Section 2:

The Bangladesh Forest Inventory

Photo: Roadside plantation, ©*FD*

Section 2

2.1

The Bangladesh Forest Inventory process

The Bangladesh Forest Inventory (BFI) is a multi-source and multi-purpose NFMS that assesses, evaluates, interprets and reports the status of trees and forest resources nationally. The BFI is also a process of assessing the relationships of tree and forest resources to livelihoods and forest management. The BFI process integrates biophysical and socio-economic data with GIS and RS technologies in the design, mapping, survey and reporting phases. The concept behind the BFI originates from the Bangladesh REDD+ Readiness Roadmap and the need to report for activities to reduce deforestation and forest degradation, monitor greenhouse gas emissions and removals, and enhance sustainable forest management (UN-REDD 2012). For example, BFI results provide “data and information suitable for measuring, reporting and verifying (MRV) anthropogenic forest-related emissions”, which supports potential mechanisms for payments of environmental services, including REDD+ (UN-REDD 2015, FAO 2015a). It follows the decision of the United Nations Convention on Climate Change, stipulating the need to use a combination of remote sensing and ground-based forest carbon inventory approaches for estimating anthropogenic forest-related greenhouse gas emissions and removals, forest carbon stocks and forest area changes (Decision 4/CP15) (UNFCCC 2009). The BFI further adheres to the technical recommendations provided in the guidance documents of the Global Forest Observations Initiative (GFOI 2014).

The first BFI cycle was initiated in 2015 by FD[5] and will provide updated estimates of tree and forest resources in future cycles. All land uses of the country (not only forest land) are considered for facilitating nationally consistent results across different sectors. The land cover map allows for forestry and agricultural related intervention activities to be planned in a spatially explicit manner that removes technical barriers and ensures cost-efficiency as much as possible (Vargas, Alcaraz-Segura et al. 2017). Data gathered for TOF areas will support activities related to social forestry, agroforestry, sustainable land management, and climate-smart agriculture (CIAT and WB 2017).

[5] Initial implementation by the FD under the USAID-funded project “Strengthening National Forest Inventory and Satellite Land Monitoring System in Support of REDD+ in Bangladesh” (GCP/BGD/058/USA).

The biophysical and socio-economic surveys complement each other and are particularly adept to meeting the needs of monitoring and information national plans and strategies that promote sustainable forest management. Without this supporting information, forests may be under-valued, and in the light of pressing needs for socio-economic development, many policymakers may see little benefit to sustainable forest management (Kengen 1997). These issues are particularly important in Bangladesh, where the relationships between people and trees and forests are closely connected, but perhaps not fully appreciated. Characterizing this dependency at national and sub-national scales with a socio-economic survey better informs decision makers about the importance of tree and forest resources.

2.1.1 Objectives

The overall objectives of the BFI are to provide national scale baseline information about tree and forest resources and their relationships with people, with the aim to support sustainable tree and forest management and conservation in all land uses. In order to realize the aim, five specific objectives were set through a national stakeholder consultation process. The objectives consider the perspectives and needs of multiple users of the BFI data and analysis results with regards to sustainable forest management. The specific objectives are (Figure 2.1):

1. Provide baseline information for national forest monitoring
2. Identify links between forest resource use and status for assisting the valuation of ecosystem services.
3. Assist national scale management, planning, policy decisions and international reporting requirements for the forestry sector.
4. Support management objectives within sub-national zones.
5. Assist national and international reporting on tree and forest resources.

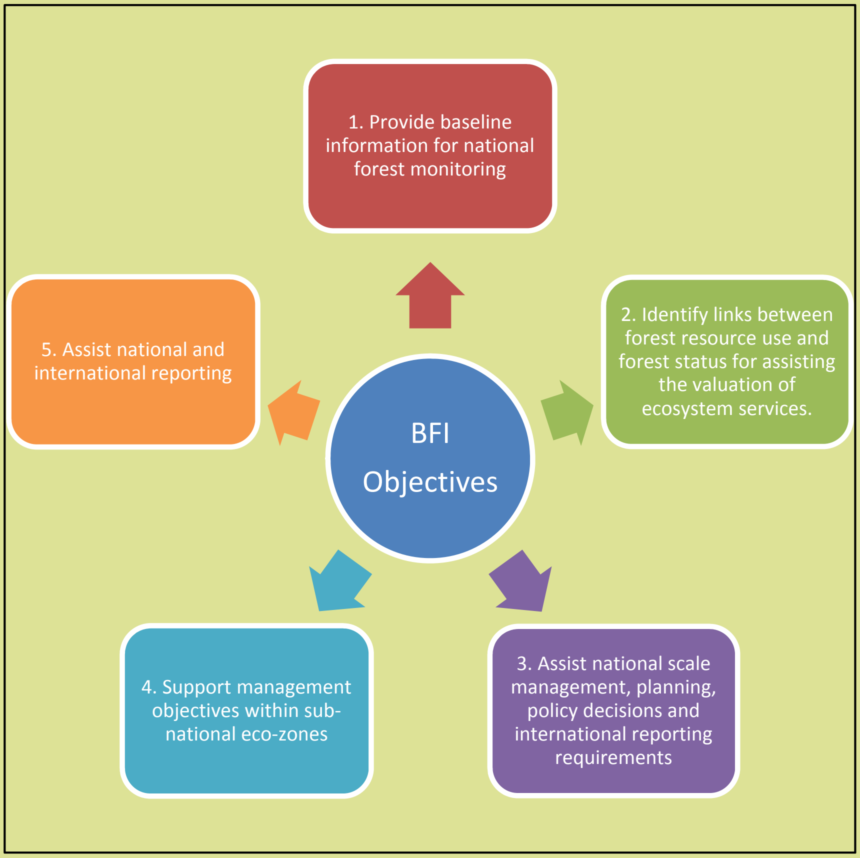

Figure 2.1. Objectives of Bangladesh Forest Inventory

2.1.2 Partnerships

The FD collaborates with multiple government agencies, universities, and national and international development partners to implement the BFI, contributing to SDG 17 on partnerships[6]. The nature of the partnerships established for the BFI process was shaped by the interests of each institution and their specific roles, mandates and resources. Many of the collaborations involved participation in working groups on topics related to allometric equations, land cover mapping, and others. Three official working groups were organized for Measurement Reporting and Verification (MRV group), National Forest Monitoring System (NFMS) and Socio-Economy. A list of institutions who collaborated with FD in the BFI process is given in Table 2.1.

[6] *SDG 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development*

Table 2.1. List of entities who collaborated with FD in the BFI process.

Sl. No.	Entities	Nature of collaboration
1	Ministry of Environment, Forest and Climate Change (MoEFCC)	Provide overall policy guidance to carry out the inventory process
2	Department of Environment (DoE)	Sharing of background information
3	Institute of Forestry and Environmental Science, Chittagong University (IFESCU)	Testing of the biophysical inventory field manual; providing quality control checks in the biophysical inventory; inputs to the plant species database
4	Forestry and Wood Technology Discipline, Khulna University (KU)	Allometric equation database, development of allometric equations, testing of inventory field manual and analysis of soil and litter samples, field and laboratory training on allometric biomass model development, establishing soil archive; providing quality control checks in the biophysical inventory
5	Department of Forestry and Environmental Science, Shahjalal University of Science and Technology (SUST)	Testing of Inventory Field Manual; development of allometric equations; development of quality control checks in the biophysical inventory
6	Bangladesh National Herbarium (BNH)	Provide training for identification of plant specimen, develop taxonomic keys for identification of tree and other plant species in the field, identification of samples collected from unknown species.
7	Soil Resource Development Institute (SRDI)	Development of soil sample collection methods; training on collection of soil samples
8	Center for Environmental and Geographic Information Services (CEGIS)	Participate in land cover mapping; Land Cover Classification System (LCCS) field data collection; supported piloting of land forest boundaries
9	Bangladesh Bureau of Statistics (BBS)	Approval of the biophysical and socio-economic survey designs; provide quality control checks of the socio-economic survey; provide analysis and feedback of socio-economic data; provide basic statistical information on population census and administrative units.
10	Bangladesh University of Engineering and Technology (BUET)	Participate in land cover mapping
11	Bangladesh Space Research and Remote Sensing Organization (SPARRSO)	Participate in land cover mapping
12	Survey of Bangladesh (SOB)	Participate in land cover mapping; provide topographic maps for field teams; provide geodetic reference points for DGPS work.
13	Ministry of Land (MoL)	Participate in land cover mapping
14	Directorate of Land Records & Surveys (DLRS)	Participate in land cover mapping
15	Bangladesh Forest Research Institute (BFRI)	Development of allometric equations and; support finalization of existing allometric equation database; participate in biophysical data collection
16	Department of Soil, Water & Environment, University of Dhaka (DU)	Prepared guidelines for soil sample collection and testing manual
17	Institute of Statistical Research and Training, University of Dhaka (ISRT DU)	Socio-economic sampling design; analysis and feedback from socio-economic data
18	Forestry Science & Technology Institute (FSTI)	Participate in biophysical data collection

Sl. No.	Entities	Nature of collaboration
19	Bangladesh Society of Geo-Informatics (BSGI)	Participate in land cover mapping; Land Cover Classification System (LCCS) field data collection and land feature data collection protocol preparation
20	Bangladesh Institute of Planners (BIP)	Participate in land cover mapping
21	Bangladesh Agricultural Research Institute (BARI)	Participate in land cover mapping
22	Center for Natural Resource Studies (CNRS)	Socio-economic survey implementation
23	Sthapati LLC	Georeferencing biophysical plot centers with DGPS
24	DATEX	Supported piloting of forest land boundary delineation
25	Arannyak Foundation (AF)	Socio-economic sampling design; analysis and feedback from socio-economic data
26	Overseas Marketing Company (OMC)	Support for DGPS training

2.1.3 Institutionalization process

The first cycle of the Bangladesh Forest Inventory (BFI) was implemented as a project by the FD under the Ministry of Environment, Forest and Climate Change (MoEFCC). Project activities were executed through a National Project Coordinator (NPC) who had the overall responsibility for planning, managing, coordinating and supervising BFI activities. The activities were further monitored and advised by a National Forest Monitoring System (NFMS) Working Group constituted by the Chief Conservator of Forests and the Project Steering Committee (PSC).

It is critical that a full-fledged NFMS such as the BFI be institutionalized to maximize its potential for informing country strategies and goals (FAO 2015b, FAO 2017b). The institutionalization process includes official institutional arrangement and set of formal documents such as policy directives, laws, mandates and inclusion in the official organogram. It also requires long-term support from qualified and committed professionals from relevant disciplines. Financial support and skilled human resources, especially information technology, are equally important to the process. Strengthening national and international collaborations and the continuous involvement of research organizations and youth will provide future expertise and ensure the process remains up-to-date regarding technological advancement and ability to meet societal needs. Furthermore, the institutionalization process will make the BFI a critical tool to engage national entities and provide the necessary baselines to robustly monitor progress towards forestry related goals (FAO 2015b, FAO 2017b).

