine Woody Debris. See section 2.3.3.1 of analysis R-script for details of DWM volume estimation.

$Y_{DWMvi} = \frac{\pi^2}{8\times L} \times \sum_{j=1}^{n} d_{ij}^2$ ------------------------------ Equation 5

Here, Y_{DWMvi} = Volume of Down Woody Material (t/ha) for i^{th} transact

L = Length (m) of transact where the CWD or FWD is surveyed. In BFI, there are 4 transacts in each plot and length of each transact is 8m for CWD. On the other and, for FWD the transact number is same but the length of transact is 8m for large FWD and 3m for small and medium FWD.

$n =$ Number DWD in i^{th} transact.

d_{ij} = Diameter (cm) of the j^{th} DWD of i^{th} transact. In case of CWD the recorded diameter is used but for FWD the average diameter was used for each of the classes following the FWD class definition.

The transact level volume was then averaged at subplot and land feature level for each plot using equation 6. The volume density was then multiplied with the sampled area (A_{ijl}) for getting total DWD volume at subplot and land feature level (Equation 7).

$\overline{Y_{DWMv}} = \frac{1}{4}\sum_{i=1}^{n} Y_{DWMvi}$ ------------------------------ Equation 6

Here, $\overline{Y_{DWMv}}$ = DWD volume (t/ha) at subplot level

$Y_{tDWMvijl} = \overline{Y_{DWMv}} \times A_{ijk}$ ------------------------------ Equation 7

Here, $Y_{tDWDvijl}$ = total DWD volume (t) of l^{th} land feature of j^{th} subplot under i^{th} plot

A_{ijl} = Sampled area of l^{th} land feature of j^{th} subplot under i^{th} plot

3.3.2.3 *Stump (dead) volume*

Stump (dead) volume was estimated following the volume Equation 2 mentioned under stump biomass estimation section (paragraph 3.3.1.2). See section 2.3.2 of analysis R-script for more details.

3.4 Biomass estimation

Biomass is estimated following the definition of Above Ground Biomass (AGB) and Below Ground Biomass (BGB) proposed by FAO (2018b) for global forest resource assessment 2020 (FAO, 2018a). All live tree (DBH ≥2 cm), bamboo and live stump data collected in the BFI was used for estimating above ground and below ground biomass. See section 2.4 of analysis R-script for more details.

3.4.1 Above ground biomass

The above ground biomass is the function of tree diameter, height and wood density. Above ground biomass contains the biomass of trees, saplings, bamboos and live stumps (Equation 8). Estimation procedure of above ground biomass for trees and saplings, bamboos and stumps are different. See section 2.4.1 to 2.4.3 of analysis R-script for more details.

$Y_{agb} = Y_{TSagb} + Y_{Bagb} + Y_{Sagb}$ ------------------------------ Equation 8

Here, Y_{agb} = Above ground biomass,

Y_{TSagb} = Tree and Sapling AGB,

Y_{Bagb}= Bamboo AGB, and

Y_{Sagb} = Stump (live) AGB.

3.4.1.1 *Tree and sapling above ground biomass*

A number of allometric equations were developed under the BFI for the five zones and 6 common species of Bangladesh. In addition to these there were existing allometric equations verified under the BFI process which were also considered for use to compute tree biomass. The decision tree described under paragraph 2.1.2.3 was used to select allometric equations. Table 7 showed the list of allometric equations selected finally for biomass computation. See section 2.4.1 of analysis R-script for more details.

Table 7:Allometric equations used for estimation of above ground biomass [here, Yagb = above ground biomass (kg), D = DBH (cm), H = total tree length (m), ρ = wood density (kg/m3)]

SN	Species	AE equations selected for biomass estimation	R^2	Sample size	DBH range
1	*Sonneratia apetala*	$ln\, Y_{agb} = 1.7608 + 2.0077\, ln(D) + 0.2981\, ln(H)$	0.9744	61	4-45
2	*Excoecaria agallocha*	$log\, Y_{agb} = -0.8572 + 1.0996\, log\, D^2$			
3	*Acacia auriculiformis*	$log(\sqrt{Y}) = -0.475 + 0.614\, log\, D^2$			
4	*Acacia mangium*	$log(\sqrt{Y_{agb}}) = -0.497 + 0.606\, log\, D^2$			
5	*Heritiera fomes*	$ln\, Y_{agb} = -2.1324 + 2.3895\, ln(D) + 0.1367\, ln(H)$		97	2-40
6	*Shorea robusta*	$ln\, Y_{agb} = -3.3592 + 2.1830\ \ ln(D) + 0.6787\ \ ln(H)$		42	8-38
7	*Gmelina arborea*	$\ln Y_{agb} = -3.028 + 0.925 \times \ln(D^2H)$	0.991	16	5-15
8	Sal zone	$\ln Y_{agb} = -2.46 + 2.17 \ln D + 0.367 \ln H + 0.161 \ln \rho$		59	6-31
9	Sundarbans zone	$\ln Y_{agb} = -1.956299 + 2.163361 \ln D + 0.375219 \ln H + 0.689466 \ln \rho$	0.9852	82	2-78
10	Village zone	$\ln Y_{agb} = -6.0325 + 1.9715 \ln D + 0.8193 \ln \rho$	0.9455	817	
11	Hill zone	$\ln Y_{agb} = -6.9531 + 0.8250 \ln(D^2H\rho)$	0.9334	175	15-58

3.4.1.2 *Bamboo above ground biomass*

There is no country specific allometric equation for biomass estimation of bamboo but two equations from a literature search were found suitable to be used. Equation 9 proposed by Sohel, Alamgirb, Akhter, and Rahman (2015) is suitable for Baijja bansh (*Bambusa vulgaris*) whereas the equation 10 proposed by de Melo, Sanquetta, Dalla Corte, and Mognon (2015) is used for the other bamboos. See section 2.4.2 of analysis R-script for more details.

$Y_{Bagb} = 11.403 + 0.0006(D^2H)$----------------------------Equation 9

$Y_{Bagb} = 0.67545 + 0.02813(D^2H)$----------------------------Equation 10

3.4.1.3 *Stump above ground biomass*

Only live stump is considered for biomass estimation. Stump biomass is calculated following Equation 3 and Equation 11. At first, stump volume is calculated using Equation 2 then it is converted into biomass using Equation 11. Stumps were assumed as cylindrical shaped. The form factor for stump is ignored because of it's small size. See section 2.4.3 of analysis R-script for more details.

$Y_{Sagb} = S_v \times \rho$ ------------------------ Equation 11

Here, S_v= Stump volume (m^3), Y_{Sagb} = Above ground biomass of stump, (kg), ρ = Wood density of respective tree species which stump is left.

3.4.2 Below ground biomass

Similar to that of above ground biomass, the below ground biomass is consisted of tree, sapling, bamboo and live stump. As described below the estimation procedure for all these tree and sapling, bamboo and live stump is different (Equation 12). See section 2.6 of analysis R-script for more details.

$Y_{bgb} = Y_{TSbgb} + Y_{Bbgb} + Y_{Sbgb}$ ------------------------------ Equation 12

Here, Y_{bgb} = Above ground biomass, Y_{TSbgb} = Tree and Sapling AGB, Y_{Bbgb}= Bamboo AGB, and Y_{Sbgb} = Stump (live) AGB.

3.4.2.1 *Tree and sapling below ground biomass*

Below ground biomass of trees in Sundarbans and other 4 forest zones were estimated following two different equation. The Pearson, Brown, and Birdsey (2007) formula (Equation 13) was used for estimating below ground carbon for the Hill, Sal, and Village zones. See section 2.6.1 of analysis R-script for more details.