Steps have been taken to permanently establish the BFI as the country's NFMS. The FD proposed its re-organogram in 2017 to MoEFCC wherein a BFI unit was included. The proposed organizational set-up of the FD is currently being reviewed for approval. Under the current proposal, the BFI unit will lead and facilitate the data collection, analysis and dissemination. This will provide clear concept of mandate for forest monitoring, allow for sharing data, knowledge and experiences between entities, and promote sustainable integrated efforts for national development. A data sharing policy is being reviewed to allow sharing the inventory data to national stakeholders. Figure 2.2 presents the proposed institutional arrangement.

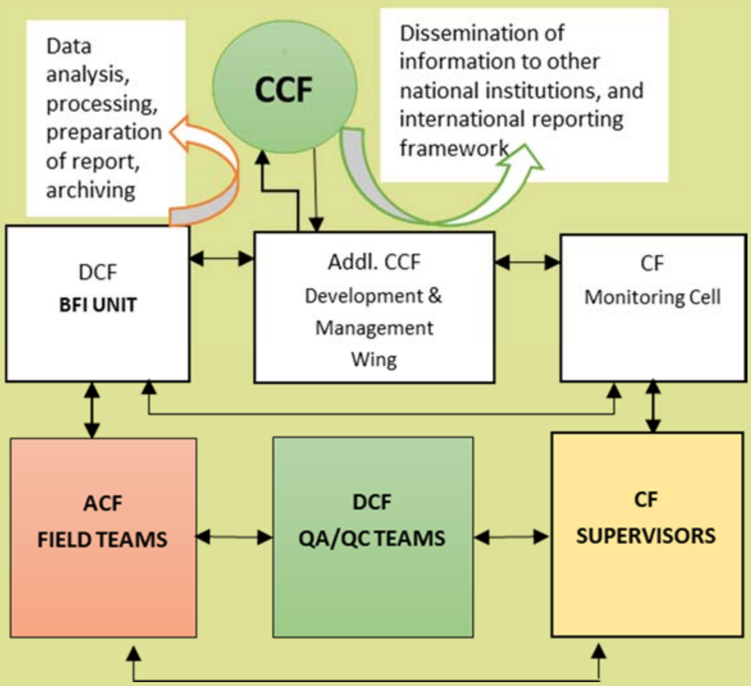

Figure 2.2. Proposed institutional setup for the sustainability of the Bangladesh Forest Inventory (DCF - Deputy Conservator of Forests, CF – Coservator of Forests, ACF - Assistant Conservator of Forests, CCF – Chief Conservator of Forests.

According to the proposed re-organogram, the BFI unit will be headed by a Deputy Conservator of Forests (DCF) and staffed with 33 personnel for conducting the biophysical inventory and coordinating the socio-economic survey. At the field level, there will be field teams, Quality Assurance/Quality Control (QA/QC) teams and supervisors for biophysical and socio-economic data collection. Field teams will be headed by Assistant Conservator of Forests (ACF); QA/QC teams will be coordinated by Deputy Conservator of Forests along with a university faculty member as technical expert. A Conservator of Forests (CF) will supervise the data collection activities at field level in their respective jurisdictions. As supervisors, CFs will initiate upward communication from CF (Monitoring

Cell) to Chief Conservator of Forests (CCF) through the Additional CCF (Development and Management Wing).

The BFI unit's role will be to coordinate the periodic assessments of national forest resources. Ideally, operationalization will include as annual field programme to collect both biophysical and socio-economic data. The data would be collected systematically in panels to ensure a yearly and statistically unbiased estimate at the national scale. All the panels would be completed every five years, resulting in a full sample and higher precision estimates (FAO 2015b, FAO 2017b). In contrast to a single year inventory, this continuous approach avoids the need for major recruitment and training at the beginning of each inventory and is currently followed or proposed in other countries (FAO 2015b).

In order to strengthen institutional relationships and collaborations for implementing the BFI, the FD will ideally sign a number of MoU's and other formal agreements with different organizations. The MoU's also serve to strengthen national capacities and promote the transparency and harmonization of datasets. The partnerships FD and different organizations to be formalized through MoU's and other agreements between are depicted in Figure 2.3.

Figure 2.3. Potential collaborations between national public and private entities under different formal agreements to achieve different components of the BFI. The acronym definitions of the insitutions are listed in Table 2.1.

2.2

Criteria and indicators

Forest assessment is a process of monitoring the value of forest benefits, including past trends and projections into the future concerning these benefits (FAO 2017a). The process starts with defining meaningful and achievable objectives related to sustainable forest management. Criteria and indicators are then used to measure the status and progress towards objectives. Criteria define the "desired results of particular programme or project in an understandable and communicable way …. and conditions against which [sustainable forest management] should be assessed … and may be described by one or more indicators" (Larrubia, Ross et al. 2017). Indicators enable results to be measured, analysed and reported in a consistent and verifiable manner. These requirements form the basis of lead questions, such as – what is the impact of government reforestation programs? The questions in turn help to determine which indicators, or variables, can be measured in field surveys. The formulation process of criteria, indicators and variables is downward starting from the objectives while the process of integrating these parameters with each other is upward (Figure 2.4).

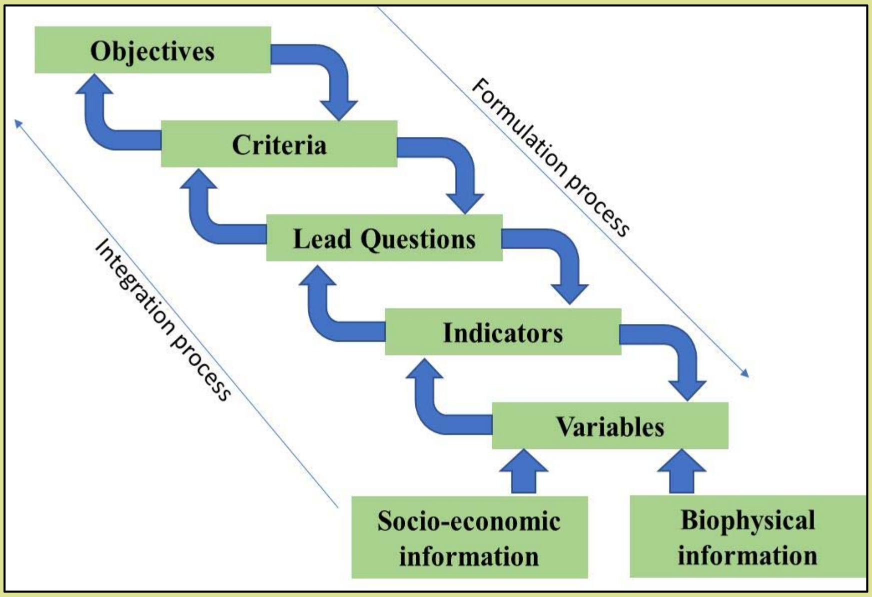

Figure 2.4. The process for determining the variables and indicators to be estimated, which then inform objectives.

BFI objectives reflect the needs of national stakeholders and international reporting frameworks and were identified through meetings, national consultations and review of the Global Forest Resources Assessment 2020 (FAO 2018b), Statistical Yearbook Bangladesh (SYB), and National Forest and Tree Resources Assessment 2005-2007 (MoEF and FAO 2007). A national consultation was carried out in March 2015 to assist in the process of defining the BFI objectives using the Design Tool for Inventory and Monitoring (DTIM) (Scott and Bush 2009, Silvacarbon 2015). DTIM was used for the identification of the broad monitoring objectives, the related monitoring questions, and the main metrics to address those questions. Through this process a set of functional objectives were proposed by various stakeholder groups and ranked in order of priority. Once the functional objectives were defined, the DTIM tool assisted in framing questions that need to be asked to meet the defined objectives. Taking into account the objectives and goals related to sustainable management of trees and forests in Bangladesh (e.g. Bangladesh's 7FYP and CIP EFCC), the criteria and indicators were defined. The resulting list of criteria closely follow FRA 2020 but are modified according to the country context and needs (Table 2.2) (FAO 2015a, Larrubia, Ross et al. 2017, FAO 2018a, FAO 2018b). For example, the results for forest extent, forest growing stock, forest disturbances, forest ownership and management are largely the same as in FRA 2020. However, additional criteria for understanding biological diversity and tree and forest livelihoods were added. In the current report, information about trees and forests is presented in sections according to criteria and indicators which will be monitored in future BFI cycles.

Photo: Soil sample collection, The Sundarban,
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2.2.1 Mapping of criteria and indicators to national plans and strategies

Several indicators have been identified to monitor the 7FYP and the CIP EFCC aim to increase the forestry sector's contribution to the GDP of Bangladesh while other may be used for international reporting or for FD and other local stakeholders. Table 2.2 presents a list of all the indicators of this report and how they are related to national plans and strategies.

Table 2.2. List of criteria and indicators and their relation to national plans and strategies. The complete list of variables within each indicator is given in Sections 3 to 9.

Criteria	Indicators		Relevant international conventions and reporting frameworks
	Name	**Unit**	
1. Forest extent and tree cover change	Extent of trees and forests	1000 ha	*FRA, UNFCCC, SDG*
	Tree cover changes	1000 ha	*7th FYP, SDG, UNFCCC*
2. Biological diversity and conservation	Tree species composition, stem density, and size characteristics	species number, stems/ha, m, cm, m^2/ha	
	Regeneration and recruitment	seedling number, seedling/ha, %	
	Plant diversity index of trees	unitless	*CBD*
	Status of native and introduced tree species	species names, stem/ha	*FRA*
	People's perception about changes in animal abundance	% HH opinion in %	
	Red List tree and animal species	stem/ha, number	*SDG, CBD, CITES*
3. Growing stock, biomass and carbon	Growing stocks	m^3/ha, million m^3	*FRA, UNFCCC*
	Tree biomass	ton/ha, million tons	*FRA, UNFCCC, SDG*
	Dead biomass and fuelwood	ton/ha, million tons	
	Carbon	ton/ha, million tons	*FRA, UNFCCC, SDG*
4. Management and ownership	Tree and forest management types	%	
	Trees and forest by ownership class	1000 ha	*FRA, SYB*
	Tree and forest product collection by ownership type	%	
5.Tree and forest disturbances	Disturbance area and disturbances most cited by households	% 1000 ha	*FRA*
	Disturbances most cited by households	%	
	Drivers of tree cover change	% HH opined for increase or decrease	

Criteria	Indicators		Relevant international conventions and reporting frameworks
	Name	**Unit**	
6. Support for sustainable forest management	Types of support received from organizations	% HH receiving support	
	Households receiving seedling support from FD	% of HH, species names, seedlings/HH	
	Seedlings purchased by households	BDT/seedling	
7. Tree and forest services and livelihoods	Quantity collected, value, and income from primary products (including NWFP)	qty/HH/yr, BDT/HH/ yr, %	*SDG, 7FYP, CIP EFCC, FRA*
	Quantity, supply, and income from processed products	qty/HH/yr, BDT/HH/ yr	
	Involvement with tree and forest related activities	% HH members	*FRA*
	Services and benefits from forest	%	*SDG, 7FYP, CIP EFCC*
	Dependence on trees and forests for energy	qty/HH/yr, %	*7FYP, CIP EFCC*
	Total annual income from trees and forest	BDT/HH/ yr, %	*SDG, 7FYP, CIP EFCC*

2.3

State of the art forest monitoring

The BFI overcomes several logistical and technical challenges to implementing a full-fledged and institutionalized national forest inventory in Bangladesh. For example, the latest technologies were used to minimize field measurement errors, reduce costs, and ensure plot re-location. A new high-resolution land cover map was created to meaningfully summarize estimation results. Updated tree species list, wood density, and allometric equation databases were developed and made accessible that benefits multiple users in the forestry sector. Finally, government and other personnel were trained in information technology support, inventory procedures, GIS and remote sensing, and statistical analysis. Both the biophysical and socio-economic components apply best practices and recommendations from the latest methodologies (Magnussen and Reed 2004, Köhl, Magnussen et al. 2006, Corona and Marchetti 2007, GFOI 2014, FAO 2017b, Masiero, Pettenella et al. 2019). The result is a rich source of information for understanding many aspects of Bangladesh's natural resources. Emphasis is placed on providing clear and interpretable results for answering key questions and meeting specific objectives.

Biophysical and socio-economic results are summarized by zones (Section 2.3.1) and land cover classes (Section 2.3.2) to meet multiple purposes. The biophysical inventory (Section 2.3.3) provides information for the assessment of carbon, biomass and timber stocks in trees and forests in the country among other supporting information such as land ownership and land use. The socio-economic survey (Section 2.3.4) provides information for understanding the relationship between human, and tree and forest resources in the country. The biophysical and socio-economic components can be integrated with the land cover map for analyzing more profoundly the relationships between trees, forests, and people.

Further supporting information to the BFI process includes new zone-specific and species-specific allometric biomass models, soils data, data quality procedures, supporting information, and efficient estimation procedures. Several zone-specific allometric equations were developed that follow recommendations for sampling schemes and best practices for selecting models (Section 2.3.5) (Henry, Cifuentes Jara et al. 2015). Quality control systems in both the biophysical and socio-economic surveys, to control errors and provide feedback to field teams (Haub, Kleinewillinghöfer et al. 2015, FAO 2017b) (Section 2.3.6). Several national and international forest statisticians have consulted the data collection and analysis procedures to determine robust and appropriate estimation procedures (Korhonen and Salmensuu 2014, Scott 2018) (Section 2.3.6). The process in its entirety supports the estimations of indicators that are linked to their criteria (Figure2.4).

In summary, the BFI process benefits from, and builds upon, state of the art best practices for implementing a multi-source and multi-purpose forest inventory (Figure2.5). The latest methods and tools, along with in-house innovations (e.g. tree species identification app, BGD Trees), have been applied to provide accurate, user-friendly, and interpretable results that are in line with internationally accepted guidelines for monitoring tree and forest resource. A dense set of manuals, trainings proceedings, and publications are available for sustaining the BFI process as Bangladesh's national forest monitoring system now and in the future.

Photo: Watershed management, Bandarban,
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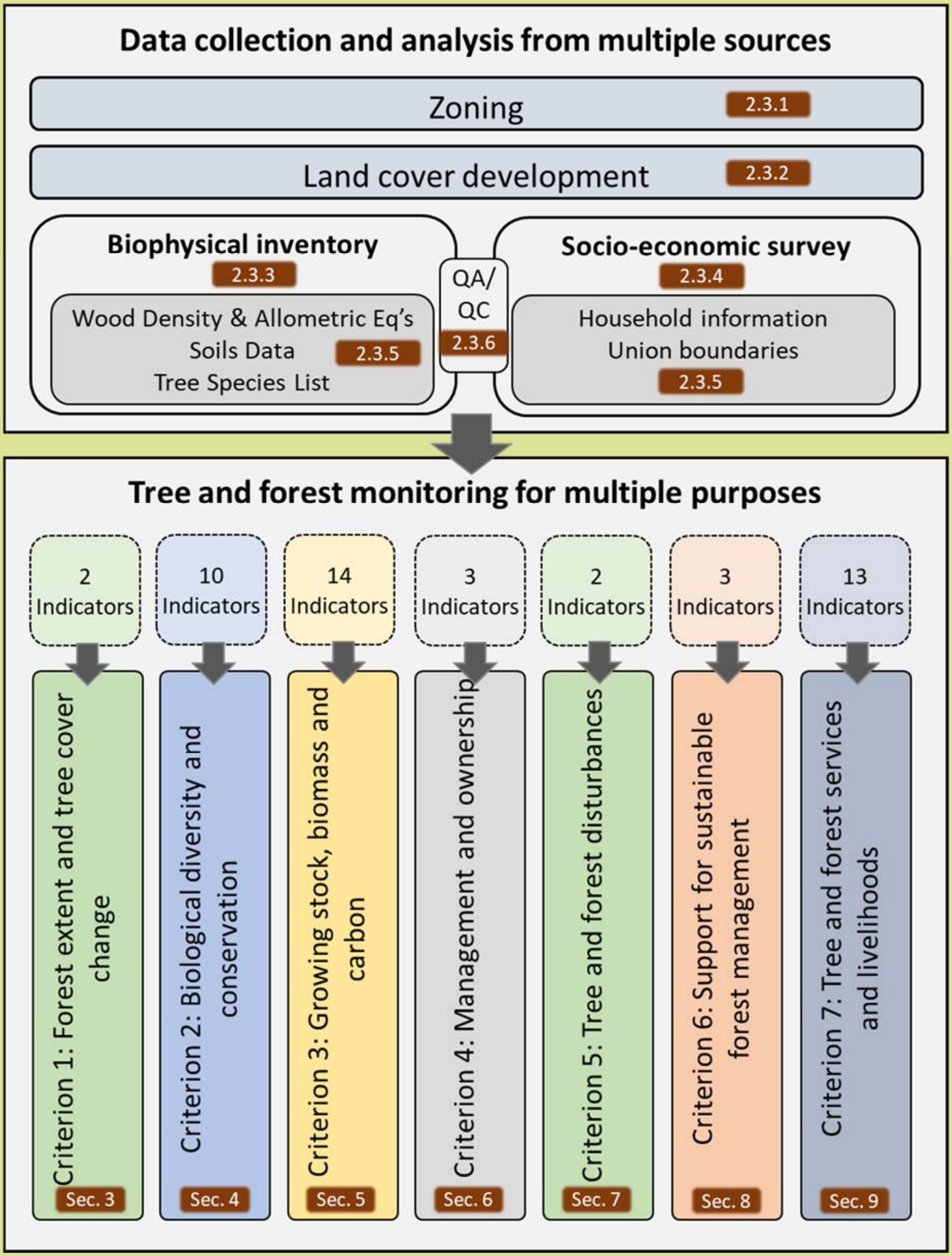

Figure 2.5. Visualization of the the relationships of data from multiple sources for multiple purposes in the BFI process. The numbering corresponds to report sections.

2.3.1 Zoning

To give context to how trees, forests and people interact, five BFI zones capture the major differences that occur geographically across the country (Figure 2.6). In the case of the biophysical inventory, the zones are Sal, Sundarban, Village, Hill, and Coastal (BFD, 2016). The socio-economic zones are identical to the biophysical zones except for the Sundarban zone is called the Sundarban periphery zone. The zones are a convenient way to report results and serve a statistical purpose for grouping results to obtain higher precision of forest attribute estimates (BFD 2016f). The boundaries of the zones are based on biotic and abiotic characteristics which do not match administrative boundaries.

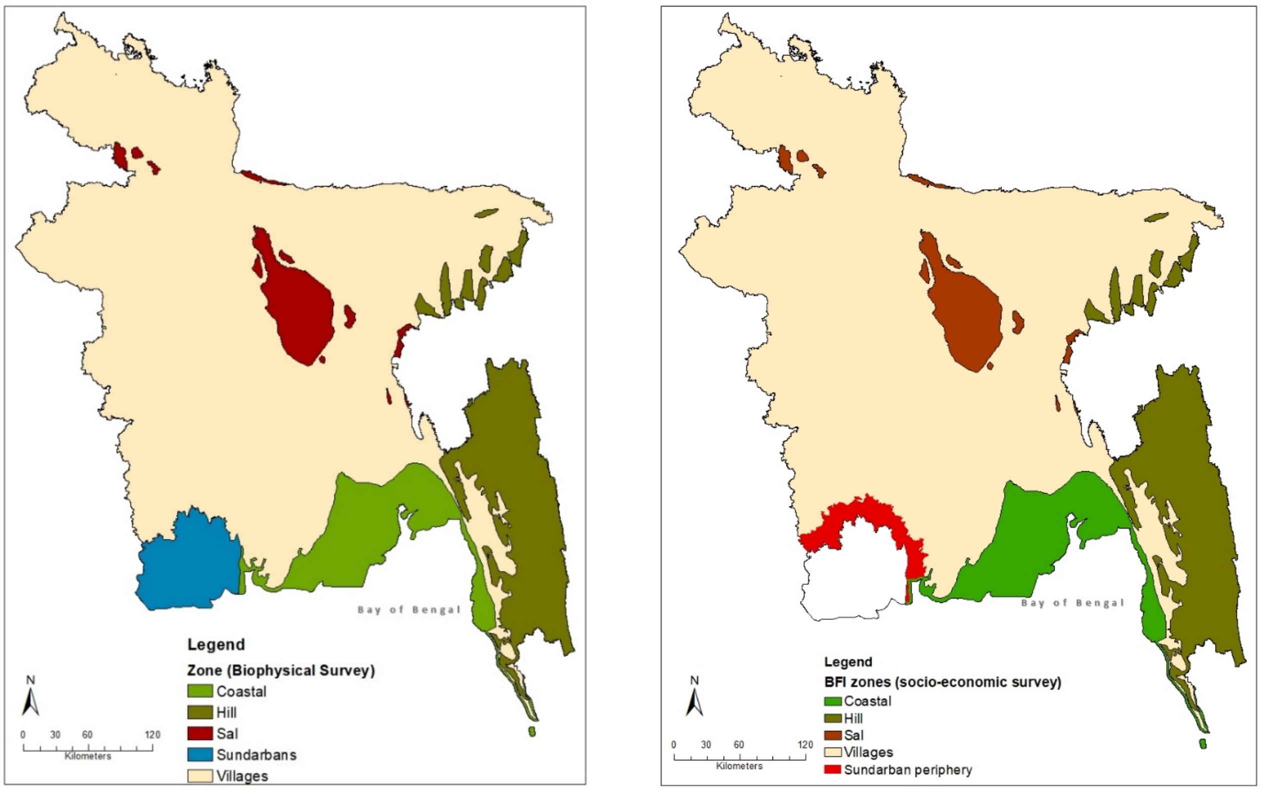

Figure 2.6. Zones of the Bangladesh Forest Inventory. In the left figure are the zones of the biophysical inventory and in the right are the zones of the socio-economic survey.