$Y_{TSbgb} = exp\left[-1.0587 + 0.8836\ ln(Y_{TSagb})\right]$ --------------------------------- Equation 13

Here, Y_{TSbgb} = Below ground biomass (t/ha) in Hill, Sal, Coastal and Sundarbans zone

Besides, below ground biomass of Sundarbans was estimated using the equation proposed by Komiyama, Ong, and Poungparn (2008), as given below (Equation 14).

$Y_{TSbgb} = 0.199 \times \rho^{0.899} \times (dbh)^{2.22}$---------------------- Equation 14

Here, Y_{TSbgb}= below ground biomass in Sundarbans zone (kg); ρ = wood density; DBH = tree diameter at breast height (cm), and 0.199, 0.899 and 2.22 are constants.

3.4.2.2 *Bamboo below ground biomass*

Below ground biomass of *Bambusa vulgaris* is calculated based on the conversion factor proposed by Stokes, Lucas, and Jouneau (2007) and Bijaya and Bhandari (2008) who showed that the rhizome of bamboo is 5% of the culms. For the other bamboo species, the ratio is 26% as reported by Lobovikov, Ball, Guardia, and Russo (2007). Therefore, to get the bamboo BGB following formula (Equation 15 and Equation 16) were used. See section 2.6.2 of analysis R-script for more details.

$Y_{Bbgb} = Y_{Bagb} \times 0.05$-----------------------Equation 15

$Y_{Bbgb} = Y_{Bagb} \times 0.26$-----------------------Equation 16

Here, Y_{Bagb} = Above ground biomass (kg), Y_{Bbgb} = Bamboo below ground biomass (kg).

3.4.2.3 *Stump (live) below ground biomass*

Roots of live stumps possess substantial amount of biomass which doesn't depend on the above ground biomass of the stump. But, the diameter of the stump has a positive relationship with the extent of root biomass. That's why below ground biomass of stump is estimated following the equation prescribed by Hjelm (2015). We used Equation 17 where DBH is the independent variable that indicates the relations with the below ground wood (root) biomass. See section 2.6.3 of analysis R-script for more details.

$$Y_{Sbgb} = \frac{0.00001 \times D^{2.529}}{1000} \text{ ------------------------ Equation 17}$$

3.4.3 Dead wood biomass

The dead biomass, also known as dead matter, is composed of standing dead tree, down woody debris, dead stump biomass and litter dry weight (Equation 18). Estimation procedure of the dead woods is described in the following sections. See section 2.5 of analysis R-script for more details.

$$Y_{db} = Y_{SDTb} + Y_{DWDb} + Y_{DSb} + \frac{Y_{lit}}{100} \text{ ------------------------------ Equation 18}$$

Here, Y_{Db} = Dead wood biomass, Y_{SDTb} = Standing dead tree biomass, Y_{DWDb} = Biomass of Down Woody Debris, Y_{DSb} = Dead stump biomass, Y_{lit} = litter oven dry matter (g/m^2) and 100 is used to divide litter oven dry weight in order to convert g/m^2 unit to t/ha.

3.4.3.1 *Standing dead tree biomass*

Standing dead tree biomass (Y_{SDTb}) is calculated following the same procedure that followed for live trees. But, a reduction factor (calculated temporarily from the biomass data of Sal and Sundarbans forests of Bangladesh) for wood density (ρ) was used based on the wood decay classes prescribed in BFI manual. Wood density of the recorded species was multiplied by the reduction factor following Harmon, Woodall, Fasth, Sexton, and Yatkov (2011) to get reduced wood density under three defined decay classes (Table 8 and Equation 19). The reduced wood density was then used in the selected allometric equations (in necessary cases) for biomass calculation of standing dead trees. See section 2.5.1 of analysis R-script for more details.

Table 8: Wood density reduction factors for standing dead trees

Decay class	**WD reduction factor (ρ_{rf})**	**Composition**
Decay class 1	0.99	Bole + all branches (no leaves)
Decay class 2	0.8	Bole + big branches (no leaves and small branches)
Decay class 3	0.54	Bole without bark (No leaves, branches and bark)

$$\rho_r = \rho_{rf} \times \rho \text{ ------------------------- Equation 19}$$

Here, ρ = Wood density, ρ_{rf} = Wood density reduction factor. ρ_r = Reduced wood density (kg/m^3)

3.4.3.2 *Biomass of Down Woody Material*

Total biomass of down woody debris is the sum of fine woody debris and coarse woody debris. It is calculated using the following formula (Equation 20). See section 2.5.3 -2.5.4 of analysis R-script for more details.

$$Y_{DWMb} = Y_{CWDb} + Y_{FWDb} \text{ --------------------------- Equation 20}$$

Here, Y_{DWMb}= Biomass of Down Woody Material, Y_{CWDb} = Biomass of Coarse Woody Debris, Y_{FWDb} = Biomass of Coarse Woody Debris.

Biomass of Down Woody Matter was computed at plot, subplot, land feature, transact and decay class level using the Equation 21 following Marshall et al. (2000).

$$Y_{DWMbi} = \frac{\pi^2}{8 \times L} \times \sum_{j=1}^{n} d_{ijk}^2 \, \rho_{rk} \text{ ------------------------------ Equation 21}$$

Here,
$Y_{\mathrm{DWM}bi}$ = Biomass of Down Woody Matter (CWD or FWD) (t/ha) for i^{th} transact,

L = Length (m) of transact where the DWM (CWD or FWD) is sampled. In there are 4 transacts in each plot and length of each transact is 8m for CWD. On the other and, for FWD the transact number is same but the length of transact is 8m for large FWD and 3m for small and medium FWD.

d_{ijk} = Diameter (cm) of the j^{th} DWD of k^{th} decay class under i^{th} transact. In case of CWD the recorded diameter is used but for FWD the average diameter was used for each of the classes following the FWD class definition.

ρ_{rk} = Reduced wood density of the k^{th} decay class. It was calculated using Equation 19 where the ρ_{rf} (wood density reduction factor) for CWD is taken from the following Table 9 which was reported by Harmon et al. (2011). In is relevant to mention here that the wood density used here is 0.6133782 g/cm^2. No decay class is recorded for the FWD so the wood density (0.6133782 g/cm^3) was multiplied with an average reduction factor (0.51) was to get an approximate reduced wood density (ρ_r).

Table 9: Average density reduction factor (decayed density/undecayed density) for Downed Woody Material (DWM) trees by decay class for hardwood species (Adjusted from Harmon et al. 2011)

Type	Decay class	Downed dead wood	N
Hardwood	1	0.95 (0.01)	51
	2	0.74 (0.02)	58
	3	0.51 (0.03)	60
	4	0.29 (0.02)	55
	5	0.22 (0.02)	31

Note: Values are means with standard errors in parentheses. "n" is the number of DDM studied.

The transact level biomass was then averaged at subplot and land feature level for each plot using equation 22. The biomass density was then multiplied with the sampled area for getting total biomass of DWM at subplot level and land feature level (Equation 23).

$$\overline{Y_{\mathrm{DWMb}}} = \frac{1}{4} \sum_{i=1}^{n} Y_{\mathrm{DWMbi}} \text{ ------------------------------ Equation 22}$$

Here, $\overline{Y_{DWDb}}$ = Mean DWD biomass (t/ha) at subplot level

$$Y_{tDWMbijl} = \overline{Y_{DWMb}} \times A_{ijl} \text{ ------------------------------ Equation 23}$$

Here, $Y_{tDWMvijl}$ = total DWM biomass (in ton) in l^{th} land feature of j^{th} subplot under i^{th} plot

A_{ijl} = Sampled area of l^{th} land feature of j^{th} subplot under i^{th} plot

3.4.3.3 *Stump (dead) biomass*

Stump (dead) biomass estimation procedure is similar to that described for live stump (paragraph 3.4.1.3). See section 2.5.2 of analysis R-script for more details.