The Hill zone represents hilly geographical areas in the eastern part of the country. The average elevation is 125 m, and water and terrestrial land area occupy 3% and 97% of the land, respectively (GoB 2019). The mean annual precipitation is 2720 mm (2061 - 4370 mm) (Hijmans, Cameron et al. 2005). The soils of Hill zone have been classified as acid sulphate, brown hill, and noncalcareous grey floodplain (nonsaline) (FAO-UNDP 1988). Evergreen and semi-evergreen forest types dominate, and the most common tree species are *Dipterocarpus spp., Syzygium spp., Gmelina arborea, Ficus carica, Grewia spp., Albizia spp., Acacia auriculiformis, Artocarpus heterophyllus, Swietenia mahagoni, Tectona grandis, Acacia auriculiformis,* and homestead tree species such as *Mangifera indica*.

The Sundarban zone represents the mangroves of the sundarban reserve forest found in the south-western part of the country. The elevation ranges from 2 to 9m with an average of 6 m. Water and terrestrial land area occupy 37% and 63%, respectively. The mean annual precipitation is 2004 mm (1783 - 2343 mm). The soils have been classified as acid sulphate and non-calcareous grey floodplain (non-saline). This zone consists of natural mangrove forest and the most common tree species are *Heritiera fomes*, *Excoecaria algallocha*, and *Ceriops decandra*.

Box 2 – The Sundarban periphery zone of the socio-economic survey

The Sundarban is unique among the zones because it has the highest stem density and lowest population density. Its socio-economic importance to the surrounding communities is well documented (e.g. Abdullah et al. 2016) and needs special consideration in a national level survey such as the BFI. As there is no sizable population within the Sundarban forest, the socio-economic survey was not conducted within the Sundarban zone, but instead within a 10 km buffer outside the zone boundaries which included 89 unions. The same number of unions and households were surveyed as the other zones. Throughout this report, the socio-economic results from this area are summarized and referred to as the “Sundarban periphery” to distinguish it from the “Sundarban” zone of the biophysical inventory.

The Sal zone represents the geographical areas in Madhupur and Barind tract with small hillocks and plain land. The average elevation is 17 m, and water and terrestrial land area occupy 3% and 97%, respectively. The mean annual precipitation is 2040 mm (1804 - 2462mm). The soils of sal zone have been classified as acid basin clays, brown hill, brown mottled terrace, deep red-brown terrace, shallow grey and shallow red-brown terrace. This zone consists of deciduous Sal forest, and the most common tree species are *Shorea robusta, Albizia spp., Artocarpus heterophyllus, Swietenia mahagoni, Acacia auriculiformis* etc. and homestead tree species such as *Mangifera indica*.

The Coastal zone represents geographical areas with accreted land in the southern part of the country. The average elevation of coastal zone is 3 m, and water and terrestrial land area occupy 55% and 45%, respectively. The mean annual precipitation is 2870 mm (2267 - 3698 mm). The soils of coastal zone have been classified as brown hill, acid sulphate, calcareous alluvium (non-saline), calcareous grey floodplain, non-calcareous alluvium and noncalcareous grey floodplain. The most common tree species are *Sonneratia apetala*, *Avicennia officinalis, Excoecaria agallocha, Areca catechu and homestead tree species such as Artocarpus heterophyllus, Samanea saman, Azadirachta indica* and *Mangifera indica*.

The Village zone covers the rest of the area not occupied by the Hill, Sundarban, Sal or Coastal zones. The average elevation is 16m, and water and terrestrial land area occupy 8% and 92%, respectively. The mean annual precipitation is 1600 mm. The soils of village zone have been classified as acid basin clays, brown hill, calcareous alluvium (non-saline), calcareous brown floodplain, calcareous dark grey floodplain, deep grey terrace, grey piedmont, non-calcareous alluvium, non-calcareous brown floodplain, non-calcareous dark grey floodplain, non-calcareous grey floodplain (non-saline), and shallow Grey Terrace. The most common tree species are *Swietenia mahagoni, Areca catechu, Mangifera indica, Acacia auriculiformis, Samanea saman,* and *Eucalyptus camaldulensis*.

2.3.2 Land cover mapping

In response to prevailing classification inconsistency between land cover maps and in order to provide a solid reference to mapping activities, an object-based Land Representation System of Bangladesh (LRSB) has been developed (GoB 2019, Jalal, Iqbal et al. 2019). The LRSB is a result of several processes of data collection, translation, gap identification and analysis of existing land cover/use mapping processes. This process was started in 2013 and finalized in 2016 (Akhter 2013, Di Gregorio 2013, Shaheduzzaman and Akhter 2013, Di Gregorio, Akhter et al. 2014, Costello and Piazza 2015, BSGI 2016, Di Gregorio 2016, Franceschini, Jalal et al. 2016, Hadi 2016, Hadi 2016). The legends of three existing national land cover/use maps were collected, documented and translated using the Land Cover Classification System (LCCS v3) – an implementation tool of the ISO standard (ISO 19144-2) Land Cover Meta Language (LCML) (Di Gregorio, 2016).

The legend classes for the national land cover map 2015 have been derived from the LRSB (Figure 2.7) based on the distinction of classes from satellite image interpretation, availability of ancillary data, and expert knowledge (Islam, Iqbal et al. 2016). These initial classes were further refined during map development process with the ground information to develop the final legend. Multi-spectral ortho (Level 3) SPOT6/7 images of 6-meter spatial resolution with maximum 10% cloud coverage were used for the whole country. To delineate some land cover classes with temporal variability (e.g., single and multiple crops) Landsat 8 and Sentinel 2 images were used. The multi resolution segmentation algorithm was used to develop image objects using the bands green, red and NIR with equal weights as input layers. The delineated image objects were used as the basic unit of classification, and a land cover code was assigned. Not-qualified image segments were manually edited to correspond well to geo-objects in geometry before assigning appropriate land cover code. Quality checking was an integral part of the land cover process (Franceschini, Jalal et al. 2016) and was completed using multiple approaches, including spatial topology check, attribute check, and consistency check. The accuracy assessment analysis was designed using a pseudo-ground truth validation technique, with a stratified random sampling by district and by land cover class (Jalal, Iqbal et al. 2019). Sample numbers for each of the land cover classes within a district were chosen based on the district size and the relative occurrence (in terms of area) of the land cover class in the district.

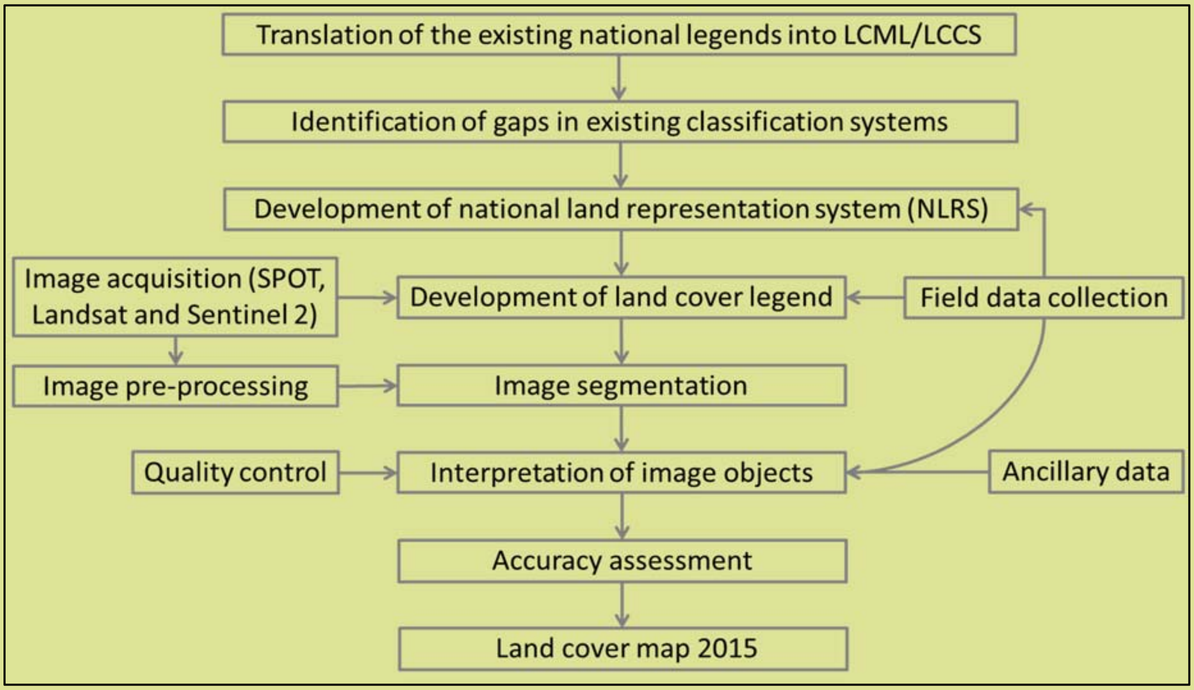

Figure 2.7. Flow diagram of the process for developing the Land Representation System of Bangladesh and Land cover map 2015.

Land cover classes and maps form the basis, which can be further refined, by which tree and forest characteristics may be summarized and compared. Additionally, land cover classes can be used to link and integrate biophysical and socio-economic data. Land cover classes of land features in the biophysical inventory plots were determined post-hoc (i.e. not determined directly by field teams). Furthermore, the biophysical plots occurred in only 28 of the 33 classes and trees occurred in only 22 of the classes (Appendix 2.1).

Box 3 - Trees Outside Forest

One of the major objectives of the BFI is to quantity both the biophysical and socio-economic contributions of Trees Outside Forest (TOF). TOF are extremely important to the livelihoods of many people in the world, especially in a highly productive and densely populated country such as Bangladesh (de Foresta, Temu et al. 2013). Fruit, timber, and non-timber forest products are all collected throughout Bangladesh from TOF. TOF also contribute significantly to total biomass estimates and play an important role in the carbon cycle, though they are often excluded from national forest inventories (Johnson, Birdsey et al. 2015, Schnell, Kleinn et al. 2015). However, the BFI plots cover all land uses, not only forests, to quantify and report on the importance of these areas.

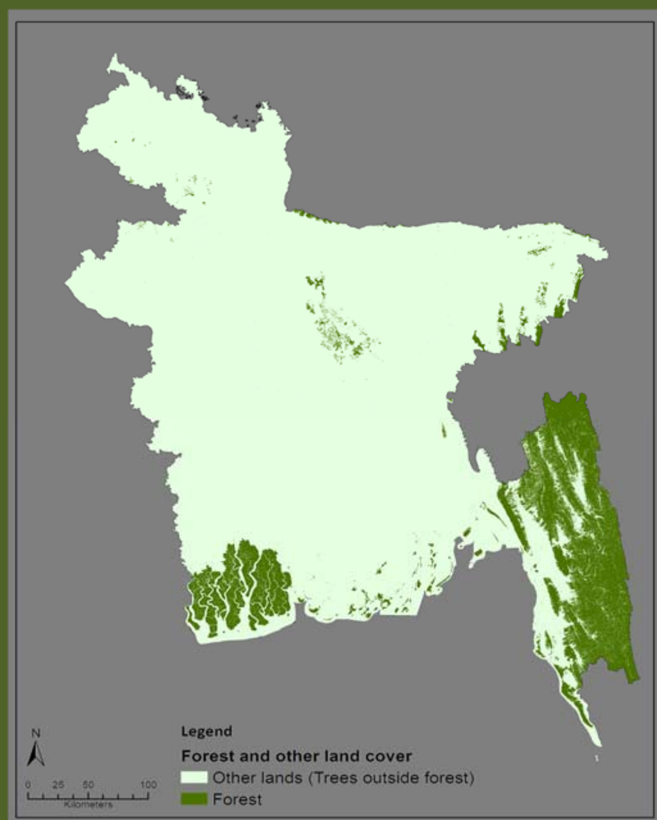

Figure 2.8. Map showing the locations of Forest and Other Land according to FRA (2018) definitions. Other Land is synonymous with Trees Outside Forest in this report.

In the BFI, the 33 land cover classes of the 2015 Land Cover Map were aggregated into Forest or Other Land following FRA definitions (FAO 2018b). Other Land is synonymous with TOF in this report. Other Land is simply "all land that is not classified as Forest or Other wooded land [and] includes agricultural land, meadows and pastures, built-up areas, barren land, … etc" (FAO 2018b). The Land Cover Map classes considered as Other Land include Permanent Crop, Rural Settlement, Tree Orchards and Other Plantations, Shrub Orchards and Other Plantations, and Herb Dominated Area (see Appendix 2.1 for the complete list). Using this system, FD will be able to monitor separately the changes in indicators for both Forest and TOF which will in turn enable effective and targeted policies towards sustainable management of both areas.

2.3.3 Biophysical inventory design

The field inventory design was developed following a step-wise methodology. Variables has been selected through consultation with scientists, academics, national and international experts, forest department officials and research institutes. To collect national level data within an acceptable range of error, the following process was considered (Iqbal, Kuegler et al. 2016):

1. National consultation to identify stakeholder needs and general inventory objectives,
2. Identification of the preferred sampling design,
3. Identification of specific objectives and targeted precision,
4. Stratification of the national territory into zones,
5. Design of the plot and determination of the main attributes to be measured,
6. Accessiblity assessment and forest land selection in all zones for stratification,
7. Assessment of the cost for the measurement of plots and subplots in the different zones, and
8. Optimization of the plot number and plot shape considering the objectives and available resources.

The design of the biophysical component of the BFI is a pre-stratified systematic sample with different intensities for each zone or stratum (Table 2.3) (Iqbal, Kuegler et al. 2016). Hence, the sample intensity within each zone differs and was determined by a target precision requirement of 5% confidence interval for tree resource estimates. The plots are located randomly within a hexagonal grid, where the distance between plots was between 5900 and 10400 meters. The final result was the selection of 2245 plot locations, of which 1858 fell on land and required sampling field visits (Figure 2.9).

Table 2.3. Zone areas and sampling intensities of the biophysical component of the BFI.

Zone	Area (ha)	Number of Plots	Plot size (ha)	Sample Intensity (%)
Coastal	986618	113	0.340	0.003897
Hill	1716149	429	0.567	0.014175
Sal	534430	145	0.567	0.015385
Sundarban	632680	173	0.340	0.009303
Village	10887123	998	0.567	0.005198
Bangladesh	14757000	1858		0.006700

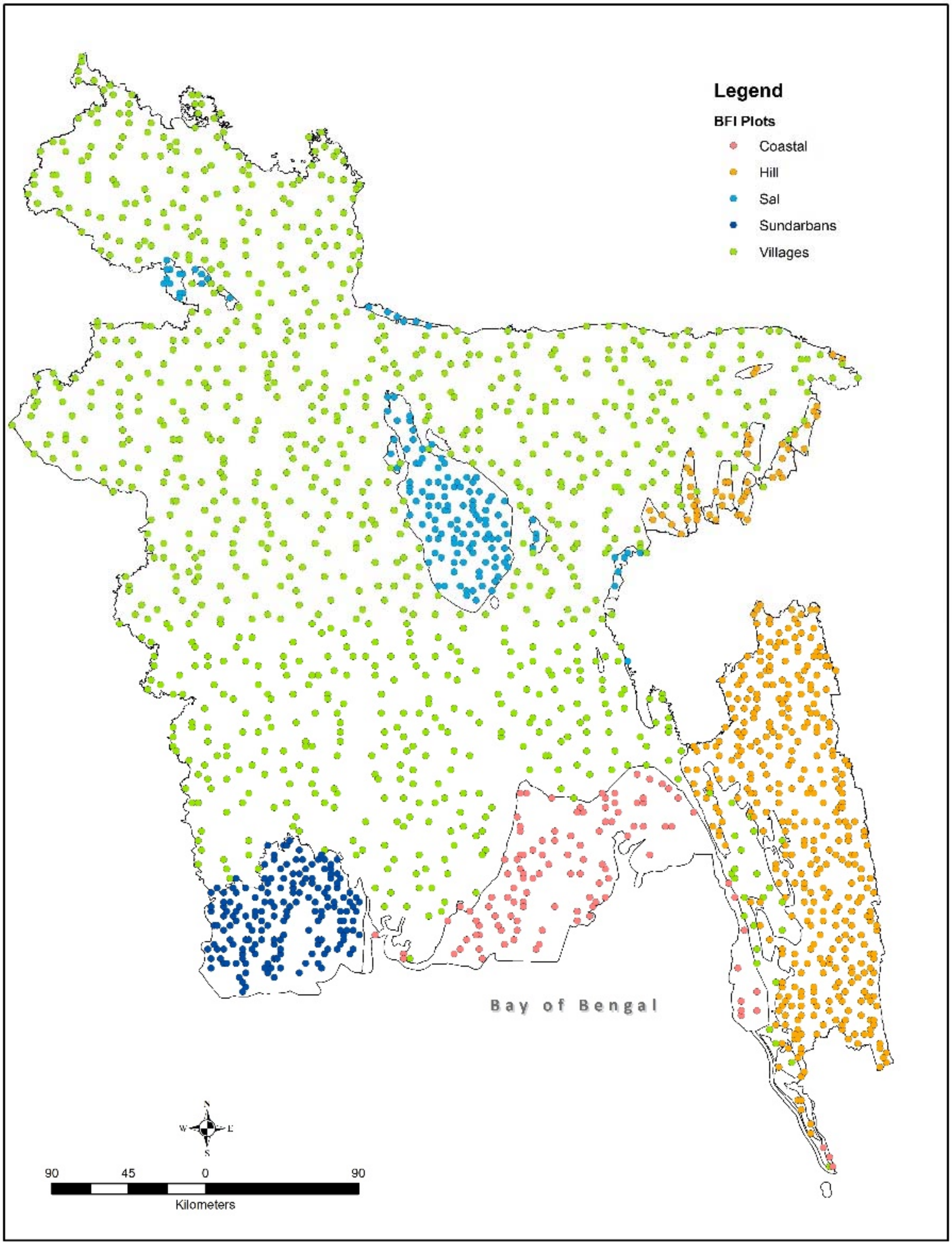

Figure 2.9. The distribution of biophysical inventory plots among five zones in Bangladesh.

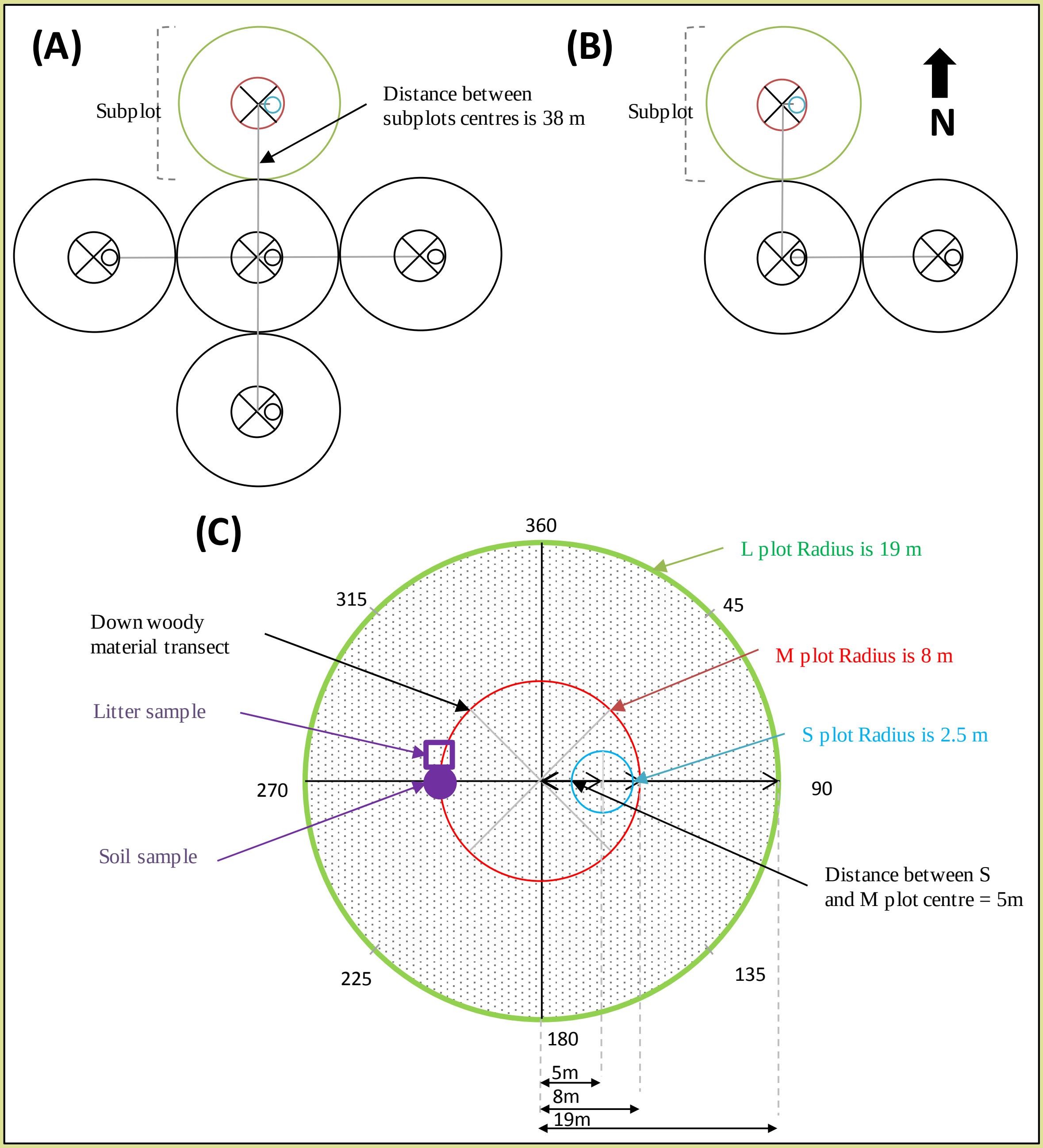

Figure 2.10. (A) Plot design for Hill, Sal, Coastal and Village zones- one plot is composed by five sub-plots, (B) Plot design of Sundarban zone- one plot is composed by three sub-plots. (C) Subplot layout for data collection.