3.4.3.4 *Litter oven dry weight*

Litter samples were collected from the sample plots at plot, subplot and land feature level. The collected samples were then analyzed in the laboratory and received data as oven dry weight directly was in g/m^2 unit. See section 2.7.4 of analysis R-script for more details.

3.5 Carbon estimation

Carbon stock was estimated for 5 different pools - carbon in above ground biomass (CAGB), carbon in below ground biomass (CBGB), carbon in down woody matter (CDWM), carbon in litter and soil organic carbon (SOC). The methods of estimating carbon density and stocks in different pools is described in the following paragraphs. See section 2.7 of analysis R-script for more details.

3.5.1 Carbon in above ground biomass

Carbon in AGB is the sum of carbon from AGB of trees and saplings, bamboos and live stumps (Equation 24). The proportion of carbon in AGB of trees and saplings, bamboo and live stump are different. Hence the computation method is also different as described in the following paragraphs 3.5.1.1 to 3.5.1.3. See section 2.7.1 of analysis R-script for more details.

$$C_{agb} = C_{TSagb} + C_{Bagb} + C_{Sagb} \text{ ------------------------------ Equation 24}$$

Here, C_{agb} = Carbon in above ground biomass,

C_{TSagb} = Carbon in tree and sapling AGB,

C_{Bagb}= Carbon in bamboo AGB, and

C_{Sagb} = Carbon in stump (live) AGB. Live stumps occurred when branching and leaves from a cut stump was observed.

3.5.1.1 *Tree and sapling carbon*

Carbon in above ground biomass of trees and saplings is estimated using the allometric equations mentioned in Table 10. As mentioned earlier a number of allometric equations were developed under the BFI program and selected based on the decision tree described in paragraph 2.1.2.3. The common allometric equation for computing carbon in the trees and saplings of village zone was used to compute carbon for all the species of coastal zone except the species having specific carbon allometric equation (i.e. *Sonneratia apetala, E. agallocha* etc.). See section 2.7.1.1 of analysis R-script for more details.

Table 10: Allometric equations used for estimating the carbon estimation (Here, AGB= Above-ground Biomass, CAGB = Carbon in AGB, D = Diameter at Breast Height, H = Total Height, WD = Wood Density)

SN	zone	Equation	R^2	Sample size	DBH range
1	*Acacia auriculiformis*	log10 ($\sqrt{}$CAGB) = -0.630 + 0.614×log10(D^2)			
2	*Acacia mangium*	log10 ($\sqrt{}$CAGB) = -0.652 + 0.607×log10 (D^2)			
3	*Heritiera fomes*	Ln (CAGB) = -2.7488 + 2.4723×Ln (D)			
4	*Shorea robusta*	Ln (CAGB) = -3.9802 + 2.1660×Ln (D) + 0.6984×Ln (H),		42	8-38

SN	zone	Equation	R^2	Sample size	DBH range
5	*Sonneratia apetala*	Ln (CAGB) = -2.5035 + 2.0042×Ln (D) + 0.3188×Ln (H)	0.9754	61	4-45
6	Hill zone	Ln (CAGB) = -7.7129 + 0.8268×Ln (D^2×H×WD)	0.9342	175	15-58
7	Sundarbans zone	Ln (CAGB) = -7.5236 + 2.1628 × Ln (D) + 0.3834 × Ln (H) + 0.7004 × Ln (WD).	0.9853	82	2-78
8	Sal zone	ln (CAGB) = -3.014 + 2.206×ln (D) + 0.302×ln (H) + 0.262×ln (WD)		59	6-31

3.5.1.2 *Carbon in bamboo AGB*

Bamboo carbon is estimated using the conversion factor of Allen (1986) that says carbon content is 54% of bamboo oven dry biomass (Equation 25). See section 2.7.1.2 of analysis R-script for more details.

$$C_{Bagb} = Y_{Bagb} \times 0.54 \text{ ------------------------ Equation 25}$$

Here, C_{Bagb}= Carbon in bamboo AGB (t/ha), Y_{agb}= bamboo AGB (t/ha) and 0.54 is the conversion factor to convert biomass into carbon.

3.5.1.3 *Carbon in stump (live) AGB*

Carbon in stump (live) AGB was estimated as 50% of AGB (Equation 26). See section 2.7.1.3 of analysis R-script for more details.

$$C_{Sagb} = Y_{Sagb} \times 0.5 \text{ ------------------------ Equation 26}$$

Here, C_{Sagb}= Carbon in stump (live) AGB (t/ha), Y_{agb}= Stump (live) AGB and 0.5 is the conversion factor to convert biomass into carbon.

3.5.2 Carbon in below ground biomass

Carbon in BGB is the sum of carbon in BGB of trees and saplings, bamboos and live stumps (Equation 27). Carbon in BGB of trees and saplings, bamboos and live stumps was estimated as the 50% of the BGB (Hairiah, Sitompul, van Noordwijk, & Palm, 2001; Matthews, 1997). See section 2.7.2 of analysis R-script for more details.

$$C_{bgb} = C_{TSbgb} + C_{Bbgb} + C_{Sbgb} \text{ ----------------------------- Equation 27}$$

Here, C_{bgb} = Carbon in BGB,

C_{TSbgb} = Carbon in tree and sapling BGB,

C_{Bbgb}= Carbon in bamboo BGB, and

C_{Sbgb} = Carbon in stump (live) BGB.

3.5.3 Carbon in dead wood

Dead wood carbon was computed from the dead wood biomass stock. The carbon concentration in dead wood biomass is approximately 50% (Kauffman, Cummings, Ward, & Babbitt, 1995). Applying this conversion factor, the carbon content of dead wood is computed from the plot, subplot and land feature level dead biomass (Equation 14). See section 2.7.3 of analysis R-script for more details.

$$C_{db} = Y_{db} \times 0.50 \text{-------------------------Equation 28}$$

Here, C_{db}= Carbon stock in dead wood (t), Y_{db}= Biomass of dead wood (t)

3.5.4 Carbon in litter

Litter sample was collected and analyzed in the laboratory to get litter dry weight at plot, subplot and land feature level in g/m^2. In addition to the litter dry weight, the same litter sample was used to estimate carbon percentages at plot and land feature levels. Then the litter carbon percentage is used to compute litter carbon (Equation 29). Taking into account the sampled area per plot, subplot and land feature the litter carbon data (t/m^2) was then extrapolated for estimations of mean and variance. In cases the litter was not found the value for litter of the respective subplots was let 0 and in cases the litter data was absent for any reasons it was treated as missing value during estimations. See section 2.7.4 of analysis R-script for more details.

$$C_{lit} = \frac{Y_{lit}}{10^6} \times C_{litP} \text{ ---------------------------- Equation 29}$$

Here, C_{lit}= Litter carbon (t/m^2), Y_{lit}= litter dry biomass (g/m^2), C_{litP}= Litter carbon (%)

3.5.5 Soil carbon

Soil samples were analyzed in the laboratory for bulk density (g/cm^3) and soil organic carbon (SOC) percentage (%). Soil organic carbon was determined by the Loss on Ignition (LOI) method and then multiplying %LOI by 0.5. Carbonates were not removed before performing LOI analysis, which yields a higher estimate of SOC than other methods such as Walkley-Black wet oxidation method. This is especially true in highly calcareous soils of the Sundarban and Coastal zone.