In each plot, tree, seedling, sapling, litter, down woody debris and soil and other major forest attributes were sampled (BFD 2016c). The subplot descriptions (Figure 2.10C) and protocols for data collection are as follows:

- Seedling and sapling information was collected within a radius of 2.5 meter from the small plot ("S plot").
- All trees having a Diameter at Breast Height (DBH) from >10 cm to 30 cm were measured within the 8-meter radius of the medium plot ("M plot").
- All trees having >30 cm DBH were measured within the 19-meter radius of the large plot ("L plot").
- Litter and soil sample were collected at 8 meters distance from the plot center at 270 degrees.
- Down woody debris data was collected along two transects within the M plot.
- Land feature, objects info, leaf cover, crown cover, land management, disturbance information were also collected. Photos were taken of the land features.

The measurements on field plots were performed by 13 field inventory teams[7], while local Conservators of Forests supervised the implementation of the biophysical inventory in each district. Field teams consisted of seven members, including team leaders, technical experts, and labourers. Local people were engaged as much as possible in the composition of the field team or as guides (Costello and Henry 2016). Local FD staff helped by providing information about access conditions to the plot and recruiting local people with required local knowledge. In some cases, some tree species could not be identified in the field, usually when leaf samples could not be gathered. Data were collected using open source software (Open Foris) installed on android-based tablets.

Field work began in 2016 when 5% of the plots were visited, but the majority of plots were visited in 2017 (65%) and 2018 (26%) before finally finishing in 2019 (4%). 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 nonsampled plots (1.9%). In the case of inaccessible plots, a visit was attempted but tree measurements were not possible in any subplot, 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%). Partially accessible plots were cases where at least one subplot could be measured but other subplots could not due to water (44%), hazardous conditions such as steep slopes (25%), walls or buildings (21%), or other reasons (10%) such as denied access and restricted areas or border areas. Finally, a nonsampled plot status means that no visit was attempted, usually due to plot falling in an extremely remote location (69%), restricted area (20%), or other reason such as water or border areas (11%). The effect of inaccessible and nonsampled 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 2.12).

[7] In 2019, an additional team team was formed specifically to measure the BFI plots in remote and difficult areas in the Chittagong Hill Tracts

Box 4 – Ensuring the relocation of biophysical plots

It is critical in forest monitoring to relocate the plots to ensure the same area is measured in each successive inventory. In some cases, moving the plot center only a few cm can cause gross errors in counting and measuring trees (Figure 2.11). Some common approaches to relocate plots include recording multiple reference points, inserting metal bars into the plot center, tagging trees, and recording the plot coordinates with a GPS. In practice, however, none of these is completely effective. For example, trees used as reference points may be cut down between inventories, metal bars may be exposed and removed by locals, trees tags often fall out, and GPS points may have errors of up to 10m. Using a combination of these approaches further increases the chances of relocating a plots, but may still not be enough.

Figure 2.11. Accurate biophysical data collection depends on locating the plot center with high precision. The BFI uses DGPS technology to obtain cm level coordinates for future teams to navigate to the plot center.

The BFI overcomes challenges of plot relocation by recording the center of most plots with Differential Global Positioning System (DGPS) for cm-level accuracy. To accomplish this work, DGPS teams from the FD and Sthapati were trained and deployed to georeference the plots with DGPS coordinates after they had been initially established by regular field teams. Additionally, to address problems related to tree marking and tagging, Radio Frequency Identification (RFID) chips are inserted into reference trees (Kumar, Mahamud et al. 2017). Nearly all the plots were completed to ensure the most accurate measurements are taken in future cycles. Plots in the Hill zone were not georeferenced due to difficulties of working in that area.

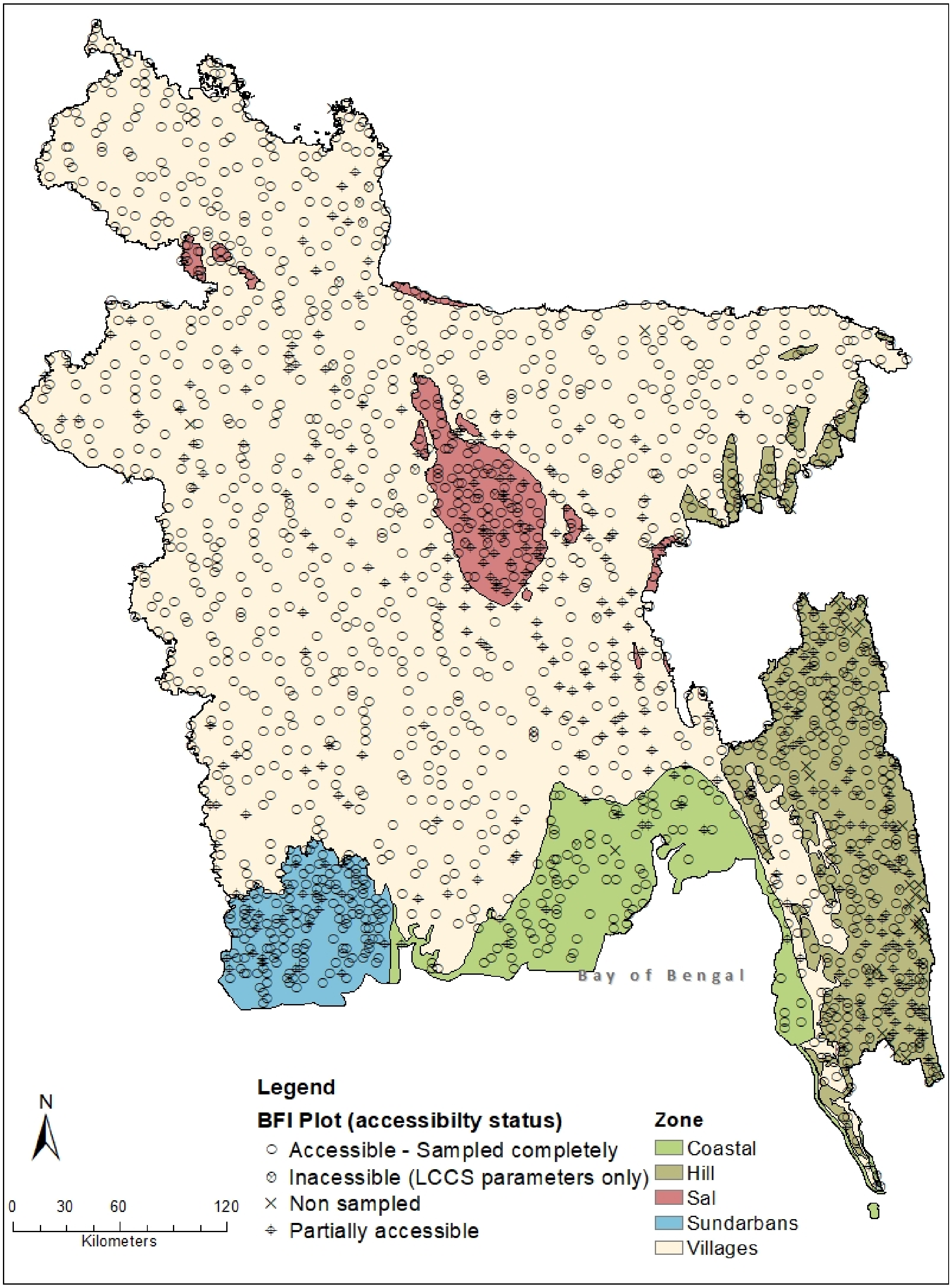

Figure 2.12. The distribution of BFI plots according to plot status.

2.3.4 Socio-economic survey design

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 national estimates and 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).

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 tree cover per household, which was used as a proxy for the quantity of tree and forest resources available). Tree cover was obtained from remotely sensed Landsat data from 2014 (Potapov, Siddiqui 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:

$$\text{Household Tree Availability} = \frac{\left(\frac{\text{TC area}}{\text{Union area}}\right)}{\text{Number HH's}} = \frac{\%TC}{HH}.$$

This metric was then defined into four Household Tree Availability Classes (HTAC) within each zone by quartiles, and unions were assigned an HTAC class. 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 (Table 2.4). 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 (Table 2.4) (GoB 2017b).

Table 2.4. Household Tree Availabililty Classes (HTAC) used as strata within each zone and each strata's characteristics in terms of tree cover percentage, number of households and %TC HH^{-1}.

Strata	Total No. Unions	Sampled No. Unions	Mean %TC	Mean No. HH's	Min %TC HH^{-1}	Mean %TC HH^{-1}	Max %TC HH^{-1}
Coastal_1	62	16	2.2	6459	0	0.000480	0.00096
Coastal_2	61	16	9.6	5460	0.00098	0.001910	0.00284
Coastal_3	61	16	17.1	2960	0.00290	0.014750	0.02660
Coastal_4	61	16	34.0	441	0.02760	0.145085	0.26257
Hill_1	73	16	20.4	4980	0.00012	0.003030	0.00594
Hill_2	72	16	33.6	3726	0.00599	0.009875	0.01376
Hill_3	72	16	45.3	2287	0.01387	0.021895	0.02992
Hill_4	72	16	46.9	1027	0.03003	0.105525	0.18102
Sal_1	99	16	0.2	14418	0	0.000025	0.00005
Sal_2	99	16	6.2	15590	0.00005	0.000640	0.00123
Sal_3	98	16	20.1	7691	0.00128	0.003065	0.00485
Sal_4	99	16	25.3	2399	0.00490	0.140630	0.27636
SundarbanP_1	23	16	0.1	4982	0	0.000025	0.00005
SundarbanP_2	22	16	1.0	4703	0.00005	0.000220	0.00039
SundarbanP_3	22	16	7.7	4873	0.00041	0.001395	0.00238
SundarbanP_4	22	16	17.8	2331	0.00242	0.034530	0.06664
Village_1	1723	16	2.8	5648	0	0.000550	0.00110
Village_2	1723	16	10.5	5642	0.00110	0.002010	0.00292
Village_3	1722	16	17.9	3439	0.00293	0.007270	0.01161
Village_4	1723	16	28.5	887	0.01161	4.499605	8.98760

SundarbanP: Sundarban periphery zone of the socio-economic survey

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 2.13). 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 2017a). Of the respondents, 53% were female and 47% were male, while 94% identified as Bengali, 3% as Chakma, 1% as Marma, and 2% as other ethnicity. The full questionnaire can be found in the Appendix 2.2.