To achieve more comparable estimates to Walkley-Black Organic Carbon in the Sundarban and Coastal zones, the values may be multiplied by 0.53 and 0.3402, respectively, to account for the carbonates amounts known to occur in the soils of those zones. These relationships are derived from empirical data and analysis performed by Khulna University (Figures 5 and 6).

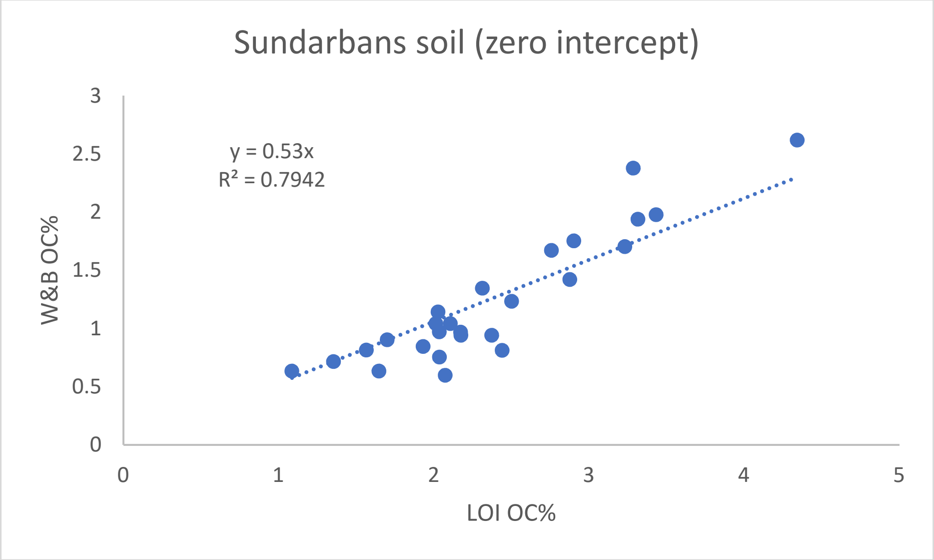

Figure 5: Comparison of OC conversion from LOI method and W&B method for Sunarbans zone soil

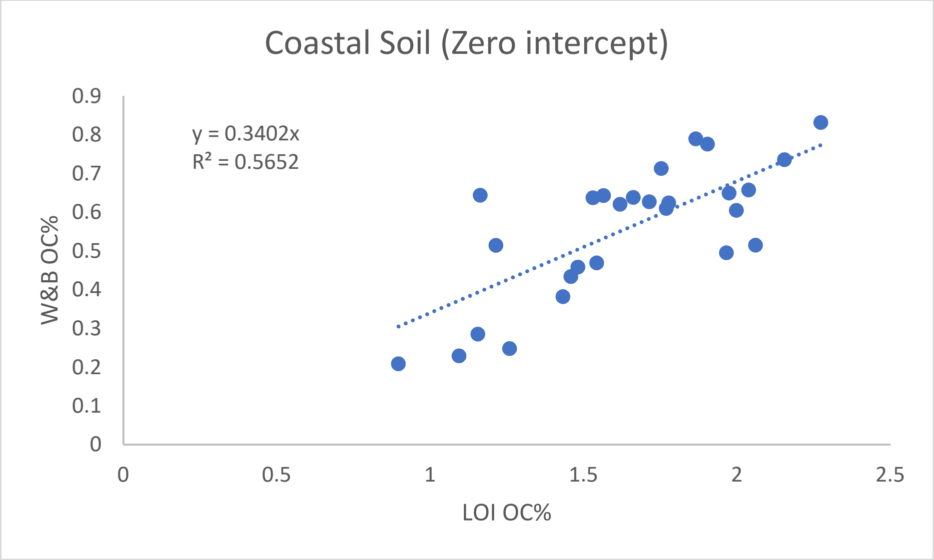

Figure 6: Comparison of OC conversion from LOI method and W&B method for Coastal zone soil

Soil samples for bulk density and SOC were collected from the first three subplots (SP 1 to SP 3) of each plot. For bulk density, individual samples were collected for analysis whereas the SOC sample was a mixed for each land feature within the plot. In case of inaccessibility of any of these plots field were allowed to collect soil sample from the 4th or 5th subplots. In Sundarbans and Coastal zones soil samples were collected from three depths (i.e. 5-10 cm, 20-25 cm and 65-70 cm for bulk density and 0-15cm, 15-30 cm and 30-100 cm for SOC) whereas in the remaining three zones (Hill, Sal and Village zones) soil samples were collected from the first two depths (i.e. 5-10 cm and 20-25 cm for bulk density and 0-15cm and 15-30 cm for SOC). For each layer, soil carbon was calculated from soil organic carbon and bulk density data following method (Equation 30) proposed by Donato, Kauffman, and Stidham (2009). SOC in t/ha was derived for each plot, subplot and land feature which was the interpolated in ton unit taking into account the sampled area at plot, subplot and land feature level. See section 2.7.5 of analysis R-script for more details.

$$S_{OCijkp} = B_{Dijkp} \times C_{jkp} \times S_{Di} \times 100 \text{----------------------- Equation 30}$$

Here,

S_{OCijkp}= Soil organic carbon (t/ha) in ith soil layer under jth land feature of kth subplot and pth plot,

B_{Dijkp}= Bulk density (g/cm^3) of ith soil layer under jth land feature of kth subplot and pth plot,

S_{Di} = Soil depth interval of ith layer (cm). Soil depth interval is 15 cm for 0-15 cm soil layer, 15 cm for 15-30 cm soil layer, and 70 cm for 30-100 cm soil layer,

C_i = Organic carbon (%) of jth land feature under kth subplot and pth plot, and

100 is a conversion factor to convert the units to t/ha.

At plot, subplot and land feature level the total soil carbon is the sum of carbon in all the subsequent layers of respective zone. In case of Sundarbans and Coastal zone the total depth is 100 cm (Equation 31) whereas in Hill, Sal and Villages zones the total depth is 30 cm (Equation 32) (BFD, 2016; Iqbal et al., 2016).

$$C_{si} = C_{l1i} + C_{l2i} \text{ ----------------------------------- Equation 31}$$

$$C_{sij} = C_{l1i} + C_{l2i} + C_{l3i} \text{ ----------------------------------- Equation 32}$$

Here, C_{si}= Total soil carbon in ith subplot, C_{l1i} = Carbon stock (t/ha) in 0-15 cm layer, C_{l2i} = Carbon stock (t/ha) in 15-30 cm layer, C_{l3i} = Carbon stock (t/ha) in 30-100 cm layer

3.6 Estimation of additional parameters

Growing stock, biomass and carbon in 5 different polls were the key estimations of BFI. In addition to these basal area, stem density, diversity index, seedlings density and recruitment percentage of seedlings were estimated at different levels.

3.6.1 Stem density

Stem density is the simple count of tree or sampling individuals per unit area. Number of tree and sapling individuals sampled at small (2.5 m radius) and medium (8 m radius) plots were extrapolated to large plot (19 m radius) or subplot level. Stem density was then estimated at different levels i.e. species, land cover classes, zone etc. following methods of Scott (2018) as described in the paragraph 3.7.

3.6.2 Basal area and stem density

Basal area of individual tree and sapling is calculated using the following Equation 33.

$$BA = \pi \frac{D^2}{4} \text{ -------------------------------- Equation 33}$$

3.6.3 Diversity indices

Four common diversity indices were computed at zone and Land Cover Class (LCC) level following the ecosystem level equations as described below. The diversity indices named Shannon-Wiener Diversity Index, Margalef's Richness Index, Simpson's Dominance Index and Pilou's Evenness Index were computed following Shannon (1963), Margalef (1958), Simpson (1949) and Pielou (1966). For reference the equations (Equation 34 - 37) are mentioned below.

$H = -\sum_{i=1}^{S} P_i(\ln P_i)$ ------------------------------- Equation 34

$R = \frac{(S-1)}{\ln(N)}$ ------------------------------- Equation 35

$S_D = \left(1 - \frac{\sum_{i=1}^{S} n_i(n_i-1)}{N(N-1)}\right)$ ------------------------------- Equation 36

$E = \frac{H}{\ln(S)}$ ------------------------------- Equation 37

Here, H = Shannon-Wiener Diversity Index, R = Margalef's Richness Index, SD = Simpson's Dominance Index, E = Pilou's Evenness Index, N = total number of individuals of all the species; n = number of individuals of i^th^ species; Pi = proportional occurrence of i^th^ species (n_i/N); S = total number of species.

3.7 Population level estimations of means, total, variance, and confidence interval

After having the estimates at plot, subplot and land feature level the means, totals, variance and sampling error were done following the ratio-to-size estimators applicable for Stratified Random Sampling. The estimators were developed by Scott (2018). It is also relevant to mention that these estimators are based on the assumptions and formula of Scott (2018) and Korhonen & Salmensuu (2014).

3.7.1 Ratio-to-Size Estimation

The Ratio-to-Size estimator is a ratio estimator that is used when the cluster size of a two-stage sample varies, thus taking advantage of the relationship between the total of the attribute observed and the size of the sampling unit (cluster). Korhonen and Salmensuu (2014) used the estimator to take advantage of the relationship between any two attributes measured on the cluster. Specifically, this estimator is efficient when the attribute of interest is correlated with the size of the attribute in the denominator. A common example in forest inventory is the tree volume or biomass on a plot is related to the portion of the plot that is forested. This situation occurs when plots are randomly placed on the landscape without regard to whether the location is forested in order to determine the total forest area and volume within the population. A given plot may straddle the boundary between forest and non-forest or between two different domains of interest, such as forest types. This may also happen when a portion of the plot cannot be measured for safety or other reasons (source: *adapted from Scott 2018*).

3.7.2 Attributes from Different Plot Sizes

Often in forest inventory, nested or concentric plots are used to sample trees of different sizes as used in BFI. Seedlings and sapling were sampled on small plots (2.5 m radius) while medium trees (30 cm > DBH ≥ 10 cm) were sampled from medium sized plots (8 m radius) and large trees (DBH ≥ 30 cm) were sampled on large plots (19 m radius). In order to estimate an attribute of interest across plot sizes, such as total number of trees. Conceptually the total number of trees can be estimated using **Equation 45** for each size class, then summing across the size classes. The variance of this would be very difficult to determine due to the covariances between the size class estimates. Instead, a simplification is to rescale each size class, j, to the largest size class, J. The plot attribute becomes (**Equation 38**):

$y_{id} = \sum_{j}^{J} y_{ijd} \frac{\sum_{i}^{n} a_{iJ}}{\sum_{i}^{n} a_{ij}}$ ------------------------------- Equation 38

where:

y_{ijd} = sum of the attribute of interest in domain of interest d on plot i on plot size j

a_{ij} = plot size j area measured on plot i.

3.7.3 Estimation of means and totals

3.7.3.1 *Estimation of attributes of interest for simple random sampling*

In BFI, under each strata (zone) the survey method is simple random sampling. Hence, the mean, total, ratio and variance estimations of the attributes of interest at stratum (zone) level were done following the **Equations 39 to 42**. See section 3.1 to 3.14 of analysis R-script for more details.

The mean of the attribute of interest, such as biomass, in domain d across all land is computed with a numerator as the total biomass measured that is in the domain of interest and the denominator as the total area measured:

$$\bar{y}_d = \frac{\sum_i^n y_{id}}{\sum_i^n a_i} = \frac{\sum_i^n \sum_k y_{ikd}}{\sum_i^n a_i} \text{ ------------------------------- Equation 39}$$

where:

y_{id} = sum of the attribute of interest in domain of interest d on plot i

y_{ikd} = the attribute of interest in domain d in plot i in condition k. The domain can refer to area characteristics or can refer to the observational unit, such as tree species. Note that observation unit values are simply summed and are not expressed on a per unit area basis, such as the sum of sampled tree volumes.

When estimating values for trees sampled using different plot sizes, the largest plot size is used in the denominator. For trees observed with smaller plot sizes, then the attribute is expanded to the larger plot size by multiplying it by the larger plot area divided by the smaller plot area.

The attribute total (or the value for any category of interest) is estimated as:

$$\hat{Y}_d = A \cdot \bar{y}_d \text{ ------------------------------- Equation 40}$$

Where:

A = total area in the population

The variance of the estimated mean, (**Equation 39**), is obtained using **Equation 41** as:

$$v(\bar{y}_d) = \frac{n}{n-1} \frac{\sum_i^n (y_{id} - a_i \bar{y}_d)^2}{\left(\sum_i^n a_i\right)^2} = \frac{n}{n-1} \frac{\sum_i^n y_{id}^2 - 2\bar{y}_d \sum_i^n y_{id} a_i + \bar{y}_d^2 \sum_i^n a_i^2}{\left(\sum_i^n a_i\right)^2} \text{ --------------------------- Equation 41}$$

and for the total is (**Equation 42**):

$$v(\hat{Y}_d) = A^2 \cdot v(\bar{y}_d) \text{ ------------------------------- Equation 42}$$

Ratio Estimates: Often estimates of means are of more interest for a particular subcategory of land, rather than the whole land area, such as biomass per hectare of forest land. It can be estimated as the ratio of the mean of the attribute across all land (**Equation 39**) divided by the mean area proportion across all land:

$$\hat{R}_{dd'} = \frac{\bar{y}_d}{\bar{x}_{d'}} = \frac{\sum_i^n y_{id} \Big/ \sum_i^n a_i}{\sum_i^n x_{id'} \Big/ \sum_i^n a_i} = \frac{\sum_i^n y_{id}}{\sum_i^n x_{id'}} \text{ -------------------------------- Equation 43}$$

where:

y_{id} = the attribute of interest in domain of interest d on plot i where d is a subdomain of d', for example d is the teak volume on forest land.

$x_{id'}$ = the attribute of interest in domain of interest d' on plot i, where d' is the primary domain such as forest land.

The simplification is performed by noting that the denominators for both x and y are the same. Often the denominator is a specific domain of an area attribute, such as forest area or forest type.

The variance of the ratio estimate can be computed using the same approach as in **Equation 41**, but replacing a_i with $x_{id'}$. That is, instead of summing across all measured areas, only those areas in the domain of interest are summed.

$$v\left(\hat{R}_{dd'}\right) = \frac{n}{n-1} \frac{\sum_i^n (y_{id} - \hat{R}_{dd'} x_{id'})^2}{\left(\sum_i^n x_{id'}\right)^2} = \frac{n}{n-1} \frac{\sum_i^n y_{id}^2 - 2\hat{R}_{dd'} \sum_i^n y_{id} x_{id'} + \hat{R}_{dd'}^2 \sum_i^n x_{id'}^2}{\left(\sum_i^n x_{id'}\right)^2} \text{ ------------------- Equation 44}$$

3.7.3.2 *Estimation of attributes of interest for stratified random sampling*

The biophysical survey of BFI, as a whole, is a stratified random sampling. Hence, the mean, total, ratio and variance estimations of the attributes of interest at stratum (zone) level were done following the **Equation 45** to **Equation 53**. See section 3.1 to 3.14 of analysis R-script for more details.