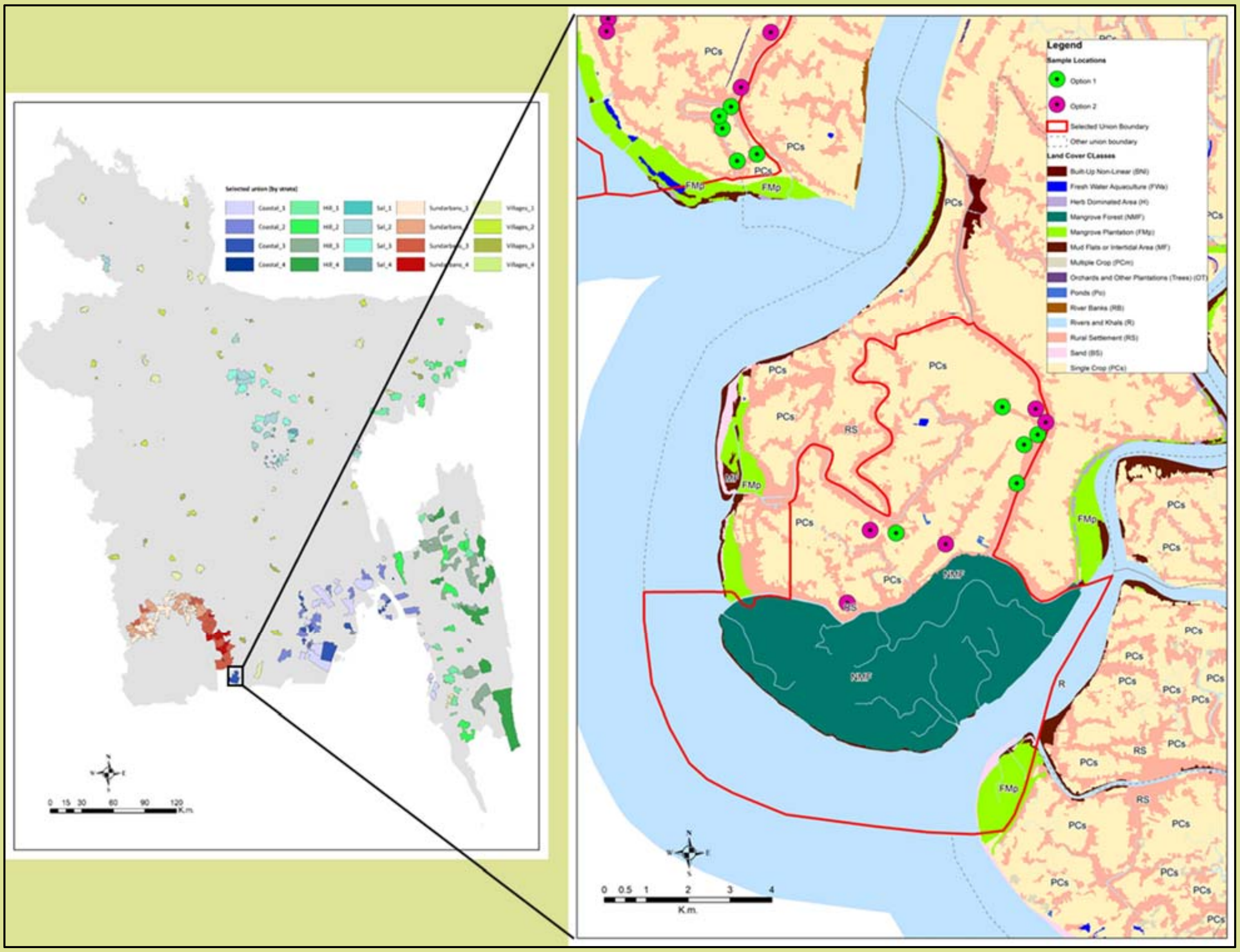

Figure 2.13. Left: Map of 320 unions selected for socio-economic field data collection stratified by 20 HTAC's. Right: Map of a single union indicating 10 GPS points where field teams chose to visit either even or odd numbers, but not both.

In addition to quantitative data collected from household surveys, qualitative techniques were used to collect in-depth and perceptual information at the community level. Five unions were randomly selected in each stratum, i.e. 100 unions (5 unions*20 strata) and thus 20 community surveys were performed in each zone. The main purpose of the community survey was to collect the information related to trends of land use, access to services, tree and forest products prices based on market value, benefits from tree and forest resources. The survey was administered among the community people using Focus Group Discussion (FGD) methodology where 8-10 participants attended in the selected union or ward (BFD 2017a). The target groups of the community survey were forest resource users in the society that were believed to have important impacts on forest and tree resources of the country.

Box 5 - Learning from and engaging local communities in the BFI

Trees and forests play an important role in the development of household livelihoods. Two important activities of the BFI sought to better understand how local communities use these resources and to engage them in the BFI process. Firstly, 100 FGD’s were conducted in each of the five socio-economic zones with the objectives of learning about the use of tree and forest resources in communities. FGD techniques were applied such as interviewing men and women separately to encourage open discussions and capture gender specific answers (e.g. men and women might not always have same perception on the importance and use of forest resources) (BFD 2017a). A total of 20 FGD’s (10 women and 10 men) were conducted in each zone. Besides tree and forest resource users, the participants included small businesses owners and community leaders. A structured questionnaire was used to collect information on biodiversity and conservation, economics and livelihoods (e.g. tree and forest products collection amounts, selling time, and unit prices), tree and forest product access and conflict, community benefits for conserving trees and forests, illegal activities, law enforcement and REDD+ safeguards. The FGD was an efficient way to capture information about general patterns in the community and also helped to interpret the results of the household survey.

In a separate activity, FD arranged three separate community meetings in the Khagrachari, Rangamati and Bandarban Hill districts to raise awareness about the BFI, its role and objectives and factilitate the operationalization in Chittagong Hill Tracts. Later, several meetings were held with Chairmen of the Chittagong Hill Tracts Regional Council (CHTRC) which led to the organization of 24 additional information sharing meetings at Upazila level (sub-district). The meetings served the purpose of obtaining consent and guidance from the local people and institutions for conducting the BFI in their areas. Among the participants were representatives from 12 ethnic minority groups, traditional institutions, government and non-government stakeholders. The meetings were critical for engaging the local support needed to efficiently implement the BFI and were a step towards future participatory forest monitoring. Additionally, they provided a platform for community leaders to reflect on the importance of forest resources, communicate specific needs, and give feedback related to forest monitoring (Chakma 2016).

2.3.5 Volume, biomass and carbon stock estimations

Supporting information for estimating volume, biomass and carbon stocks includes a tree species database, wood density database, soils analysis and tree allometric equations. The precision of the tree volume, biomass, and carbon estimations largely depends on reliable and appropriate allometric equations (Picard, Saint André et al. 2012). A list of 517 allometric equations for 39 tree species were reviewed in terms of statistical performance and operational applicability (Hossain 2016). Because of the lack of available allometric equations in terms of number and quality, additional allometric biomass models were developed at both zone and species level through extensive field data collections in all five zones (Figure 2.14) (BFD 2016f, Mahmood 2018, Hossain, Anik et al. 2019). In addition to these, biomass expansion factor, wood density of selected species as well as allometric equations for biomass and carbon (on biomass) estimations of the tree parts (i.e. leaf, branch and stem) were also developed. A decision tree was developed with expert consultation for selecting appropriate volume, biomass or carbon allometric equations at different levels (species or zone) considering the statistical features of the model such as diameter range, sample size, and co-efficient of determination. A complete list of all the allometric equations used for volume, biomass, and

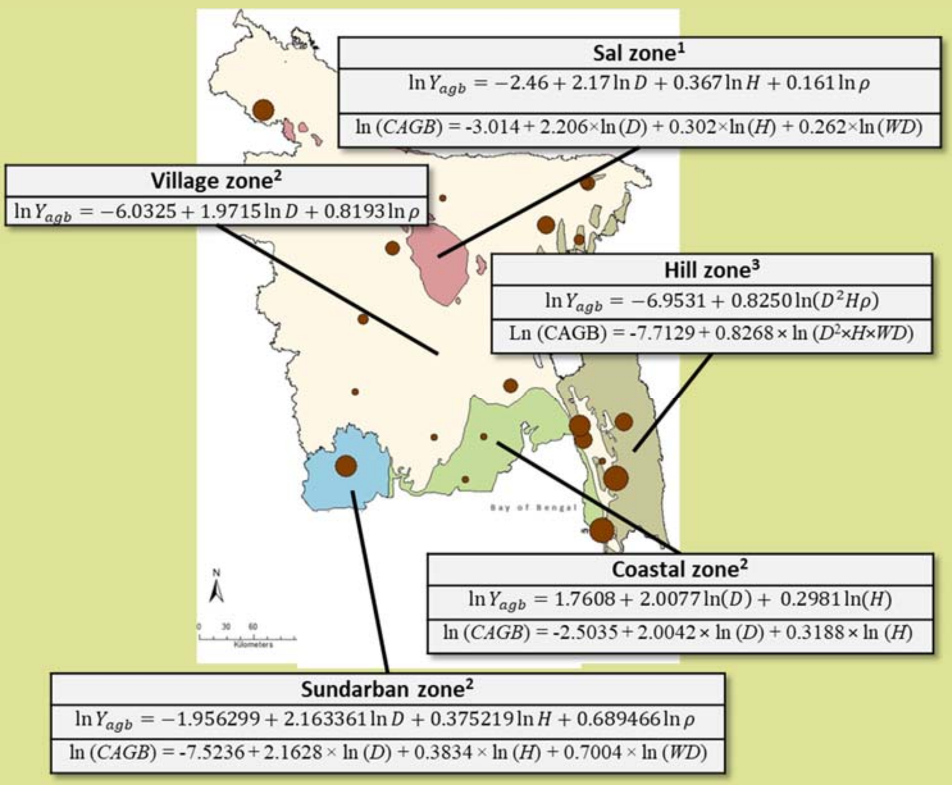

Figure 2.14. Spatial distribution of 517 species specific and nine zone specific allometric equations considered for volume, carbon, and biomass estimations. Larger circles represent more species specific equations from locations throughout Bangladesh. Boxed equations refer to zone specific equations documented in [1]Mahmood, Siddique et al. (2019a), [2]BFD (2018), and [3]Mahmood, Siddique et al. (2019b).

carbon estimation, and the decision tree, are found in the Appendix tables 2.3 to 2.6 and the Bangladesh Forest Information System web platform (see Section 2.3.6), and further described in Hossain, Anik et al. (2019).

Similar to aboveground biomass, below ground biomass was estimated for trees, saplings, bamboos and live stumps. However, unlike aboveground biomass, the equations used for belowground biomass were from secondary sources not specific to Bangladesh (Hossain, Anik et al. 2019). The biomass and volume of standing dead trees and down woody debris (DWD) were estimated using the equations prescribed in current literature (Marshall, Davis et al. 2000, Harmon, Woodall et al. 2011). Above ground bamboo biomass was calculated applying the model proposed by de Melo, Sanquetta et al. (2015) whereas the belowground bamboo biomass was assumed to be 5% of culm as per conversion factor of Stokes, Lucas et al. (2007).

Other supporting information and resources have been developed to further facilitate the estimation procedures such as tree species and wood density databases (BFD 2016a). The databases are available online through the Bangladesh Forest Inventory System (see section 2.4 Access to information). Besides soils carbon, analyses included soil texture, soil bulk density, and soil pH and salinity for the Sundarban and Coastal zones (BFD 2016d). An agreement was established between FD and Khulna University to establish a soil archive for the soil samples under the BFI and for any future analyses. Finally, for the socio-economic survey, the sample design depended on important information about Union boundaries, and number of households.