The mean across the entire population area is estimated as (**Equation 45**):

$$\bar{Y}_d = \sum_h^H W_h \bar{Y}_{hd} = \sum_h^H W_h \frac{\sum_i^{n_h} y_{hid}}{\sum_i^{n_h} a_{hi}} \text{ ------------------------------ Equation 45}$$

where:

W_h = weight for stratum h = N_h/N

N_h = area or number of first-phase sample points in stratum h

N = total area or total number of first-phase sample points across all strata

n_h = total number of sample plots in stratum h

n = total number of sample plots across all strata

y_{hid} = the attribute of interest in domain of interest d on plot i in stratum h

The total is estimated by multiplying by the total area (**Equation 46**):

$$\hat{Y}_d = A\,\bar{Y}_d \text{ ------------------------------ Equation 46}$$

Often estimates of means are of more interest for a particular subcategory of land, rather than the whole land area, such as biomass per hectare of forest land. The ratio is computed by dividing the total of attribute, Y, in domain d by the total of attribute, X, in domain of interest, d′ where d is a subset of d′ (**Equation 47**):

$\hat{R}_{dd\prime} = \frac{\hat{Y}_d}{\hat{X}_{d\prime}} = \frac{A\sum_h^H W_h\bar{Y}_{hd}}{A\sum_h^H W_h\bar{X}_{hd\prime}} = \frac{\sum_h^H W_h\bar{Y}_{hd}}{\sum_h^H W_h\bar{X}_{hd\prime}}$ ------------------------------ Equation 47

Note: It is important to first estimate the totals of Y and X across strata then create the ratio estimate, rather than doing the ratio estimate by strata then averaging. The first method is unbiased, the second is not.

The variances of these depend on the sampling design used. Stratified Random Sampling uses a predetermined sample size in each stratum. Samples are drawn randomly within each stratum (Cochran 1977). The sizes of each stratum are known. The variance estimator of the mean for Stratified Random Sampling (when N is large relative to n) is (**Equation 48**):

$v(\bar{Y}_d) = \sum_h^H \frac{W_h^2 s_h^2}{n_h}$ ------------------------------ Equation 48

where the stratum variance is (**Equation 49**):

$s_h^2 = \frac{n_h^2}{n_h-1} \frac{\sum_i^{n_h} y_{hid}^2 - 2\bar{y}_{hd}\sum_i^{n_h} y_{hid}a_{hi} + \bar{y}_{hd}^2 \sum_i^{n_h} a_{hi}^2}{\left(\sum_i^{n_h} a_{hi}\right)^2}$ ------------------------------ Equation 49

The variance of the total is:

$v(\hat{Y}_d) = A^2\, v(\bar{Y}_d) = A^2 \sum_h^H \frac{W_h^2 s_h^2}{n_h}$ ------------------------------ Equation 50

The variance of the <u>ratio</u> estimate is approximated as:

$v(\hat{R}_{dd'}) = \frac{1}{\hat{X}_{d'}^2}\left[v(\hat{Y}_d) + \hat{R}_{dd'}^2\, v(\hat{X}_{d'}) - 2\,\hat{R}_{dd'}\, cov(\hat{Y}_d\,,\ \hat{X}_{d\prime})\right]$ ------------------------ Equation 51

where the covariance is:

$cov(\hat{Y}_d\,, \hat{X}_{d'}) = A^2 \sum_h^H \frac{W_h^2 cov(Y_{hd}\,,\ X_{hd'})}{n_h}$ --------------------------- Equation 52

In the simple means case, the stratum covariance is:

$cov(Y_{hd}\,,\ X_{hd'}) = \frac{\sum_i^n y_{hid}x_{hid'} - n_h\bar{y}_{hd}\bar{x}_{hd'}}{(n_h-1)}$ --------------------------- Equation 53a

and in the Ratio-to-Size case, the stratum covariance is:

$$cov(Y_{hd}\,,\ X_{hd'}) = \frac{n_h^2}{(n_h-1)} \frac{\sum_i^{n_h}(y_{hid} - a_{hi}\bar{y}_{hd})(x_{hid'} - a_{hi}\bar{x}_{hd'})}{\left(\sum_i^{n_h} a_{hi}\right)^2}$$

$$= \frac{n_h^2}{(n_h-1)} \frac{\sum_i^{n_h} y_{hid}x_{hid'} - \bar{y}_{hd}\sum_i^{n_h} a_{hi}x_{hid'} - \bar{x}_{hd}\sum_i^{n_h} a_{hi}y_{hid'} + \left(\sum_i^{n_h} a_{hi}^2\right)\bar{y}_{hd}\bar{x}_{hd'}}{\left(\sum_i^{n_h} a_{hi}\right)^2} \text{ ------- Equation 54}$$

4 Estimation of socio-economic indicators

The motivation for the socio-economic survey was to understand the interaction between human and tree and forests. The survey and the data collection instruments were designed in light of the set criterion which were developed in a participatory process where FD, forest experts, academicians and civil society organizations actively participated. This section describes the estimation procedure and techniques used in the analysis. The results are presented at zone and national level. The indicators are estimated through using Bootstrap estimation using replicate weight variables in STATA 14 with 320 replications (i.e. total number of unions surveyed) and setting number of PSUs to be 16 (i.e. number of unions selected from each stratum). But, as limited number of households were involved in production and selling of processed products, in indicators related to these products, the number of replicates was greater than the number of available units for some strata, and ultimately Bootstrap estimation was not possible. For processed products the estimates were derived using the Stata command svyset, declaring the appropriate weight and setting zones as strata. During the survey the households were asked about quantity, price, days employed, income earned, different services received from tree and forests and other livelihood related questions. However, for estimating value and income from tree and forest products it was necessary to know product price. But product price was not available for the households who did not sell the product. Moreover some households did not report price, particularly when the product was not a regular selling item. In such cases the zone level average product specific price was used. In the cases that no household in the zone reported price, the average of other zones is used. Future estimations of socio-economic indicators will be done using R-scripts.

4.1 Indicator 1: Quantity of each of the primary tree and forest products collected

Core Indicator: Average quantity of each of the primary tree and forest products collected by a HH

Unit: Quantity/HH/year

$$q_{kj} = \frac{\sum_i^n (q_{ikj} w_j)}{\sum_i^n w_j} \qquad (54a)$$

where,

q_{kj}= average quantity of the kth primary tree and forest product annually collected from zone j (Quantity/HH/year);

q_{ikj}= annual quantity of the kth product collected by the ith HH in zone j (Quantity/year);

n = number of HHs surveyed in zone j;

$w_j = w_u + w_{hh}$ weight assigned for the zone j. The Bootstrap weights for complex surveys is calculated using the computer programme STATA 14 which is combination of the following two components:

1) w_u = the sample weight of the union selection within the zone = number unions in a zone / total number of unions surveyed in that zone
2) w_{hh} = the sample weight of the HH selection = number of HH in the selected union / total number of HHs surveyed in the union.

The national average was estimated as weighted sum of all the zones through the following equation:

$$q_k = \sum_{j}^{5} \frac{N_j q_{kj}}{N} \qquad (54b)$$

where,

q_k= quantity of the kth primary tree and forest product collected from all the zones (Quantity/HH/year); and

N = total number of HHs in Bangladesh.

Derived Indicator: Total quantity of each of the primary tree and forest products collected by all the HHs in a zone or nationally

Unit: Quantity/year

$$tq_{kj} = q_{kj} * N_j \qquad (54c)$$

where,

tq_{kj}= total quantity of the kth primary tree and forest product annually collected from zone j (Quantity/ year); and

N_j = total number of HHs in the zone j.

4.2 Indicator 2: Economic value of primary tree and forest products collected

Core indicator: Economic value of primary tree and forest products collected by a HH

Unit: BDT/HH/year

$$av_j = \frac{\sum_i^n (q_{ikj} p_{ikj} w_j)}{\sum_i^n w_j} \qquad (55a)$$

where,

av_j= average value of primary tree and forest products annually collected from zone j (BDT/HH/year);

q_{ikj}= quantity of the kth product collected by the ith HH in zone j per year (quantity/year);

p_{ikj}= price of the kth product for the ith HH in zone j (BDT/unit);[1]

n = number of HHs surveyed in zone j; and

w_j= weight assigned for the zone j, which is same as described in Eq. 54a.

The national average was generated as the weighted sum of all the zones, similar to the Eq. 54b.

In similar way, average (BDT/HH/year) and total (million BDT/year) values of different primary tree & forest products collected by households across zones were estimated.

Derived indicator: Total economic value of primary tree and forest products collected in zone j

Unit: BDT/year

$$tv_j = av_j * N_j \qquad (55b)$$

where,

tv_j= total economic value of primary tree and forest products from zone j (BDT/year); and

N_j = total number of HHs in the zone j.

4.3 Indicator 3: Quantity of each of the collected primary tree and forest products sold

Core Indicator: Average quantity of each of the collected primary tree and forest products sold by a HH

Unit: Quantity/HH/year

$$sold_{kj} = \frac{\sum_i^n \sum_k^m (sold_{ikj})}{n} w_j \qquad (55a)$$

where,

$sold_{kj}$= average quantity of the kth primary product annually sold in zone j (Quantity/HH/year);

$sold_{ikj}$= quantity of the kth primary product annually sold by the ith HH in zone j (Quantity/year);

n = number of HHs surveyed in zone j;

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[1] If the households did not sell the product or did not report price, the zone level average product specific price was used. In extreme cases, where no household in the zone reported price, the average of other zones is used.

w_j= weight assigned for the zone j, which is same as described in Eq. 54a.

The national average was generated as the weighted sum of all the zones, similar to the Eq. 54b.

Derived Indicator: Total quantity of each of the collected primary tree and forest products sold by the HHs

Unit: Quantity/year

$$tsold_{kj} = sold_{kj} * N_j \qquad (55c)$$

where,

$tsold_{kj}$= total quantity of the kth primary product sold in zone j (Quantity/year); and

N_j = total number of HHs in the zone j.

b) Share of each of the collected primary tree and forest products sold

Core Indicator: Share of each of the collected primary tree and forest products sold by a HH

Unit: %

$$s_{kj} = \frac{\sum_i^n \sum_k^m \left({sold_{ikj}}/{q_{ikj}} \right)}{n} w_j \qquad (55d)$$

where,

s_{kj}= share of the kth tree and forest product sold in zone j (%);

$sold_{ikj}$= annual quantity of the kth product sold by the ith HH in zone j (Quantity/year);[2]

q_{ikj}= annual quantity of the kth product collected by the ith HH in zone j (Quantity/year);[3]

n = number of HHs surveyed in zone j;

w_j= weight assigned for the zone j which is same as described in Eq. 54a.

The national average was generated as the weighted sum of all the zones, similar to the Eq. 54b.

4.4 Indicator 4: Income from selling primary tree and forest products

Core indicator: Average annual income earned by a HH from selling primary tree and forest products

Unit: BDT/HH/year

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[2] Same as in Eq. 9.3.1

[3] Same as in Eq. 54a

$$a\_income_j = \frac{\sum_i^n \sum_k^m (g\_income_{ikj} - cost_{ikj}) w_j}{\sum_i^n w_j} w_j \qquad (56a)$$

where,

a_income_j= average annual income earned by a HH from selling primary products in zone j (BDT/HH/year);

g_income_{ikj}= gross income earned by the ith HH from selling the kth primary product in zone j (BDT/year);

$cost_{ikj}$= cost associated with the selling of kth primary tree and forest product for the ith HH in zone j (BDT/year);

n = number of HHs surveyed in zone j; and

w_j= weight assigned for the zone j, which is same as described in Eq. 54a.

The national average was generated as the weighted sum of all the zones, similar to the Eq. 54b.

In similar way, average (BDT/HH/year) and total (million BDT/year) income from different primary tree and forest products collected by households across zones were estimated.

Derived indicator: Total annual income earned by all the HHs from selling primary tree and forest products

Unit: BDT/year

$$t\_income_j = a\_income_j * N_j \qquad (56b)$$

where,

t_income_j= total annual income earned by all the HHs in zone j from selling primary tree and forest products (BDT/year); and

N = total number of HHs in the zone j.

4.5 Indicator 5: Quantity of the processed tree and forest products

Core Indicator: Average quantity of each of the processed tree and forest products produced

Unit: Quantity/HH/year

$$q_{kj} = \frac{\sum_i^n (q_{ikj} w_j)}{\sum_i^n w_j} \qquad (57a)$$

where,

q_{kj}= average quantity of the kth processed tree and forest product produced in zone j (Quantity/HH/year);

q_{ikj}= quantity of the kth processed product annually produced by the ith HH in zone j (Quantity/year);

n = number of HHs surveyed in zone j;

w_j= weight assigned for the zone j, which is same as described in Eq. 54a.

The national level average was generated as the weighted sum of all the zones, similar to the Eq. 54b.

Derived Indicator: Total quantity of each of the processed tree and forest products produced by all the HHs in a zone or nationally

Unit: Quantity/year

$$tq_{kj} = q_{kj} * N_j \qquad (57b)$$

where,

tq_{kj}= total quantity of the kth processed tree and forest product produced in zone j (Quantity/ year); and

N_j = total number of HHs in the zone j.

4.6 Indicator 6: Quantity of each of the processed tree and forest products sold

Core Indicator: Average quantity of each of the processed tree and forest products sold by a HH

Unit: Quantity/HH/year

$$s_{kj} = \frac{\sum_i^n (s_{ikj} w_j)}{\sum_i^n w_j} \qquad (58a)$$

where,

s_{kj}= average quantity of the kth processed tree and forest product sold in zone j (Quantity/HH/year);

s_{ikj}= quantity of the kth processed product annually sold by the ith HH in zone j (Quantity/year);

n = number of HHs surveyed in zone j;

w_j= weight assigned for the zone j, which is same as described in Eq. 54a.

The national average was generated as the weighted sum of all the zones, similar to the Eq. 54b.

Derived Indicator: Total quantity of each of the processed tree and forest products sold

Unit: Quantity/year

$$ts_{kj} = s_{kj} * N_j \qquad (58b)$$

where,

ts_{kj}= total quantity of the kth processed tree and forest product sold in zone j (Quantity/year); and

N_j = total number of HHs in the zone j.

4.7 Indicator 7: Income from selling processed tree and forest products

Core indicator: Average income from selling processed tree and forest products

Unit: BDT/HH/year

$$a\_income_j = \frac{\sum_i^n \sum_k^m (g\_income_{ikj} - cost_{ikj}) w_j}{\sum_i^n w_j} \qquad (59a)$$

where,

a_income_j= average income from selling processed tree and forest products in zone j (BDT/HH/year);

g_income_{ikj}= gross income earned by the ith HH from selling the kth processed tree and forest product in zone j (BDT/year);

$cost_{ikj}$= cost (e.g. labour, raw materials, transportation, selling, etc.) associated with the selling of kth processed tree and forest product for the ith HH in zone j (BDT/year);

n = number of HHs surveyed in zone j; and

w_j= weight assigned for the zone j, which is same as described in Eq. 54a.