For reporting sample-based estimates and uncertainties for any forest attribute in the biophysical inventory, estimators were selected that were consistent with the sampling method (McRoberts, Tomppo et al. 2015). Ratio to size estimators were used for computing the means and variances of the variable (e.g. Table 2.3) (Korhonen and Salmensuu 2014, Scott 2018). The areas used for expanding the ratio estimates to totals by zone are the areas defined by the zone map. The areas used to expand ratios to totals by land cover class were extracted from the 2015 land cover map after overlaying the subplot boundaries on the map in order to make the area estimates determined from the land cover map and the sample more consistent. Therefore the subplot level areas could be affected by geolocation error, but this effect is reduced by the use of DGPS for georeferening the plot center (Box 4). Biophysical estimations were done in R statistical software version 3.5.0, while socio-economic estimations were done using Stata statistical software. The R-scripts are be found in the BFIS e-library (Section 2.4) (Hossain 2017, Hossain, Laurent et al. 2017, Hossain, Laurent et al. 2017, Laurent and Hossain 2017). The full details of the equations for both the biophysical inventory or the socio-economic survey are found in Hossain, Anik et al. (2019).

2.3.6 Data management and data quality control

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, BFD 2016e, Kumar, Costello et al. 2017, BFD 2017b) (Figure 2.15). Open Foris software was installed on mobile tablets after it was tested in several field trials. Paper forms were also used in the case of drawing sketch maps and in the rare case the tablet could not be used. Data collection was completed in batches of plots, i.e. field teams visited as many as 20 plots at a time, and then submitted their data to a central team electronically. As field data were collected, they were checked for outliers or suspect data entries, both manually and with R scripts. If an obvious correction was needed, it was updated in the Open Foris database, otherwise the field teams were consulted about suspect data to understand the problem and take further decision.

At the same time, four QA/QC teams consisting of government and academic foresters performed quality assessments of data collection directly in the field through hot and cold checks (BFD 2016b, BFD 2017b). Hot checks refer to quality assessments of plot attributes or household responses in the presence of the field team, allowing for the opportunity to give feedback in the field. Cold checks refer to quality assessments done through an independent visit to a plot or household subsequent to the original visit. In the biophysical inventory, QA/QC teams visited a total of 93 plots (39 hot checks, 54 cold checks), or about 5% of the sampled plots. The most common errors made by the field teams were: 1) incomplete identification of land feature objects, 2) incorrect identification of reference point, and 3) incomplete tree diameters and heights. In the case of egregious errors, the field teams were sent back to re-measure the plots. The total number of plots re-measured was 52. For the socio-economic survey, QA/QC teams visited 267 households (254 hot checks, 13 cold checks), or about 4% of the total number of households sampled.

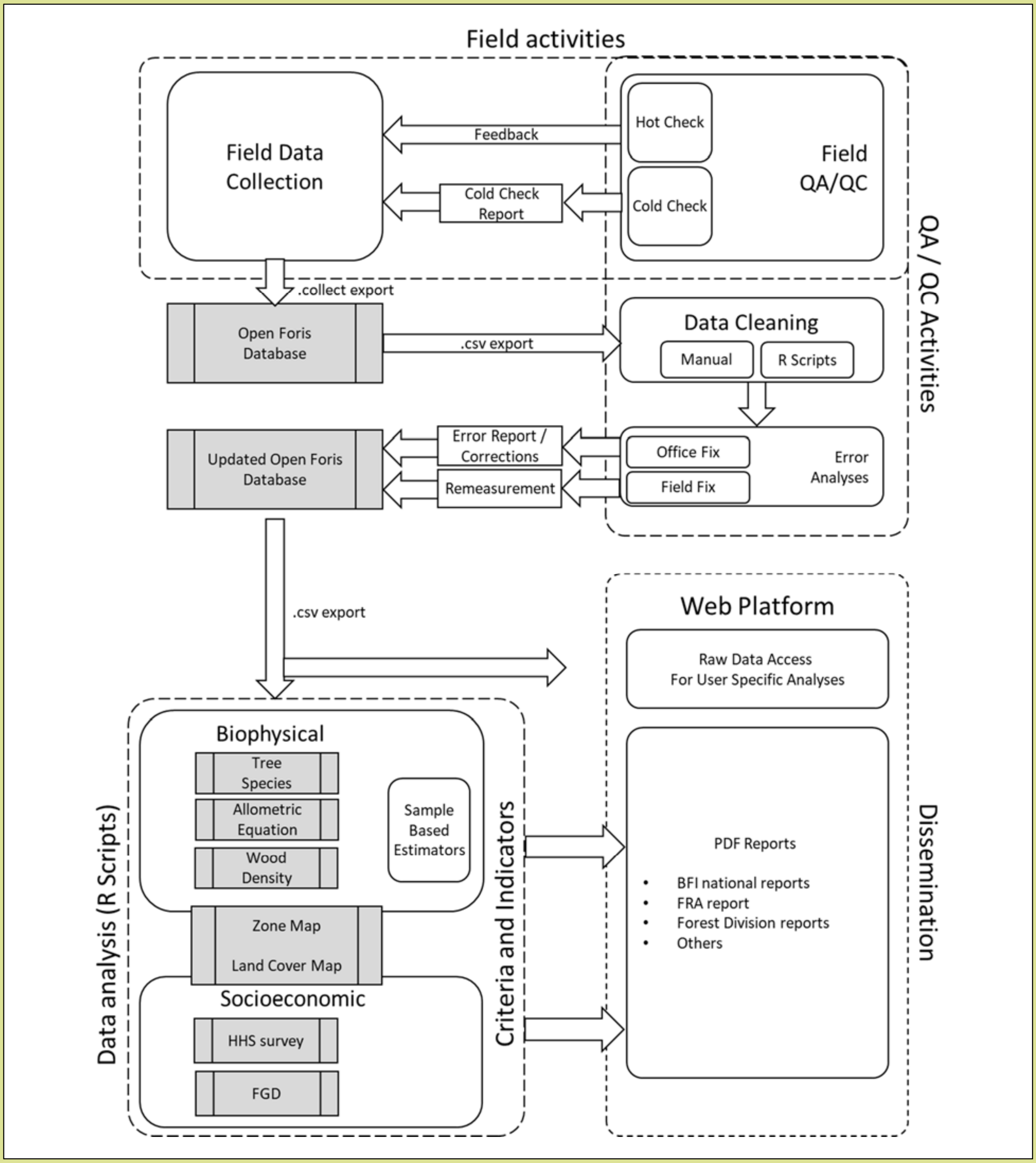

Figure 2.15. Flow diagram of the data management, data cleaning, QA/QC and estimation processes used in the biophysical and socio-economic surveys.

Box 6 – Adapting BFI data for multiple purposes

Both the biophysical and socio-economic data can be enhanced, intensified, or modified to meet more specific needs. For example, the biophysical plot design was used for the assessment of fuelwood supply and demand in and around refugee camps in Cox's Bazar (FAO-IOM, 2016). Fourteen additional plots were measured and combined with remote sensing datasets. One finding was that 40% of the standing biomass was already depleted before the main influx of refugees in August 2017. The results also helped inform a strategy for reducing the demand on forest resources to stabilize the landscape.

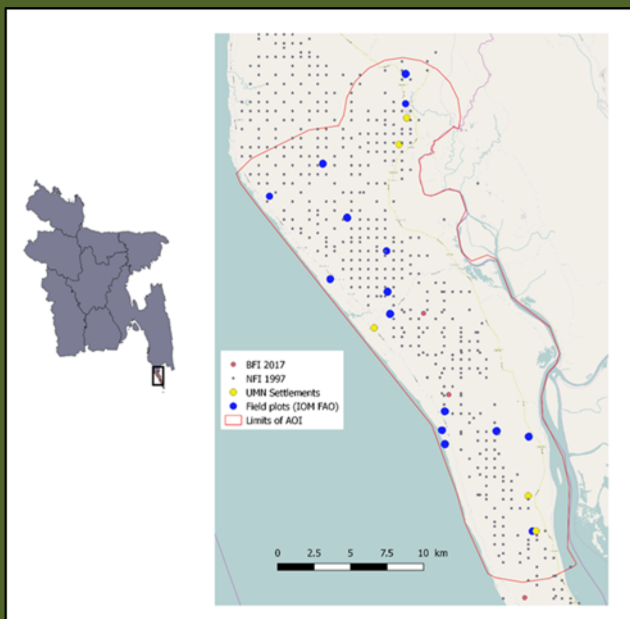

Figure 2.16. The locations of 14 additional field plots that were integrated with existing BFI plots in Cox's Bazar district.

In another example, both biophysical and socio-economic BFI data can be summarized by FD Forest Divisions to help inform forest planning and monitor changes of programs implemented in that Division. Basic statistics about species composition, volume, seedling densities, fuelwood stock together with fuelwood collection and planting preferences by households can give a forester a good idea of the status of tree and forest resources in their area. Other potential applications of BFI that inform intervention activities could include enhancing soil analyses to understand the spatial distribution of the impacts of soil salinity on rice production and assessing the extent and location of potential areas for wetland rehabilitation.

2.4

Access to information

Despite technological advancements in forest monitoring tools, data archiving, management and analysis, Bangladesh has traditionally not been able to take advantage of most of them until the BFI. To ensure proper management and dissemination of information, the Bangladesh Forest Information System (BFIS) was developed[8] (Figure 2.17). The BFIS supports the BFI through a module that provides access to biophysical and socio-economic data that were collected from all over the country. The BFI data are accessible to FD, government agencies, research communities and other stakeholders to be engaged in getting accurate information about forest status for decision making, reporting and research purposes. Previously, there was no such platform maintained by FD to share forestry related data. Through proper data sharing policies, the BFIS allows easy and automated access to information without going through complicated data access procedures. All the data collected under the first BFI cycle is uploaded and available to users specified by the FD.

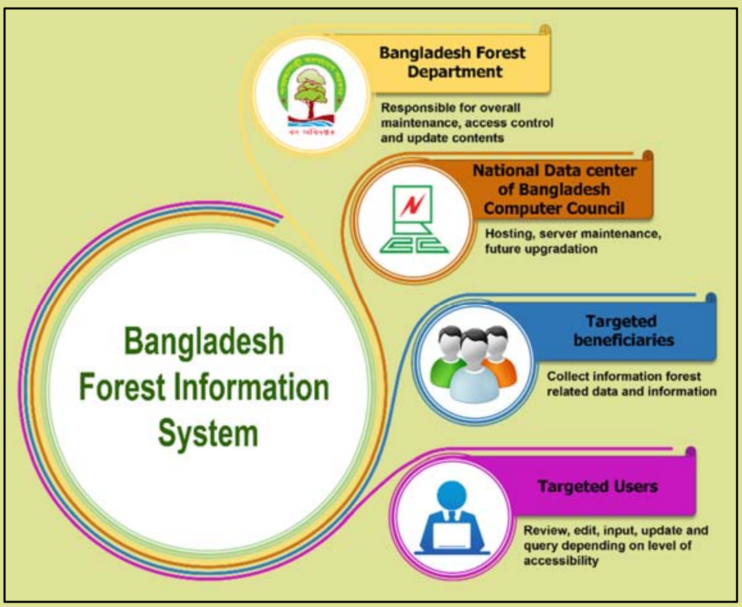

Figure 2.17. The purposes and users of the Bangladesh Forest Information System.

[8] http://bfis.bforest.gov.bd/bfis/