The national average was generated as the weighted sum of all the zones, similar to the Eq. 54b.

Derived indicator: Total income from selling processed tree and forest products

Unit: BDT/year

$$t\_income_j = a\_income_j * \ N_j \qquad (59b)$$

where,

t_income_j= total income earned in zone j from selling processed tree and forest products (BDT/year); and

N = total number of HHs in the zone j.

4.8 Indicator 8: Involvement with tree and forest related activities

a) Number of family members involved

Core indicator: Average number of household members involved in different tree and forest related activities

Unit: no/HH/year

$$no_{jk} = \frac{\sum_i^n no_{ikj} w_j}{\sum_i^n w_j} \qquad (60a)$$

where,

no_{jk}= average number of family members involved with kth activity (e.g. collection, processing, selling) in zone j (no/year);

no_{ikj}= number of family members involved with kth activity in the ith HH in zone j (no/HH/year);

n = number of HHs surveyed in zone j; and

w_j= weight assigned for the zone j, which is same as described in Eq. 54a.

The national average was generated as the weighted sum of all the zones, similar to the Eq. 54b.

Derived indicator: Total number of household members involved in different tree and forest related activities

Unit: no/year

$$tno_k = no_{jk} * N_j \qquad (60b)$$

where,

tno_k= total number of HH members involved with kth activity in zone j (no/year); and

N_j = total number of HHs in the zone j.

4.9 Indicator 9: Proportion of households receiving different tree and forest related services

Core Indicator: Proportion of households receiving services

Unit: %

$$sh_{kj} = \sum_i^n \sum_k^m \left({}^{h_{ikj}}/_{n} \right) * w_j * 100 \qquad (61)$$

where,

sh_{kj}= proportion of the households in zone j receiving kth service (%);

h_{ikj}= total number of HHs in zone j receiving kth service (no);

n = number of HHs surveyed in zone j;

w_j= weight assigned for the zone j which is same as described in Eq. 54a.

The national average was generated as the weighted sum of all the zones, similar to the Eq. 54b.

4.10 Indicator 10: Value of collected tree and forest products used for cooking and heating

Core indicator: Average value of collected tree and forest products used for cooking and heating

Unit: BDT/HH/year

$$av_j = \frac{\sum_i^n (q_{ikj} p_{ikj}) w_j}{\sum_i^n w_j} \qquad (62a)$$

where,

av_j= average value of collected cooking and heating products used for cooking by a HH in zone j (BDT/HH/year);

q_{ikj}= quantity of the kth product (i.e. firewood and leaves) collected by the ith HH in zone j per year (kg/year);

p_{ikj}= price of the kth product for the ith HH in zone j (BDT/kg);[4]

n = number of HHs surveyed in zone j; and

w_j= weight assigned for the zone j, which is same as described in Eq. 54a.

The national average was generated as the weighted sum of all the zones, similar to the Eq. 54b.

Derived indicator: Total value of collected tree and forest products used for cooking and heating

Unit: BDT/year

$$tv_j = av_j * N_j \qquad (62b)$$

where,

tv_j= total value of tree and forest products used for cooking and heating in zone j (BDT/year); and

N_j = total number of HHs in the zone j.

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[4] If the households did not report price, the zone level average product specific price was used.

4.11 Indicator 11: Cost of buying tree and forest products used for cooking and heating

Core indicator: Average cost of purchasing tree and forest products used for cooking and heating

Unit: BDT/HH/year

$$ac_j = \frac{\sum_i^n (c_{ikj} * 12) w_j}{\sum_i^n w_j} \qquad (63a)$$

where,

ac_j= average annual cost of purchasing energy products used for cooking and heating in zone j (BDT/HH/year);

c_{ikj}= monthly cost of purchasing the kth energy product by the ith HH in zone j (BDT/month);

n = number of HHs surveyed in zone j; and

w_j= weight assigned for the zone j, which is same as described in Eq. 54a.

Derived indicator: Total cost of purchasing tree and forest products used for cooking and heating

The national average was generated as the weighted sum of all the zones, similar to the Eq. 54b.

Unit: BDT/year

$$tc_j = ac_j * N_j \qquad (63b)$$

where,

tc_j= total cost of purchasing energy products used for cooking and heating in zone j (BDT/year); and

N_j = total number of HHs in the zone j.

4.12 Indicator 12: Presumed amount of purchased tree and forest products used for energy

Core indicator: Average presumed amount of purchased tree and forest products used for energy

Unit: kg/HH/year

$$av_j = \frac{\sum_i^n (q_{ikj} - p_{ikj}) w_j}{\sum_i^n w_j} \qquad (64a)$$

where,

av_j= average presumed amount of purchased tree and forest products used for energy in zone j (kg/HH/year);

q_{ikj}= annual amount of the kth energy product (i.e. firewood and leaves) collected by the ith HH in zone j (kg/year);

p_{ikj}= annual quantity of the kth product (i.e. fuelwood and leaves) purchased by the ith HH in zone j (BDT/kg);

n = number of the HHs surveyed in zone j; and

w_j= weight assigned for the zone j, which is same as described in Eq. 54a.

The national average was generated as the weighted sum of all the zones, similar to the Eq. 54b.

Derived indicator: Total presumed amount of purchased tree and forest products used for energy

Unit: t/year

$$tv_j = av_j * N_j \qquad (64b)$$

where,

tv_j= total presumed amount of purchased tree and forest products used for energy in zone j (t/year); and

N_j = total number of HHs in the zone j.

4.13 Indicator 13: Total annual income from tree and forest

Core indicator: Average annual income from tree and forest

Unit: BDT/HH/year

$$a\_income_j = \frac{\sum_i^n f\_income_{ikj} w_j}{\sum_i^n w_j} \qquad (65a)$$

where,

a_income_j= average annual income from tree and forest in zone j (BDT/HH/year);

f_income_{ikj}= net income (i.e. cost adjusted) earned by the ith HH from kth forest related activities (i.e. income from primary and processed products, salary) in zone j (BDT/year);

n = number of HHs surveyed in zone j; and

w_j= weight assigned for the zone j, which is same as described in Eq. 54a.

The national average was generated as the weighted sum of all the zones, similar to the Eq. 54b.

Derived indicator: Total annual income from tree and forest

Unit: BDT/year

$$t\_income_j = a\_income_j * N_j \qquad (65b)$$

where,

t_income_j= total annual income earned by all the HHs in zone j from tree and forest (BDT/year); and

N = total number of HHs in the zone j.

b) Percentage of total income received by HHs from tree and forest

Core indicator: Percentage of total annual income received by HHs from tree and forest

Unit: %

$$s_{kj} = \frac{\sum_i^n \sum_k^m \left({f\_income_{ij}}\Big/{t\_income_{ikj}} \right)}{n} w_j \qquad (65c)$$

where,

s_{kj}= share of ith HH's total annual income earned from tree and forest in zone j (%);

f_income_{ikj}= total annual income earned by the ith HH in zone j from forest (BDT/HH/year);[5]

t_income_{ikj}= total annual income for the ith HH in zone j (BDT/HH/year);

n = number of HHs surveyed in zone j;

w_j= weight assigned for the zone j which is same as described in Eq. 54a.

The national average was generated as the weighted sum of all the zones, similar to the Eq. 54b.

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[5] Same as estimated in Eq. 9.13.1.

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